

Chemical Analysis and Safety Standards of Halal Food Additives: Ensuring Purity and Compliance with Islamic Guidelines

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Abstract

Driven by the growing demand for safe, ethical, and religiously acceptable foods, the halal food industry has experienced tremendous growth worldwide. Food additives are an integral component of the modern food processing industry; however, given their chemical complexity and diverse sources, they present significant halal integrity issues. This review explores the chemical composition, functionality, and safety of commonly used food additives in halal-certified foods, including preservatives, colorants, emulsifiers, flavor enhancers, stabilizers, and antioxidants. It also assesses the compatibility of these additives with Islamic dietary laws, focusing on source verification, processing methods, and contamination risks. This study systematically examines regulatory frameworks, including international halal standards and certifications, and identifies discrepancies that hinder global harmonization. Furthermore, advanced analytical methods, such as high-performance liquid chromatography (HPLC), gas chromatography (GC), mass spectrometry (MS), and DNA testing, along with emerging technologies like artificial intelligence (AI), blockchain, and Internet of Things (IoT)-based traceability systems, are evaluated for their contributions to enhancing halal authentication. The findings indicate that ensuring halal compliance requires a comprehensive approach involving chemical analysis, molecular diagnostics, and robust certification systems grounded in the concept of halal-tayyib. Despite technological advancements, significant challenges remain, including a lack of unified standards, contamination risks, and high certification costs. Ultimately, this review highlights the importance of harmonized international standards, improved analytical methods, and closer collaboration among regulatory authorities to enhance the reliability and integrity of halal food additive certification.

Keywords: Halal food additives, Chemical, Halal certification, Quality assurance, Halal-Tayyib framework.



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INTRODUCTION

The global halal food industry has expanded rapidly over the past decade, driven by increasing consumer awareness of halal integrity, food safety, and product quality. Central to this growth is the Halalan Toyyiban concept, which extends beyond religious permissibility to encompass hygiene, safety, nutritional quality, and ethical production. Consequently, halal assurance has become an integral component of the international food industry, serving both Muslim and non-Muslim consumers seeking safe and trustworthy food products (Noor et al., 2023).

Food additives are indispensable in modern food manufacturing because they improve flavour, texture, appearance, stability, preservation, and shelf life. Common additives include preservatives, emulsifiers, colourants, stabilizers, sweeteners, antioxidants, and flavour enhancers. Although these compounds perform essential technological functions, their halal status may be compromised by raw material origin, fermentation substrates, processing aids, alcohol-based solvents, or cross-contamination during manufacture. The increasing use of synthetic and highly processed additives has therefore complicated halal verification, creating challenges for manufacturers, certification bodies, and regulatory authorities (Alzeer et al., 2025).

Traditional verification approaches are often inadequate for confirming the authenticity of additives in complex food matrices, particularly when non-halal contaminants are present at trace levels or when extensive chemical processing obscures ingredient origin. Consequently, halal authentication has increasingly adopted advanced analytical technologies, including polymerase chain reaction (PCR), high-performance liquid chromatography (HPLC), chromatography coupled with mass spectrometry, spectroscopy, biosensors, DNA-based methods, and emerging molecular platforms such as CRISPR-Cas. These techniques provide highly sensitive identification of prohibited ingredients, adulterants, and contamination while improving the reliability of halal verification systems (Ahmad et al., 2025; Nurani et al., 2022; Kua et al., 2022; Wahyudi et al., 2025). Their effectiveness is further strengthened through method validation, laboratory standardization, and multivariate analytical approaches that improve analytical accuracy and reproducibility (Rafi, 2024; Sani et al., 2023, 2025).

Despite substantial progress in halal food research, the available literature remains fragmented. Most published reviews emphasize halal regulations, certification, consumer perception, or food safety. In contrast, relatively few comprehensively integrate the chemical characteristics of food additives, advanced analytical chemistry, molecular diagnostic techniques, regulatory verification, and food safety assessment within a single evidence-based framework. Furthermore, limited attention has been given to evaluating how emerging analytical technologies and digital verification systems can collectively improve halal authentication of increasingly complex food additives in industrial food production (Nazri et al., 2025; Nusran & Sitnah, 2023). Harmonized analytical protocols are also needed to

minimize contamination, adulteration, and fraudulent labelling across international halal supply chains (Filipa-Silva et al., 2024; Usman et al., 2023).

Accordingly, this review provides a comprehensive evaluation of the chemical characteristics, sources, functional roles, and safety considerations of food additives used in halal food products. It critically examines the application of modern analytical chemistry, molecular diagnostic techniques, and emerging digital technologies for halal verification, while also evaluating current regulatory frameworks, halal certification systems, and laboratory verification strategies. By integrating scientific evidence with regulatory and halal compliance requirements, this review provides a comprehensive perspective on strengthening the authenticity, safety, traceability, and global standardization of halal food additive verification.

RESEARCH METHOD

Study Design and Review Protocol

A systematic review was conducted to evaluate current scientific knowledge and regulatory perspectives concerning the definitions, chemical composition, analytical characterization, safety evaluation, and halal compliance status of food additives used in halal food production. The review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to enhance transparency, reproducibility, and methodological quality. A predefined review protocol was established, including the objectives, search strategy, eligibility criteria, study selection process, data extraction procedure, and quality assessment framework. The review focused on scientific publications and regulatory documents addressing halal food additives, their chemical properties, analytical authentication approaches, and safety requirements.

Literature Search Strategy and Information Sources

A systematic literature search was conducted using electronic databases, including PubMed, Scopus, Web of Science, and Google Scholar, to identify relevant studies published between 2020 and 2025. Additional information was obtained from official halal certification organizations and regulatory authorities, including the Islamic Food and Nutrition Council of America (IFANCA), Halal Certification Authority (HCA), Department of Islamic Development Malaysia (JAKIM), and other internationally recognized halal regulatory bodies. The search strategy was developed using combinations of keywords related to halal food additives, chemical characterization, analytical verification, and food safety. The following search terms and Boolean operators were applied: (“halal food” OR “halal certification” OR “halal authentication” OR “halal compliance”) AND (“food additives” OR “food ingredients” OR “preservatives” OR “emulsifiers” OR “colourants” OR “flavouring agents” OR “E-numbers”) AND (“chemical composition” OR “molecular characterization” OR “analytical detection” OR “chromatography” OR “spectroscopy” OR “biosensor” OR “authentication methods”) AND (“food safety” OR “toxicity assessment” OR “regulatory limits” OR “permissible limits”). Reference lists of selected articles were also examined to identify relevant studies not retrieved through electronic database searches.

Eligibility Criteria

Inclusion Criteria

Studies were included when they fulfilled the following criteria:

- a. Investigated halal food additives, ingredients, or processing components associated with halal food production.
- b. Reported chemical composition, molecular structure, physicochemical properties, or sources of food additives.

- c. Evaluated analytical approaches for halal authentication, adulteration detection, or contamination monitoring.
- d. Discussed food safety assessment, toxicological evaluation, permissible limits, or regulatory requirements.
- e. Examined halal certification standards, international regulations, or authentication frameworks.
- f. Applied analytical methods such as chromatography, spectroscopy, molecular techniques, biosensors, immunological assays, or physicochemical analysis.
- g. Were published as peer-reviewed research articles, conference proceedings, technical reports, or official regulatory documents.

Exclusion Criteria

Studies were excluded when they:

- a. Were unrelated to halal food certification or additive verification.
- b. Did not address chemical characterization, safety assessment, or analytical authentication.
- c. Were duplicate publications.
- d. Lacked adequate methodological information.
- e. Represented non-scientific sources, commercial materials, unsupported online content, or opinion-based publications.

Study Selection and PRISMA Screening Process

The study selection process followed a structured PRISMA workflow. All identified records were exported into reference management software, and duplicate records were removed before screening.

- a. The screening process consisted of four sequential stages: Identification: Relevant records were identified through database searching and additional sources.
- b. Screening: Titles and abstracts were evaluated against predefined eligibility criteria.
- c. Eligibility assessment: Full-text articles were assessed for methodological relevance and compliance with inclusion criteria.
- d. Final inclusion: Studies meeting all eligibility requirements were included for qualitative synthesis.

Following the screening process, 53 studies were included in the final qualitative synthesis.

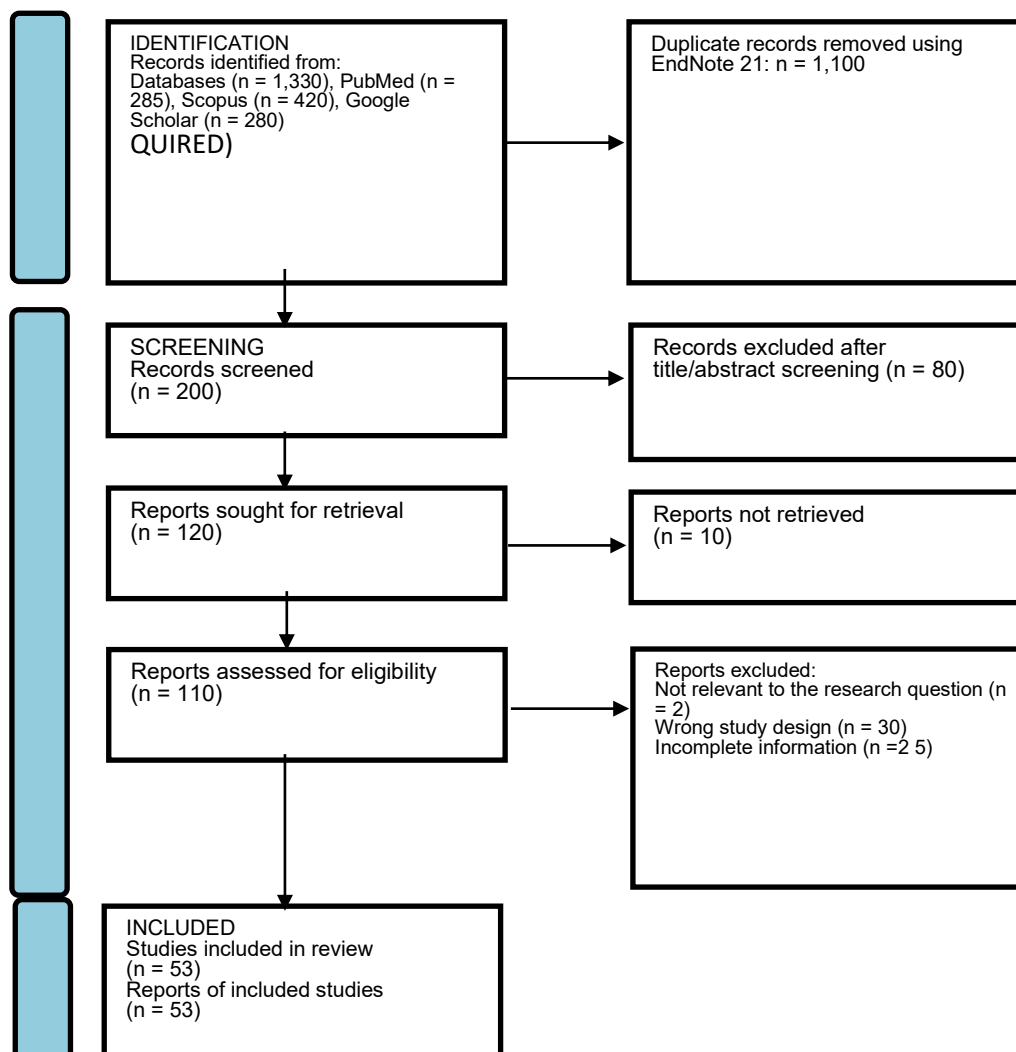


Figure 1. Prisma Diagram

Data Extraction and Analysis

A standardized data extraction framework was used to collect relevant information from the selected studies. The extracted data included:

- Author(s) and publication year
- Type and classification of food additives
- Chemical composition and molecular characteristics
- Sources and production processes
- Industrial applications in halal food systems
- Analytical methods used for authentication and characterization
- Food safety considerations and regulatory limits
- Halal certification requirements and compliance criteria

The extracted information was synthesized qualitatively to identify major themes related to food additive chemistry, halal status determination, analytical verification strategies, and regulatory challenges.

Quality Assessment of Included Studies

The methodological quality of the included studies was critically evaluated based on study design, analytical reliability, methodological transparency, and reporting quality. Experimental studies involving chemical characterization and analytical detection were assessed according to:

- a. Adequacy of analytical methodology
- b. Validation of analytical procedures
- c. Reliability and reproducibility of results
- d. Description of sample preparation and analysis conditions
- e. Appropriate interpretation of findings
- f. Regulatory guidelines and halal certification standards were evaluated according to their issuing authority, international recognition, transparency of certification criteria, and relevance to halal food additive regulation.

Based on methodological strength, studies were classified as:

High quality: Studies with validated methods, clear methodology, and reliable analytical evidence. Moderate quality: Studies with acceptable methodology but limited validation or incomplete reporting. Low quality: Studies with insufficient methodological details or unclear analytical procedures.

Comparative Analysis of Halal Certification Systems

A comparative evaluation of international halal certification systems was conducted to assess variations in definitions, regulatory requirements, additive classification, and authentication procedures among different countries and certification organizations.

The comparison considered:

- a. Criteria for halal and non-halal additive classification
- b. Requirements for ingredient traceability
- c. Certification and auditing procedures
- d. Analytical verification approaches
- e. Differences between international halal regulatory frameworks

RESULTS AND DISCUSSION

Chemical Composition of Halal Food Additives

Halal-certified food additives comprise a chemically diverse group of substances incorporated into foods to improve preservation, sensory quality, stability, and processing performance. In addition to fulfilling technological functions, these additives must comply with the Halal-Tayyib principles, which require ingredients to be permissible, safe, and wholesome (Alzeer et al., 2025). Consequently, halal evaluation extends beyond the molecular composition of an additive to include its raw material origin, manufacturing process, and the possibility of contamination throughout production (Mariyam et al., 2022). As modern food processing increasingly relies on synthetic and semi-synthetic compounds, rigorous verification is essential to ensure that additives remain free from non-halal materials and cross-contamination (Ghifari & Priyatno, 2024).

Common halal food additives include preservatives, flavour enhancers, colourants, processing aids, and stabilizers. Preservatives such as sorbates and benzoates inhibit microbial growth and extend shelf life, whereas monosodium glutamate (MSG) enhances flavour without substantially altering the chemical composition of foods. Natural pigments, including carotenoids and anthocyanins, improve visual appeal and consumer acceptance. Although these additives are generally regarded as chemically safe, their halal status depends on the source of

raw materials, extraction solvents, fermentation media, processing aids, and manufacturing conditions.

Processing aids such as activated carbon and emulsifiers may originate from plant, animal, or synthetic sources, making source verification essential for halal compliance (Arifin et al., 2021). Likewise, the increasing use of synthetic and E-coded additives presents additional challenges because extensive chemical modification can obscure their source, while carriers and processing aids are not always declared on product labels (Altun & Aydemir, 2021; N. & M., 2023). These factors highlight the need for robust traceability systems and systematic identification protocols capable of verifying ingredient authenticity throughout the production chain (Margaretha, 2025).

Table 1. Common Halal Food Additives and Their Chemical Characteristics

Additive Type	Examples	Chemical Role	Primary Source	Halal Consideration
Preservatives	Sorbates, Benzoates	Inhibit microbial growth	Synthetic / plant-based	Must be free from alcohol-based or non-halal carriers
Flavor Enhancers	Monosodium glutamate (MSG)	Enhances umami taste	Fermentation (plant-based)	Must ensure fermentation medium is halal-compliant
Colorants	Carotenoids, Anthocyanins	Provide natural coloration	Plants, microorganisms	Risk of solvent or extraction contamination
Processing Aids	Activated carbon, emulsifiers	Aid food processing stability	Plant/animal/synthetic	Requires strict source verification
Stabilizers	Gums, starch derivatives	Maintain texture and consistency	Plant-based	Generally, halal if uncontaminated

The chemical composition of food additives must therefore be evaluated alongside their production history because chemically identical compounds may originate from plant, animal, or synthetic sources. This structural similarity complicates halal authentication, particularly when additives are produced through fermentation or chemical synthesis involving animal-derived substrates or non-halal processing materials (Mariyam et al., 2022). As a result, molecular structure alone cannot always establish halal status, necessitating analytical approaches capable of tracing ingredient origin (Maknu et al., 2021). Regulatory frameworks such as the Halal-Tayyib Positive List have therefore been developed to define permissible additives based on both scientific safety assessments and Islamic jurisprudence (Alzeer et al., 2025).

Reliable halal authentication increasingly depends on advanced analytical techniques capable of resolving complex molecular compositions. High-resolution methods such as liquid chromatography–tandem mass spectrometry (LC–MS/MS) and gas chromatography–mass spectrometry (GC–MS) enable precise characterization of lipid-based additives and facilitate discrimination between halal and non-halal sources based on compositional profiles (Sani et al., 2025). Complementary spectroscopic techniques, including nuclear magnetic resonance (NMR) and Fourier-transform infrared (FTIR) spectroscopy, provide characteristic molecular fingerprints that are particularly useful for distinguishing plant-derived and animal-derived additives in complex food matrices such as dairy products and confectionery (Gramita et al., 2026; Gramita et al., 2026a, 2026b). Together, these techniques strengthen halal authentication by providing reliable scientific evidence for regulatory compliance.

Food additives may become contaminated with non-halal substances at any stage of manufacturing, handling, storage, or distribution. Potential contaminants include pork-derived materials, blood products, improperly slaughtered animal ingredients, and alcohol used as solvents or carriers in flavourings and colourants (Ghifari & Priyatno, 2024; Al-Mahmood & Fraser, 2023). The risk is particularly significant in large-scale manufacturing facilities where halal and non-halal products share equipment or production lines (Ahmad et al., 2023). Consequently, effective segregation of production facilities, dedicated equipment, validated cleaning procedures, and appropriate ritual cleansing where required are essential to prevent cross-contamination (Sidarto & Hamka, 2021).

Comprehensive supplier verification and certified halal sourcing further strengthen contamination control by ensuring ingredient traceability and regulatory compliance throughout the supply chain (Khan et al., 2022; Mustaniroh et al., 2025). Formal halal agreements with suppliers improve transparency and reduce the likelihood of introducing non-compliant ingredients into food production (Andespa et al., 2024). In addition, automated traceability systems combined with molecular detection technologies facilitate continuous monitoring of ingredient movement and enable the identification of prohibited DNA, enzymes, or other non-halal constituents within complex food formulations (Azmi et al., 2021; Islam et al., 2023). Collectively, these measures enhance the integrity of halal-certified food additives from raw material procurement to the finished product.

Halal Certification and Regulatory Standards

Halal certification is a structured regulatory framework designed to verify that food products, including additives, comply with Islamic dietary requirements throughout the production chain. Certification bodies function as independent authorities responsible for evaluating ingredients, production systems, and supply chain practices against established halal criteria. Their assessment begins with raw material screening to confirm that ingredients originate from permissible sources and are free from non-halal substances (Al-Mahmood & Fraser, 2023). This initial verification step minimizes the risk of introducing non-compliant materials into food manufacturing processes.

Beyond ingredient assessment, halal certification bodies perform comprehensive facility inspections to evaluate hygiene practices, equipment separation, storage conditions, and production procedures. These audits ensure that manufacturing environments prevent cross-contamination between halal and non-halal products. In addition, some certification systems incorporate continuous monitoring after certification through periodic inspections and compliance reviews to maintain halal integrity during processing, storage, and distribution (Yanuardin, 2024).

Modern halal certification increasingly integrates laboratory analysis and documentation verification to complement physical inspections. Scientific assessments are used to confirm ingredient authenticity, identify potential contaminants, and verify the compliance of processing aids and additives with halal requirements (Prawiro & Fathudin, 2023). The combination of regulatory auditing and analytical testing strengthens halal assurance by providing both procedural and scientific evidence of compliance.

The growing complexity of global food production has increased the importance of standardized halal certification systems. These systems provide a framework that connects Islamic jurisprudence with international food trade requirements, allowing halal products to be evaluated consistently across diverse manufacturing environments (Yuanitasari et al., 2025). However, the absence of a universally harmonized halal standard remains a major challenge. Variations among countries and certification organizations in criteria, auditing procedures, and

recognition mechanisms create regulatory fragmentation and complicate the international trade of halal-certified products (Fadhillah & Saputra, 2025; Sorna et al., 2024).

Table 2. Key Functions of Halal Certification Bodies

Function Area	Activities Performed	Purpose in Halal Assurance	Outcome
Raw Material Screening	Evaluation of ingredient sources and documentation	Ensure ingredients are halal-compliant	Prevention of non-halal inputs
Facility Audit	On-site inspection of production systems	Assess hygiene and segregation practices	Compliance verification
Process Monitoring	Continuous supervision of production stages	Maintain ongoing halal integrity	Reduced risk of contamination
Laboratory Testing	Chemical and microbiological analysis	Detect adulteration or impurities	Scientific confirmation of compliance
Documentation Review	Verification of certificates and supply chain records	Ensure traceability and transparency	Regulatory accountability
Certification Approval	Issuance of a halal certificate	Official recognition of compliance	Market authorization

Halal food additive regulations integrate international food safety standards with halal-specific requirements. Standards such as the Codex Alimentarius establish limits for food additives, contaminants, and processing aids. In contrast, halal certification organizations apply additional criteria related to ingredient origin, processing methods, and contamination risks. Organizations such as the Islamic Food and Nutrition Council of America (IFANCA) evaluate not only the safety of additives but also their production pathways to ensure compliance with Islamic dietary principles (Noor et al., 2023). The Halal-Tayyib concept further expands these requirements by emphasizing that additives must be both religiously permissible and scientifically safe, requiring assessment of toxicity, quality, and ethical sourcing (Alzeer et al., 2025; Mariyam et al., 2022).

The increasing reliance on analytical chemistry has enhanced the scientific basis of halal verification. Techniques such as chromatography, mass spectrometry, and molecular analysis enable the identification of ingredient origins, detection of prohibited substances, and confirmation of additive authenticity (Azmi et al., 2024). These approaches are particularly valuable for chemically modified additives where the final molecular structure may not reveal the source of the material.

Ensuring the safety and purity of halal food additives requires additional evaluation of toxicological, microbiological, and allergenic risks. Toxicity assessment determines potential health effects, allergenicity screening identifies immune-related risks, and microbiological analysis confirms the absence of harmful microorganisms (Çaykara, 2023). Advanced analytical platforms, including high-performance liquid chromatography (HPLC), gas chromatography (GC), DNA-based authentication, and immunological assays, provide sensitive detection of trace non-halal components and contaminants in complex food matrices (Ahmad et al., 2025). Integration of these analytical tools into quality management systems improves traceability and supports halal compliance from raw material procurement to final product packaging (Saputra et al., 2025). Furthermore, Halal Supply Chain Management approaches strengthen contamination control by improving coordination among suppliers, manufacturers, and distributors (Hakim, 2025).

Industrial applications demonstrate the practical value of halal certification systems in ensuring both regulatory compliance and consumer confidence. Many halal-approved additives undergo detailed assessments involving ingredient verification, laboratory testing, and production process evaluation. For example, fermented additives may require molecular confirmation that production media and substrates are free from non-halal materials. In contrast, synthetic additives may be examined to ensure that prohibited catalysts or alcohol-based solvents were not involved during manufacturing. These assessments demonstrate the importance of combining scientific verification with religious requirements for reliable halal certification.

Recent advances in Industry 4.0 technologies have further improved halal assurance systems. Digital traceability platforms, automated monitoring systems, and real-time supply chain tracking enhance transparency and enable continuous verification of halal status throughout production and distribution networks (Nusran & Sitnah, 2023). These innovations represent an important transition from conventional certification approaches toward integrated, technology-driven halal quality management systems.

Table 3. Case Studies of Halal Food Additive Certification

Case Study	Additive Type	Key Issue Identified	Certification Method Used	Outcome
Emulsifier certification	Emulsifiers (e.g., mono- and diglycerides)	Possible animal-derived fats (porcine or non-halal sources)	Supply chain traceability + GC-MS lipid profiling	Approved after confirming a plant-based source
Gelatin substitutes	Gelling agents	Risk of porcine gelatin contamination	DNA testing + supplier audit	Halal alternative confirmed (fish/plant gelatin)
Flavor enhancers (MSG)	Monosodium glutamate	Uncertainty in fermentation media	Microbial source verification + HPLC analysis	Certified after halal-compliant fermentation confirmed
Colorant certification	Natural colorants (carotenoids, anthocyanins)	Solvent contamination (alcohol-based extraction)	FTIR spectroscopy + solvent residue testing	Approved after solvent-free extraction validation
Preservative validation	Sorbates and benzoates	Synthetic processing aid uncertainty	Toxicological assessment + documentation review	Certified based on chemical safety compliance
Enzyme-based additives	Industrial enzymes	Risk of porcine enzyme origin	Immunoassay testing + PCR DNA screening	Rejected until a halal microbial source is confirmed

This table highlights how different categories of food additives are evaluated by scientists, regulators, and religious authorities before approval for halal certification.

Chemical Analysis Techniques for Halal Food Additives

The authentication of halal food additives relies on advanced analytical techniques capable of determining chemical composition, detecting impurities, and verifying ingredient authenticity. Chromatographic methods, including high-performance liquid chromatography

(HPLC) and gas chromatography (GC), are widely used to separate and quantify compounds in complex food matrices. HPLC is particularly suitable for non-volatile additives such as preservatives and sweeteners, whereas GC is more effective for volatile compounds, including flavouring agents and essential oils. These techniques are frequently coupled with mass spectrometry (MS), which provides highly sensitive molecular identification based on mass-to-charge ratios and fragmentation patterns, thereby improving the reliability of compound confirmation.

Robust analytical procedures are essential for detecting prohibited or undeclared ingredients and ensuring compliance with halal integrity requirements (Rafi, 2024). In practice, chromatographic techniques are often integrated with chemometric analysis, where multivariate statistical methods facilitate interpretation of complex datasets and enable discrimination between halal and non-halal products through characteristic chemical markers (Nurani et al., 2022). This combination significantly enhances analytical accuracy and food authentication.

Chemical analysis is complemented by molecular and immunological techniques, particularly when verifying additives of biological origin. DNA-based methods are highly sensitive for detecting trace amounts of animal-derived contaminants, including porcine DNA, even in highly processed food products. Likewise, immunological assays such as enzyme-linked immunosorbent assays (ELISA) and other protein-based methods enable the detection of prohibited proteins, including porcine gelatin and alcohol-derived enzymes, making them valuable for evaluating emulsifiers, stabilizers, and flavour enhancers produced from complex biological materials.

Recent technological advances have expanded halal verification beyond laboratory-based analysis. Artificial intelligence (AI), blockchain technology, and Internet of Things (IoT) systems are increasingly integrated into halal supply chains to improve traceability, transparency, and real-time monitoring of food additives from raw material sourcing to product distribution (Ahmad et al., 2025). Blockchain provides secure and immutable records of ingredient origin and processing history, while AI facilitates pattern recognition and prediction of contamination risks. Similarly, IoT technologies, including RFID tags and QR codes, enable continuous product tracking throughout the supply chain (Nugroho et al., 2024). Emerging sensor technologies such as electronic noses (e-noses) also provide rapid, non-destructive screening of volatile compounds in oils, sauces, and flavouring agents, offering an efficient alternative for preliminary halal verification (Nafi et al., 2025).

Despite these advances, the increasing complexity of modern food formulations continues to challenge conventional analytical methods. Trace adulterants in highly processed foods often cannot be identified using a single analytical technique; therefore, comprehensive halal authentication requires integrating chromatographic, molecular, spectroscopic, and digital technologies (Ng et al., 2021; Nazri, 2025). This multidisciplinary approach provides greater analytical confidence and strengthens regulatory compliance.

Table 4. Chemical Analysis Techniques for Halal Food Additive Verification

Category	Technique	Principle	Application in Halal Testing	Advantage
Chromatographic Methods	HPLC	Separation of non-volatile compounds	Detection of preservatives, sweeteners	High precision and reproducibility
Chromatographic Methods	GC	Separation of volatile compounds	Flavoring agents, oils analysis	Effective for volatile compounds
Spectrometric	MS	Mass-to-charge	Molecular	Highly sensitive

Methods		identification	confirmation of additives	detection
Molecular Methods	DNA testing	Genetic identification	Detection of pork or animal DNA	High specificity for contamination
Immunological Methods	ELISA	Antigen-antibody reaction	Detection of gelatin and proteins	Rapid and cost-effective
Chemometrics	Multivariate analysis	Statistical pattern recognition	Halal vs non-halal classification	Improves data interpretation (Nurani et al., 2022)
Digital Technologies	Blockchain & AI	Data tracking & prediction	Supply chain traceability	Enhances transparency (Ahmad et al., 2025)
Sensor Technology	Electronic nose (e-nose)	Volatile compound detection	Screening oils, sauces	Fast non-destructive testing (Nafi et al., 2025)
IoT Systems	RFID & QR codes	Real-time tracking	Supply chain monitoring	End-to-end traceability (Nugroho et al., 2024)

The Difficulties of Maintaining The Purity of Additives- Halal

Maintaining the halal purity of food additives remains challenging because halal certification systems are not globally harmonized. Differences in certification criteria, auditing procedures, and religious interpretations among certification bodies create inconsistencies in regulatory decisions and complicate international trade. Consequently, an additive approved in one jurisdiction may require additional assessment or fail to satisfy the requirements of another certification authority (Munawar & Mugiono, 2024). Although initiatives such as the Halal Positive List seek to harmonize acceptable ingredients and certification practices, their implementation remains limited because of differences in national regulations and institutional priorities (Alzeer et al., 2025).

Scientific verification presents an additional challenge, particularly for highly processed food additives. Modern manufacturing frequently involves synthetic intermediates, multiple processing stages, and chemically modified ingredients that obscure their source. Trace contamination from porcine enzymes, alcohol-based solvents, or other prohibited processing aids may occur at concentrations below the detection limits of conventional analytical methods (Islam et al., 2023; Maulana et al., 2023). Consequently, reliable halal authentication increasingly depends on sensitive chromatographic and molecular techniques capable of detecting trace contaminants in complex food matrices.

Economic considerations also influence halal compliance. Certification requires investment in laboratory analyses, supply chain audits, documentation systems, and certification fees, creating significant financial challenges for small and medium-sized enterprises (SMEs). Additional expenditures associated with segregated production facilities, dedicated storage systems, and certified packaging materials further increase production costs and may reduce market competitiveness (Andespa et al., 2024).

Consumer confidence remains fundamental to the success of halal-certified products. Confidence depends not only on certification labels but also on transparency regarding ingredient sourcing, manufacturing practices, and certification procedures. As food production

technologies continue to evolve, certification authorities must also develop expertise in emerging areas such as biotechnology, nanotechnology, and novel food additives to ensure consistent and scientifically robust evaluations. These developments highlight the need for standardized competency frameworks and continuous technical training for halal auditors.

Improving halal assurance therefore requires an integrated approach combining harmonized international standards, advanced analytical verification, digital traceability systems, and strengthened regulatory cooperation. Although the Halal Positive List represents an important step toward ingredient standardization, broader international acceptance remains necessary to achieve global consistency in halal certification (Alzeer et al., 2025). Collectively, these measures will enhance transparency, strengthen consumer confidence, and improve the credibility of halal-certified food additives in international markets.

The future of halal food additive verification will increasingly depend on integrating artificial intelligence (AI) and machine learning (ML) with advanced analytical technologies. AI-assisted platforms can automate the interpretation of chromatographic, spectroscopic, and molecular datasets, improving the speed, accuracy, and consistency of halal authentication. Machine learning algorithms also offer opportunities for predictive modelling by identifying contamination risks, recognizing chemical patterns associated with halal and non-halal ingredients, and supporting real-time decision-making throughout food production. The integration of intelligent data analysis with laboratory diagnostics therefore represents a major advancement toward digital halal assurance systems capable of minimizing human error while improving scalability across the global food industry.

A major priority for future development is harmonizing international halal certification standards. Differences in ingredient classification, certification criteria, laboratory protocols, and regulatory requirements among certification bodies continue to impede global trade and create uncertainty for manufacturers. Developing internationally accepted guidelines that integrate scientific food safety standards with Islamic jurisprudence would facilitate mutual recognition of halal certification, standardize analytical verification procedures, and improve regulatory consistency across countries. Such harmonization would enhance transparency, reduce certification costs, and strengthen consumer confidence in internationally traded halal products.

Future halal assurance systems should adopt a holistic farm-to-fork approach that integrates Sharia compliance, scientific verification, and supply chain management throughout the entire production process (Shamsudin et al., 2022). Achieving this objective will require stronger collaboration among academic institutions, regulatory agencies, certification organizations, and the food industry. Particular attention should be given to supporting small and medium-sized enterprises (SMEs), which often face technical and financial barriers to certification. Collaborative research and knowledge-sharing initiatives can improve technology transfer, expand access to analytical facilities, and strengthen halal compliance within SME production systems (Nugraha et al., 2024). Longitudinal and comparative studies are also needed to evaluate the long-term effects of halal certification on business sustainability, market competitiveness, and international trade performance (Hasibuan & Surya, 2025).

Future research should also expand beyond analytical verification to examine external factors that influence halal certification and consumer acceptance. Studies investigating regional regulatory differences, socio-environmental influences, and market dynamics would provide valuable evidence for developing globally applicable certification frameworks (Anggriani, 2024). In addition, research into consumer behaviour, including trust, religious commitment, perceived product authenticity, and purchasing intentions, would improve understanding of how certification influences market acceptance (Darmawati et al., 2023). Specialized studies focusing on emerging sectors, including novel food additives, biotechnology-derived ingredients, nanotechnology-based food systems, and precision

fermentation, are equally important for developing certification methodologies that remain effective as food technologies evolve (Islam et al., 2023).

Future progress in halal food additive certification will depend on the successful integration of scientific innovation, international policy harmonization, advanced analytical technologies, and stakeholder collaboration. These efforts will support the development of a more transparent, reliable, and globally accepted halal certification framework capable of addressing the challenges of modern food manufacturing.

CONCLUSION

This study demonstrates that ensuring the halal integrity of food additives requires a multidisciplinary approach that integrates analytical chemistry, food science, regulatory governance, and Islamic jurisprudence. Unlike conventional food safety assessments that primarily focus on chemical safety, halal verification must also establish ingredient origin, manufacturing processes, and the potential for contamination throughout the supply chain. The evidence synthesized in this review shows that advanced analytical techniques, including chromatographic, spectrometric, molecular, and immunological methods, have become indispensable for verifying ingredient authenticity and detecting trace non-halal contaminants in increasingly complex food matrices. A key contribution of this review is integrating current knowledge of the chemical characteristics of halal food additives, modern analytical verification techniques, regulatory frameworks, and emerging digital technologies into a single comprehensive framework. By critically examining these interconnected components, the review highlights that reliable halal assurance depends not on a single analytical method or certification procedure but on combining scientific verification with robust traceability systems and harmonized regulatory practices. The review also identifies persistent challenges, including inconsistent international certification standards, limited global regulatory harmonization, technical difficulties associated with highly processed additives, and the financial burden of compliance, particularly for small and medium-sized enterprises.

Looking forward, strengthening halal food additive authentication will require greater international collaboration to harmonize certification standards, wider adoption of validated analytical protocols, and continued integration of digital technologies such as artificial intelligence, blockchain, and Internet of Things–based traceability systems. Future research should also focus on validating analytical approaches for emerging food technologies, developing standardized reference materials, and evaluating the effectiveness of integrated halal assurance systems under real industrial conditions. Collectively, these advances will support the development of a scientifically robust, globally recognized, and transparent halal certification framework that enhances consumer confidence while facilitating international trade in halal food products.

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