

Brief Review

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International Alignment in Pectin Specifications: Comparative Insights into Compositional Quality and Regulatory Criteria

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Abstract

Pectin is a widely used plant-derived polysaccharide with gelling, stabilizing, and thickening functions in food and pharmaceutical applications. This comparative review analyzes official specifications and technical references from Codex/JECFA, the European Commission, China (GB standards), and Food Standards Australia New Zealand to evaluate regulatory status, compositional criteria, and safety requirements. Findings reveal substantial international harmonization: pectin is accepted as a safe food additive without a specified acceptable daily intake and is regulated according to technological need. Core compositional criteria are consistent across frameworks, notably a minimum galacturonic acid content of approximately 65% and defined methoxyl/esterification ranges that distinguish functional classes. Contaminant limits for heavy metals, sulfur dioxide, residual solvents, and insoluble matter are broadly aligned, with observed differences mainly in analytical methods and reporting. Residual nitrogen emerges as a contextual parameter reflecting processing history rather than a universal purity marker. The convergent standards support predictable quality, facilitate international trade, and highlight opportunities for future specifications to focus more on parameters directly tied to molecular structure and technological performance.

Keywords Pectin; Galacturonic acid; International standards; Compositional quality; Food additive safety

1. Introduction

Pectin is a naturally occurring polysaccharide composed mainly of α -(1→4)-linked D-galacturonic acid residues, primarily obtained from citrus peels [1] and apple pomace. It is widely used in the food and pharmaceutical industries as a gelling, stabilizing, and thickening agent [2]. The structural and functional properties of pectin are highly influenced by its botanical source as well as the

extraction and purification methods employed during its production [1, 3]. Even minor modifications in processing conditions can significantly alter its physicochemical characteristics. For instance, small variations in extraction temperature may affect important quality parameters [4] such as equivalent weight and galacturonic acid content [5]. Throughout the manufacturing process, pectin is subjected to several chemical and physical treatments that



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may influence the safety profile of the final product [2]. Therefore, in addition to evaluating its functional and compositional characteristics, it is essential to assess specific quality and safety parameters to ensure that the produced pectin is safe for consumption and does not pose any health risks to consumers.

Accordingly, pectin specifications include the monitoring of process-related impurities and potentially toxic contaminants, as its industrial manufacture involves multiple stages, including acid extraction, alcohol precipitation, purification, and, in some cases, chemical modification. Sulfur dioxide (SO₂) is routinely monitored because sulfite-containing compounds may be employed during extraction and stabilization processes to minimize oxidative degradation and inhibit microbial growth. Residual sulfites can remain in the final product and may trigger adverse reactions in sensitive individuals; therefore, regulatory specifications establish limits for sulfur dioxide in pectin products [6,7].

Residual solvents, including methanol, ethanol, and isopropanol, are also evaluated because these alcohols are commonly used during pectin precipitation and purification. Although subsequent drying and milling operations reduce solvent levels, trace amounts may persist in the final product. Consequently, specification limits are established to verify the effectiveness of purification procedures and to ensure consumer safety [2].

Sodium methyl sulfate is another process-related impurity that requires control. This compound may be generated as a by-product during pectin methylation processes involving methanol and sulfuric acid, followed by neutralization with sodium bicarbonate. Regulatory authorities therefore recognize sodium methyl sulfate as a potential impurity associated with esterification reactions in pectin production and have established corresponding limits for its presence in the final product. Notably, the U.S. Food and Drug Administration (FDA) specifies that the concentration of sodium methyl sulfate must not exceed 0.1% of the pectin weight [8].

Heavy metals, including lead, cadmium, arsenic, and mercury, are also subject to routine monitoring because they may be introduced through plant-derived raw materials, water sources, processing equipment, or purification reagents. Given their well-documented toxicity, even at trace concentrations, stringent specification limits are required to ensure the safety of pectin when used as a food additive. In addition, the European Food Safety Authority (EFSA) has proposed establishing specification limits for aluminium because aluminium salts may be used during traditional purification or flocculation processes in pectin production. Although aluminium ions are largely removed through washing with acidified alcohol-

water solutions, residual aluminium may remain in the final product and therefore requires regulatory control. Collectively, the monitoring of these contaminants and process-related impurities constitutes a critical component of pectin quality assurance, ensuring both regulatory compliance and consumer safety [2].

Due to pectin broad application, international food authorities have established compositional and safety standards to ensure the consistency, purity, and safety of pectin used in products. Major regulatory bodies such as Codex Alimentarius, the European Commission (EC), China's National Health Commission (GB standards), and Food Standards Australia New Zealand (FSANZ) have specified purity, analytical, and safety parameters for pectin. These include galacturonic acid content, ash, sulfur dioxide, and heavy metal limits. This paper integrates and compares these standards to identify common criteria, safety assurances, and analytical alignment. Although international pectin standards are largely similar, a comparative review remains valuable because regulatory information is scattered across different authorities and references. Bringing these standards together in a single analysis clarifies the current level of international harmonization, highlights minor differences in analytical and regulatory approaches, and provides a practical reference for researchers, manufacturers, and regulatory professionals involved in pectin quality and safety evaluation.

2. Methodology

This study was conducted as a comparative review based on official regulatory documents and technical references related to pectin specifications and safety evaluation, including Codex Alimentarius General Standard for Food Additives (GSFA), EC Regulations No. 1333/2008 and 231/2012 [7], GB 25533-2010 and GB 2760-2024 (China)[9,10], FSANZ Food Standards Code [11].

The analysis focused on two main aspects: (a) Regulatory and Safety Parameters such as acceptable daily intake (ADI), permitted uses, labeling, and safety classification; (b) Compositional and Analytical Criteria including galacturonic acid, degree of esterification, ash content, sulfur dioxide, and heavy metal residues. All data were cross-referenced to identify harmonized requirements and deviations between standards.

3. Results and discussion

3.1 Regulatory Overview

All regions apply nearly identical regulatory frameworks, facilitating global trade and quality assurance. Table 1 summarizes the regulatory frameworks, permitted uses, labeling requirements, and safety assessments of pectin across the major international authorities.

Table 1. Comparison of international regulatory requirements for food-grade pectin.

Region / Authority	Main Regulation	Permitted Use	Labeling Code	Safety Assessment	Reference
Codex Alimentarius	GSFA, FAO/WHO (2016)	No ADI specified	INS 440	Safe at technological levels	[6]
European Union	EC 1333/2008 & 231/2012	Quantum satis	E 440(i)/(ii)	No safety concern (EFSA)	[7]
China (GB Standards)	GB 2760-2024	Based on production necessity	—	Consistent with Codex	[10]
FSANZ (Australia/NZ)	Food Standards Code	Codex-aligned	INS 440	Safe for consumption	[11]

Table 2. Comparison of compositional and analytical specifications for food-grade pectin among major international standards.

Parameter	Codex/JECFA/FSANZ	EFSA evaluation	Commission Regulation (EU) No 231/2012	China GB 25533-2010	Note
Description	White, yellowish, light greyish or light brownish powder	Pectin (E 440i): White, light yellow, light grey or light brown powder Amidated Pectin (E440ii): White, light yellow, light greyish or light brownish powder	Pectin (E 440i): White, light yellow, light grey or light brown powder Amidated Pectin (E440ii): White, light yellow, light greyish or light brownish powder	Color white, yellow, light gray or light brown powder	Appearance
Galacturonic acid (%)	Not less than 65%	Content not less than 65% of galacturonic acid on the ash-free and anhydrous basis after washing with acid and alcohol	Content not less than 65% of galacturonic acid on the ash-free and anhydrous basis after washing with acid and alcohol	w/%≥65	Confirms purity and identity
Degree of esterification (%)	-	Low-methoxyl pectins (LM-pectins): less than 50% (typically 20–40%) of the carboxyl groups are methylated High-methoxy pectins (HM-pectins): more than 50% (typically 55–75%) are methylated	-	-	Influences gelation mechanism and functionality
Total insolubles (%)	Not more than 3%	Not more than 3%	Not more than 3 %	-	Indicates the level of insoluble impurity
Acid-insoluble ash (%)	Not more than 1%	Not more than 1% (insoluble in approximately 3N hydrochloric acid)	Not more than 1 % (insoluble in approximately 3N hydrochloric acid)	w/%≤1	Detects silicate or mineral contamination
Sulfur dioxide (mg/kg)	Not more than 50 mg/kg	Not more than 50 mg/kg on the anhydrous basis	Not more than 50 mg/kg on the anhydrous basis	≤50	Preservative residue
Loss on drying (%)	Not more than 12%	Not more than 12%	Not more than 12 %	w/%≤12	Controls moisture content
Degree of amidation	Not more than 25% of total carboxyl groups of pectin	Pectin (E 440i): - Amidated pectin (E 440ii): Not more than 25% of total carboxyl groups of pectin	Pectin (E 440i): - Amidated pectin (E 440ii): Not more than 25% of total carboxyl groups of pectin	Only amidated pectin, w/%≤25	Not applicable to ordinary pectin
Residual solvents	Not more than 1% methanol, ethanol, isopropanol, singly or in combination	Not more than 1% of free methanol, ethanol and propan-2-ol, singly or in combination, on the volatile matter-free basis	Not more than 1 % of free methanol, ethanol and propan-2-ol, singly or in combination, on the volatile matter-free basis	(Methanol, ethanol, isopropanol), w/%≤1.0	Solvent residue
Nitrogen content (%)	Not more than 2.5% after washing with acid and ethanol	Pectin (E 440i): Not more than 1.0% after washing with acid and ethanol Amidated pectin (E 440ii): Not more than 2.5% after washing with acid and ethanol	Pectin (E 440i): Not more than 1.0% after washing with acid and ethanol Amidated pectin (E 440ii): Not more than 2.5% after washing with acid and ethanol	-	Reveals the extent of chemical modification and the presence of protein-based impurities
Lead (mg/kg)	Not more than 2 mg/kg for general use and 0.5 mg/kg for use in infant formula	Not more than 5 mg/kg	Not more than 5 mg/kg	5≥	Toxicological limit
Mercury (mg/kg)	-	Not more than 1 mg/kg	Not more than 1 mg/kg	-	Toxicological limit
Cadmium (mg/kg)	-	Not more than 1 mg/kg	Not more than 1 mg/kg	-	Toxicological limit
Arsenic (mg/kg)	-	Not more than 3 mg/kg	Not more than 3 mg/kg	-	Toxicological limit

3.2 Compositional and Analytical Specifications

Table 2 presents a comparative overview of the compositional and analytical specifications for pectin across Codex/JECFA, EFSA, the European Commission, and the Chinese GB standard, highlighting both harmonized requirements and regulatory differences.

4. Discussion

The comparative assessment reveals a substantial level of consistency among the major international regulatory frameworks governing commercial pectin specifications. Despite differences in regulatory structure and terminology, Codex/JECFA, EFSA, Commission Regulation (EU) No 231/2012, and China GB 25533 share a common approach toward defining pectin identity, compositional quality, and safety requirements.

Among all evaluated parameters, galacturonic acid content remains the most universally accepted criterion for pectin identification. The consistent adoption of a minimum content of approximately 65% across Codex/JECFA, EFSA, Commission Regulation (EU) No 231/2012, and China GB 25533 reflects a broad scientific consensus regarding the structural characteristics required for commercial pectin. Because galacturonic acid constitutes the principal component of the homogalacturonan backbone, its use as a primary specification parameter directly links regulatory assessment with molecular composition. The close agreement observed among the standards suggests that pectin identity is largely defined by intrinsic structural characteristics rather than region-specific regulatory preferences.

The evaluated standards also exhibit considerable convergence in parameters related to insoluble matter, acid-insoluble ash, moisture content, and residual processing contaminants. Such consistency suggests a shared regulatory objective of ensuring that commercial pectin maintains both compositional integrity and manufacturing quality regardless of geographical jurisdiction. While minor variations in reporting formats and analytical expressions are observed, these differences do not substantially affect the underlying quality expectations.

A notable observation concerns the characterization of pectin according to its methylation status. European specifications explicitly distinguish low-methoxyl and high-methoxyl pectins through methoxyl content and degree of esterification, emphasizing the technological importance of these structural attributes. Although not all standards provide the same level of detail, the available specifications collectively acknowledge the functional significance of methylation characteristics in determining gelling behavior and application performance.

Contaminant specifications demonstrate a similarly high

degree of regulatory alignment. Limits for sulfur dioxide, residual solvents, and toxic elements are broadly comparable across the evaluated frameworks, indicating common toxicological principles and risk-management strategies. Differences that do exist are generally quantitative rather than conceptual and likely reflect regional regulatory preferences, analytical methodologies, or historical developments in food additive legislation rather than fundamental disagreements regarding product safety.

The inclusion of nitrogen-related specifications warrants particular consideration. Unlike galacturonic acid content or mineral impurities, residual nitrogen is not necessarily a direct measure of pectin purity. Instead, it may reflect the presence of amidated functionalities or residual nitrogen-containing compounds associated with raw materials and processing technologies. With the increasing adoption of protein-based purification systems [3], and other advanced bioprocessing approaches, nitrogen content may be influenced by manufacturing history without directly affecting product performance or safety. Consequently, this parameter should be interpreted cautiously and primarily as a complementary indicator rather than a universal criterion for purity assessment.

Overall, the findings indicate that contemporary pectin specifications are characterized by a high degree of international harmonization. The observed similarities in identity criteria, compositional requirements, and contaminant controls suggest that current regulatory frameworks are founded on a common scientific understanding of pectin structure, functionality, and safety.

5. Conclusion

This comparative evaluation demonstrates that the major international pectin specifications are highly harmonized with respect to identity criteria, quality requirements, functional classification, and safety-related parameters. Across the evaluated frameworks, galacturonic acid content remains the principal compositional marker of pectin identity, while specifications for insoluble matter, acid-insoluble ash, moisture, residual solvents, sulfur dioxide, and heavy metals exhibit substantial regulatory consistency.

The observed differences among standards are primarily associated with regulatory presentation and the level of detail assigned to particular parameters rather than with fundamental scientific disagreement. This high degree of convergence reflects a shared understanding of the compositional and functional attributes that define commercial pectin and supports the reliability of current international quality-assessment practices.

The analysis also suggests that certain traditional indicators, particularly nitrogen content, may require more

contextual interpretation in light of modern extraction and purification technologies. Future revisions of pectin specifications may therefore benefit from greater emphasis on parameters that directly reflect molecular structure, technological functionality, and product safety.

Overall, the substantial alignment among international standards provides a strong foundation for regulatory compatibility, facilitates global trade, and supports the consistent and safe use of pectin across food and related industrial applications.

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Declarations

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Competing interests

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