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# Analytical approaches for halal authentication in meat and meat products: A review

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## ABSTRACT
The increasing awareness among Muslim consumers regarding the importance of halal status has driven the demand for accurate, rapid, and scientifically reliable halal authentication methods, particularly for meat-based products that are highly susceptible to cross-contamination and adulteration with non-halal materials. Although numerous analytical techniques have been developed, existing studies are often fragmented, method-specific, and lacking an integrative evaluation that links analytical performance with practical implementation in halal assurance systems. This article reviews various halal authentication approaches by highlighting their working principles, advantages, limitations, and recent technological developments. The review was conducted through a systematic literature review of publications from 2015 to 2025 sourced from Scopus and ScienceDirect. The analyzed authentication methods include DNA-based molecular techniques such as PCR, qPCR, and LAMP, which offer high sensitivity and thermal stability; protein-based methods such as ELISA, aptamers, and proteomics, which detect species-specific biomarkers; and spectroscopic approaches (FTIR, Raman, NMR) combined with chemometrics for rapid and non-destructive differentiation of the chemical profiles of halal and non-halal materials. This review contributes by providing an integrated framework that compares conventional and emerging methods in terms of sensitivity, applicability to processed meat matrices, and relevance to halal verification practices. Furthermore, the findings highlight the potential role of modern analytical integration in strengthening the Halal Product Assurance System (SJPH), improving transparency, consumer trust, and the competitiveness of the halal food industry.

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## INTRODUCTION
The growing awareness among Muslim consumers regarding the importance of halal labeling on all consumed products has led to an increasing market demand for halal-certified goods, particularly in Muslim-majority countries such as Indonesia (Ng et al., 2022). This trend is supported by consumer-based evidence, with a survey study in Turkey reporting that 82.2% of respondents considered halal certification important, indicating strong consumer concern about halal assurance in food products (Aslan, 2023). However, the long and complex supply chain presents a major challenge for the global food industry in ensuring product halal integrity. Many processed meat products have uncertain halal status, and processing operations such as heating, extraction, and fermentation can alter product appearance, making physical or sensory identification of raw materials difficult. In addition, halal integrity is often compromised at critical halal points during processing, particularly when

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manufacturers use functional additives or processing aids whose origin is difficult to verify. For example, gelatin, widely used as a stabilizer or texturing agent, is considered a critical point because it may be produced from porcine-derived materials such as pig skin, which are prohibited for Muslim consumption (Rahmayanti et al., 2025). Consequently, in the current era of advanced food-processing technologies, cross-contamination between halal and non-halal materials is frequently reported, resulting in reduced consumer confidence (Dewi et al., 2023). Ensuring halal integrity today therefore requires analytical authentication methods that are valid, sensitive, and specific.

Halal authentication refers to the verification of halal status in ingredients and products using analytical techniques to support certification, industry audits, and market surveillance. Advances in analytical technology have introduced a wide range of halal authentication approaches, from chemical and biochemical assays to modern techniques based on molecular biology, immunology, and spectroscopy. DNA-based analyses, such as polymerase chain reaction (PCR) and real-time PCR (qPCR), which detect species-specific DNA sequences, have become widely adopted due to the high thermal stability of DNA, making them suitable for processed products (He & Yang, 2018). Meanwhile, protein-based methods such as enzyme-linked immunosorbent assay (ELISA), an antibody-based assay for detecting target proteins, enable rapid detection but are more susceptible to protein degradation caused by intense heat treatment (Aprilia et al., 2022). Spectroscopic techniques, including Fourier-transform infrared (FTIR), Raman, and nuclear magnetic resonance (NMR) spectroscopy, combined with chemometrics, have emerged as rapid and non-destructive tools with strong potential for fast screening in authentication processes (Rohman & Windarsih, 2020). Smart-sensor approaches, such as electronic noses and biosensors based on aptamers or molecular beacons, have demonstrated highly specific detection capabilities for species-specific biomolecules. The integration of analytical technologies with machine learning and big-data processing further enhances classification accuracy and accelerates authentication workflows for industrial applications (Abd El-Hack et al., 2018).

This review addresses the growing need for reliable halal assurance in meat and meat-based products by highlighting the gap between rapid advances in analytical authentication technologies and their practical implementation in real food processing and regulatory settings. Accordingly, this article provides a comprehensive and structured overview of conventional and emerging halal authentication methods, discussing their working principles, strengths, limitations, and recent developments. The review contributes by critically comparing each approach not only from an analytical performance perspective, but also in terms of industrial feasibility, suitability for processed meat matrices, and relevance to certification and market surveillance. Ultimately, this synthesis is expected to support researchers, the food industry, and regulatory authorities in selecting appropriate authentication strategies to strengthen halal integrity, enhance supply-chain transparency, and improve consumer trust.

## RESEARCH METHOD

### Methods

This study employed a literature review approach. Figure 1 shows that data were collected from journal articles, conference proceedings, fatwas, and official documents relevant to dairy products and their derivatives. A literature search was conducted using online databases such as ScienceDirect and Google Scholar using the following keywords: "halal," "raw materials," "processing," "additives," and "packaging" found in dairy products and their derivatives. Additional resources were manually obtained from relevant literature. Inclusion criteria focused on studies published in the last 10 years and fatwas or regulations issued by the Indonesian Ulema Council (MUI) regarding halal food and beverages. This analysis emphasized the identification of raw materials, halal milk processing, dairy product additives, and packaging as potential critical points for halal certification.

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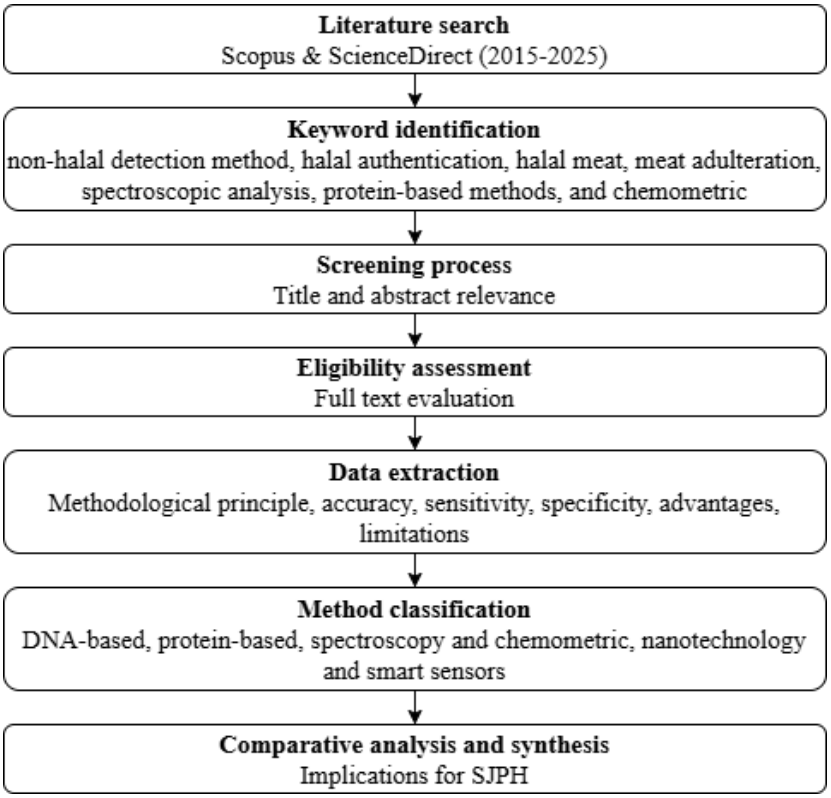



**Figure 1.** Overview of the review methodology.

## RESULT AND DISCUSSION

### Fundamental Principles of Halal Authentication

The halal authentication methods discussed in this review were selected based on their relevance, reliability, and common use in meat authentication studies. DNA-based methods were included because of their high specificity and ability to remain detectable in processed products. Protein-based methods were considered due to their rapid analysis and suitability for routine testing. Spectroscopic techniques were chosen for their non-destructive nature and effectiveness as rapid screening tools, while nanotechnology-based and smart sensor approaches were included as emerging methods with strong potential for real-time and on-site halal detection. Together, these methods represent both established practices and recent developments in halal authentication research.

The halal status of a product can change due to various factors, particularly the complexity of the supply chain, the use of globally sourced raw materials, and the increasing innovation in meat-based product formulations. Distribution processes and the use of diverse ingredients during production heighten the risk of cross-contamination or the incorporation of non-halal materials that cannot be identified visually, such as enzyme derivatives, gelatin, or emulsifiers derived from animals not slaughtered according to Islamic law. Therefore, halal authentication is essential to ensure that the ingredients used originate from halal sources and are free from contamination by non-halal substances.

Scientific approaches to halal authentication aim to provide objective evidence through standardized, rapid, and accurate analytical methods. Commonly applied techniques include DNA-based (molecular) methods, protein-based assays, and spectroscopic or chemical analysis (Airin et al., 2025; He & Yang, 2018; Suratno et al., 2025). DNA-based methods are widely used because DNA remains stable under thermal processing and enables highly specific identification of animal species. The advancement of DNA sequence databases has further facilitated and accelerated halal authentication in food products. In addition, protein-based techniques such as ELISA rely on species-specific protein biomarkers. Chemical analytical approaches such as FTIR, GC-MS, and LC-MS are also employed to differentiate halal and non-halal ingredients by examining lipid profiles or metabolite patterns.

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The development and application of scientific methods for halal authentication not only support a more efficient and transparent halal certification process but also play a crucial role in safeguarding the integrity of the halal food supply chain. Through DNA-based, protein-based, and chemical analytical techniques, the detection of non-halal substances can be conducted more accurately and scientifically accountable. These approaches align with the core principles of halal authentication: ensuring authenticity, purity, and traceability of materials used throughout each stage of production (Rejeb, 2018). The capability of these methods to identify ingredients at the molecular level makes them essential tools in detecting potential cross-contamination occurring during processing, storage, or distribution. Consequently, the implementation of halal authentication techniques strengthens consumer confidence in the integrity of halal products while ensuring industry compliance with increasingly stringent halal standards and regulations driven by global demands for transparency and accountability.

**Molecular Methods (DNA-Based Methods)**

**Table 1.** DNA-based methods for halal authentication.

| Method | Analysis Target/ Gene | Advantages | Limitations | Reference |
|---|---|---|---|---|
| Colorimetric DNA biosensor based on gold nanoparticles (AuNPs) | Specific mitochondrial DNA fragments of pork | Rapid detection<br>Does not require complex equipment<br>Results can be visually observed through color changes<br>Capable of detecting concentrations as low as 0,001-0,1 mmol/L DNA | Lower sensitivity compared to PCR;<br>Susceptible to interpretation errors related to color changes;<br>Limited to specific target species. | He & Yang (2018) |
| Conventional multiplex PCR combined with magnetic nanoparticle DNA extraction | Mitochondrial genes Cyt b, COIII, ATPase 8/6 (chicken, duck, pork, beef) | Able to detect multiple species simultaneously<br>High sensitivity (up to 0,05%)<br>Improves DNA extraction purity by reducing the presence of PCR inhibitors<br>Does not require expensive instrumentation | Optimal performance requires dry samples;<br>Sensitivity decreases in fatty or wet meat products. | Qin et al. (2019) |
| Multiplex and duplex conventional PCR | Mitochondrial genes 12S rRNA and Cyt b (cattle, chicken, pork, dog, sheep, rat) | High sensitivity, accuracy, and specificity | Requires laboratory procedures and PCR temperature optimization;<br>Risk of cross-contamination. | Setiani et al. (2025) |
| Multiplex Real-Time PCR (qPCR) | Species-specific nuclear genes: TNFRSF10A (cattle), PRNP (pork), TGF-β3 (chicken), ACTB (duck) | High sensitivity and specificity (LOD 10-20 copies of DNA)<br>Provides quantitative and real-time results | High cost<br>Requires advanced laboratory equipment. | Chang et al. (2025) |

Table 1 shows numerous studies that demonstrated that DNA-based techniques, particularly PCR and its derivatives, are highly effective for halal authentication and the detection of non-halal materials in meat products. DNA-based methods are among the most reliable approaches for halal authentication and the detection of non-halal materials in meat-based food products. The fundamental principle of this method is that each species possesses a unique DNA sequence that functions as a genetic "fingerprint,"

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enabling highly specific identification even after the material has undergone intense heating or processing. In general, molecular techniques detect species-specific DNA through amplification of target gene fragments, such as mitochondrial Cytochrome b (Cyt b), Cytochrome oxidase subunit III (COIII), or 12S rRNA, using polymerase chain reaction (PCR). These gene regions are selected because they contain sufficient interspecies variation, allowing for highly accurate species discrimination (He & Yang, 2018; Qin et al., 2019; Setiani et al., 2025). The adoption of DNA-based approaches in food authentication has grown in parallel with the rapid development of PCR, known for its sensitivity and speed. In the context of halal integrity, the application of PCR has expanded significantly following global concerns surrounding fraud involving non-halal components such as porcine gelatin, animal fats, and mixed meat products.

Advancements in molecular technology have driven the evolution of DNA-based authentication toward real-time PCR (qPCR), loop-mediated isothermal amplification (LAMP), and nanoparticle-based DNA biosensors, all of which offer improved sensitivity and faster detection times. DNA methods have been widely applied not only for identifying species substitution in meat mixtures but also for detecting porcine contamination in processed products. Qin et al. (2019), for example, developed a multiplex PCR targeting mitochondrial genes from several species, including cattle, pigs, chicken, and duck. Their method integrated magnetic nanoparticles (MNPs) for DNA extraction, resulting in significantly enhanced detection sensitivity. The improved performance was attributed to the ability of MNPs to yield high-purity DNA free from PCR inhibitors, a notable advantage over conventional extraction methods that often leave residual solvents such as phenol and chloroform.

Another innovative approach for halal authentication involves a nanoparticle-based colorimetric assay using gold nanoparticles (AuNPs), which can detect porcine-specific mitochondrial DNA (He & Yang, 2018). When the target DNA is present, AuNP-conjugated oligonucleotide probes hybridize with the DNA and induce nanoparticle aggregation, producing a visible color shift from red to blue. This simple visual change enables rapid and cost-effective detection without requiring complex laboratory instrumentation.

In Indonesia, Setiani et al. (2025) applied DNA-based techniques through multiplex and duplex PCR targeting mitochondrial 12S rRNA and Cytochrome b. Multiplex PCR was used to detect non-halal species such as pig, dog, and rat in beef floss samples, while duplex PCR was designed to identify potential substitution with chicken meat. The use of appropriate positive and negative controls, followed by gel electrophoresis confirmation, ensured analytical accuracy. Their findings revealed the presence of chicken DNA in beef floss from small-scale producers, highlighting the effectiveness of DNA methods in detecting compositional inconsistencies and violations of labeling authenticity.

PCR-based methods can also identify non-halal species beyond pork. A species-specific primer targeting the mitochondrial cytochrome b gene (CYTBCA3-kh) successfully detected canine DNA in beef products, producing a 111 bp amplicon with 99.12% similarity to Canis lupus familiaris and no cross-amplification in other species. This result confirms that mitochondrial PCR markers are reliable for detecting dog meat adulteration in processed meat products for halal authentication (Kurniasih & Erwanto, 2023).

**Protein-Based Methods**

Proteins are essential macromolecules in food materials, composed of amino acids linked by peptide bonds. In living organisms, proteins function as structural and mechanical components that maintain cellular integrity and organismal posture, and they also serve regulatory, transport, and defensive roles in response to biological stimuli. Proteins are synthesized through a complex biosynthetic process that assembles amino acids into peptides, which subsequently fold into functional macromolecules, based on genetic information encoded within nucleic acid sequences. This unique expression process makes proteins valuable biomolecular markers for analytical purposes (Abd El-Hack et al., 2018).

One of the most widely used analytical techniques for protein quantification and detection is the enzyme-linked immunosorbent assay (ELISA). ELISA is an immunological method that measures specific protein antigens based on colorimetric changes arising from antigen–antibody interactions. Aprilia et al. (2022) compared ELISA and PCR for detecting adulteration of halal-labelled beef products

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in Indonesia. Their findings showed that two out of six beef samples contained porcine adulterants as detected by ELISA, whereas these were not detected using conventional PCR, highlighting ELISA's sensitivity to protein-based markers in certain matrices.

Another protein-based approach for halal authentication is the use of aptamers. Aptamers are highly specific oligonucleotides—typically RNA, ssDNA, or peptides—that can be produced in large quantities with high purity. They are non-immunogenic, non-toxic, and capable of binding to their molecular targets with high affinity and specificity due to their unique three-dimensional structures (Abd El-Hack et al., 2018). While functionally similar to antibodies, aptamers offer advantages such as higher thermal stability, lower production costs, and wide applicability (Song et al., 2012). Widada et al. (2021) developed an aptamer-based biosensor combined with a molecular beacon probe to detect porcine-derived gelatin through porcine DNA targets. Although the application of aptamers in halal authentication remains limited, their use is expanding in general food fraud detection.

Chromatographic techniques can also detect food adulteration, particularly by analyzing fatty acid profiles, protein patterns, or other biochemical markers. Chromatography operates on separation principles whereby compounds in a mixture pass through a stationary phase at different rates depending on their physicochemical properties (Abd El-Hack et al., 2018). The accuracy of protein and peptide detection can be significantly enhanced by coupling chromatographic separation with mass spectrometry (MS). MS measures the mass-to-charge (m/z) ratio of ionized molecules, and when combined with chromatography, it offers high sensitivity and specificity for detecting and quantifying non-halal components in food products (Windarsih et al., 2022).

Sarah et al. (2016) successfully identified porcine meat using LC-QTOF-MS by targeting heat-stable, porcine-specific muscle protein-derived peptides that remain detectable after thermal processing. Four peptides—FVIEIR, EVTEFAK, LVVITAGAR, and TVLGNFAAFVQK—were consistently detected in cooked pork under MRM mode. These peptides originate from porcine muscle proteins and act as species-specific biomarkers, as their amino acid sequences are unique to pigs and are not present in halal animal species such as cattle or poultry. Their thermal stability makes them particularly suitable for halal authentication of processed meat products, where intact proteins are often degraded.

Integrating peptide mass fingerprinting (PMF) with LC-MS/MS and chemometric analyses such as PCA and OPLS-DA has also proven effective for distinguishing porcine-specific peptide markers. Volatile protein-associated biomarkers have also driven interest in developing electronic-nose systems for halal authentication. An electronic nose is an analytical instrument designed to detect volatile compounds without prior separation. Its main components include a sampling system, an array of non-specific chemical sensors, a mass spectrometer (MS) or hybrid detector, and a data-acquisition unit (Dymerski et al., 2011). Sensor arrays or MS components generate measurable signals reflecting volatile profiles. Sarno et al. (2020) developed an Optimized Electronic Nose System (OENS) capable of detecting beef adulteration with pork with an accuracy of 98.10% in only 15 minutes per sample. Due to its speed, accuracy, and reagent-free operation, this method shows promise as a rapid screening tool in the food industry.

A more traditional proteomic approach for halal authentication is gel-based electrophoresis. Recent developments include two-dimensional (2D) electrophoresis, an advancement from one-dimensional (1D) methods. In 2D electrophoresis, proteins are separated based on both isoelectric point and molecular weight, while 1D methods rely solely on molecular weight separation. In halal authentication, electrophoresis allows comparison of protein profiles between authentic and adulterated samples, including those contaminated with non-halal materials. This method can also be coupled with mass spectrometry to identify specific protein biomarkers (Abd El-Hack et al., 2018). For instance, 1D electrophoresis has been shown to differentiate porcine gelatin capsules from bovine gelatin with up to 100% accuracy. While effective and relatively straightforward, these proteomic techniques are time-consuming and require skilled analysts due to complex data interpretation (Ng et al., 2022).

**Spectroscopy and Chemometric Methods**

Table 2 summarizes studies that integrate spectroscopy and chemometrics for halal authentication. Spectroscopic methods are rapid analytical techniques widely used in halal authentication because they can detect differences in the chemical composition of food materials

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without requiring complex preparation procedures. Spectroscopy can identify structural and chemical changes related to the presence of specific non-halal animal contaminants through interactions between electromagnetic radiation at certain frequencies or wavelengths and molecular components. Non-halal materials such as proteins, fatty acids, triglycerides, and lipids exhibit distinct molecular spectral profiles at specific wavelengths and wavenumbers. These differences arise from functional groups that absorb electromagnetic radiation, enabling the detection of non-halal components in food products (Rohman & Windarsih, 2020).

**Table 2.** Previous studies employing spectroscopy and chemometrics for halal authentication.

| Reference | Target | Spectroscopy Method | Chemometric Method | Result |
|---|---|---|---|---|
| Siddiqui et al. (2023) | Lard in meat products (chicken, lamb, beef) | Fourier Transform Infrared | Principal Component Analysis and Partial Least Squares. | With an $R^2$ value of 0.846 and an accuracy of 84.6%, the method is capable of detecting porcine fat adulteration at levels as low as 10% |
| Nurani et al. (2022) | Pork in Beef Meatballs | Fourier Transform Infrared Spectroscopy | Principal Component Analysis and Partial Least Squares. | The analysis resulted in an $R^2$ value of 0.99965 |
| Lestari et al. (2024) | Rat meat in sausage | Fourier Transform Infrared – Attenuated Total Reflectance | Partial Least Squares and Principal Component Regression | The analysis resulted in an $R^2$ value of 0,9648 |
| Dashti et al. (2024) | Pork in meat products | Fourier Transform Infrared – Diffuse Reflectance | Principal Component Analysis and Support Vector Machine | Accuracy reaches 100% |
| Akhtar et al. (2021) | Biomarkers in Chicken, Chevon, Cattle, and Donkey | Nuclear Magnetic Resonance | Orthogonal Partial Least Squares – Discriminant Analysis | Specific biomarkers associated with each meat type were successfully identified |
| Ghazali & Tukiran (2021) | Pork in Recycled Cooking Oil | Raman | Principal Component Analysis | Adulterated cooking oil can be differentiated; however, the percentage of adulteration cannot be determined. |

Interactions among target components can be detected by ultraviolet light (200 – 400 nm) and visible light (400 – 800 nm) using ultraviolet-visible (UV-Vis) spectrophotometry. When UV-Vis light is applied to a sample, molecules undergo excitation through electronic transitions. The analyzed molecules must contain chromophores to absorb UV-Vis radiation. UV-Vis spectrophotometry can be used for both qualitative and quantitative analysis to determine the presence or concentration of non-halal compounds in food products (Rohman & Windarsih, 2020).

Vibrational transitions in chemical bonds can serve as unique fingerprints of a sample. Spectroscopic techniques capable of measuring these vibrational transitions include Fourier-transform near-infrared (FT-NIR), mid-infrared (FT-MIR), Raman spectroscopy, and hyperspectral imaging (HSI) (Airin et al., 2025). Infrared spectroscopy is the most commonly used technique in food analysis.

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This method relies on the interaction between the sample and infrared electromagnetic radiation, which induces vibrational transitions in molecular bonds (Rohman, 2017). Measurements obtained from this technique allow analysis of various compounds that exhibit distinct fingerprint regions at wavenumbers of 1500–900 $cm^{-1}$, which are useful in differentiating non-halal constituents (Rohman & Windarsih, 2020).

Raman spectroscopy is based on inelastic scattering that produces shifts in energy frequency. During the Raman process, molecules become excited when exposed to photons, resulting in wavelength shifts when returning to different energy states (Craig et al., 2013). Raman spectroscopy is a promising technique for halal authentication because it provides molecular fingerprints and compound profiles through Raman imaging (Rohman & Windarsih, 2020). Another advanced spectroscopic technique widely used in food analysis is nuclear magnetic resonance (NMR) spectroscopy, which analyzes interactions between molecules and radiofrequency waves. These interactions alter the spin orientation of atomic nuclei, generating fingerprint spectra that can be used to detect non-halal components (Rohman & Windarsih, 2020).

Spectroscopic measurements generate large datasets, requiring multivariate data analysis for proper processing. This mathematical and statistical evaluation is conducted through chemometrics, which extracts meaningful and interpretable information from extensive datasets. In halal authentication, chemometrics aims to classify products as halal or non-halal, predict potential non-halal components in tested samples, and support experimental planning and design. The most commonly used chemometric techniques for exploratory data analysis (EDA) in halal authentication are principal component analysis (PCA) and hierarchical cluster analysis (HCA). These techniques are used to identify similarities, detect hidden patterns among samples, and determine potential data groupings (Airin et al., 2025).

**Nanotechnology and Smart Sensors**

Advances in analytical technology in the food sector have encouraged the development of new approaches based on nanotechnology and smart sensors to improve the effectiveness of halal authentication, particularly in meat-based products that are highly susceptible to contamination by non-halal materials. This approach utilizes the unique properties of nanoscale materials, which include high surface area, excellent conductivity, and the ability to interact specifically with target biomolecules such as DNA, proteins, or metabolites from specific animal species (Cheubong et al., 2021; He & Yang, 2018; Qin et al., 2019).

In the context of halal authentication, nanotechnology enables rapid and highly sensitive detection of non-halal components. One example is the use of gold nanoparticles (AuNPs) in DNA colorimetric detection systems (He & Yang, 2018) and magnetic nanoparticles (MNPs) for DNA purification in multiplex PCR methods (Qin et al., 2019). Both techniques leverage the unique attributes of nanoscale materials—such as high surface area and magnetic or optical responsiveness—to enhance the sensitivity and selectivity of biomolecular detection. MNPs facilitate efficient DNA purification through magnetic forces without the need for toxic solvents, while AuNPs enable colorimetric detection based on visible color changes due to nanoparticle aggregation. These approaches apply nanosystem-based molecular recognition principles to strengthen halal authentication and non-halal detection in meat-based food products.

Additionally, the development of smart sensor–based biosensors has emerged as a major trend in modern halal detection systems. These sensors operate by recognizing specific biomarkers, such as volatile fatty acids or particular proteins, that differ between halal and non-halal meat. Smart sensors are capable of producing real-time results and can be integrated into digital supply chain systems to support product traceability (Cheubong et al., 2021; Muflihah et al., 2025). The application of smart sensor concepts has been demonstrated by Cheubong et al. (2021) through the use of a Fluorescent Molecularly Imprinted Polymer Nanogel (F-MIP-NG) sensor and by Muflihah et al. (2025), who implemented an electrochemical biosensor based on the CRISPR/Cas12 system with a biorecognition and signal transduction mechanism. Both studies developed sensor systems aimed at detecting specific molecular markers associated with pork contamination, namely porcine serum albumin (PCA) in Cheubong et al. (2021) and porcine DNA fragments in Muflihah et al. (2025).

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From a technological standpoint, both approaches utilize nanoscale materials to enhance detection performance. MIP nanogels provide selective binding sites with high sensitivity, whereas CRISPR/Cas12-based electrochemical sensors offer superior specificity and rapid response due to their highly precise DNA recognition mechanism. These techniques serve as modern alternatives to conventional methods such as PCR, as they do not require complex laboratory equipment and are capable of delivering results in a shorter time. Within the context of halal authentication, both methods share the same objective: ensuring the authenticity and purity of food products by enabling early detection of non-halal components such as pork. With their rapid and accurate performance, these biosensor systems hold strong potential for implementation as screening tools in the halal food industry, both during production and in post-production monitoring, thereby strengthening the scientific and efficient foundation of the Halal Assurance System (SJPH).

**Challenges and Prospects of Halal Authentication Methods and Their Implications for the Halal Assurance System (SJPH)**

The implementation of halal authentication methods faces several challenges, largely due to the complexity of food matrices that undergo various processing steps such as heating, fermentation, and extraction. These processes can hinder the detection of DNA, proteins, or chemical profiles, reducing the analytical reliability of certain techniques. Differences in sensitivity among methods, limited access to advanced laboratory facilities, high analytical costs, and the absence of harmonized international standards also pose obstacles to ensuring consistent verification outcomes across institutions. Furthermore, the incompleteness of biomarker databases often impedes optimal identification of non-halal components in locally produced food products.

Despite these limitations, the prospects for advancing halal authentication technologies are highly promising. Innovations in molecular and nanotechnology-based approaches—such as CRISPR-based sensors, gold nanoparticles, and electrochemical biosensors—enable faster, more sensitive, and portable detection of non-halal materials. Improvements in chemical analysis, spectroscopy, and AI-assisted data interpretation further enhance the accuracy of identifying contaminants within complex food matrices. The integration of multi-method platforms combining DNA, protein, and chemical profiling significantly strengthens the reliability of halal verification, making these approaches suitable for modern, highly processed food products that cannot be authenticated using a single analytical method.

The development of advanced halal authentication technologies has direct implications for strengthening Indonesia's Halal Product Assurance System (SJPH). Science-based verification methods improve the transparency of halal certification, accelerate auditing and monitoring processes, and reduce opportunities for cross-contamination throughout the supply chain. The adoption of rapid testing tools and smart sensor systems also supports the implementation of digital halal traceability, ensuring product integrity from raw material selection to distribution. Consequently, advancements in halal authentication not only reinforce the credibility of SJPH but also enhance consumer confidence and increase the competitiveness of the national halal industry.

## CONCLUSION

Halal authentication in meat-based food products is critically important, as meat ingredients are highly susceptible to adulteration, species substitution, and cross-contamination during processing, distribution, and storage. Processed meat products often undergo heating, seasoning, extraction, or emulsification, which eliminates the possibility of visual identification. Therefore, scientific approaches—such as DNA analysis, species-specific protein detection, and chemical profiling—serve as essential tools to verify the authenticity of animal species and detect the presence of non-halal components within complex food matrices. Despite ongoing challenges, including DNA and protein degradation due to thermal processing and limited laboratory capacity, technological advancements such as biosensors, CRISPR-based detection, and multimodal analytical methods have significantly improved the sensitivity and reliability of halal verification in meat products. Overall, the implementation of halal authentication methods in processed meat products plays a crucial role in strengthening the Halal Assurance System (SJPH). With more rigorous scientific oversight, the meat

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processing industry can uphold product integrity, enhance consumer trust, and improve the competitiveness of halal products in both national and global markets.

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