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Research Paper

Risk-Oriented Perspectives on Halal Compliance in Plant-Based Food Ingredients: Origin Variability and Production System Control

Kasinee Katelakha*
The Halal Science Center, Chulalongkorn University, Thailand

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Abstract

Plant-based food systems are frequently perceived as inherently permissible due to their non-animal origin. However, the increasing use of multi-origin additives, fermentation-derived ingredients, recombinant enzymes, and complex processing technologies introduces new challenges for Halal compliance. This review provides a risk-oriented assessment of Halal considerations in plant-based food ingredients, focusing on origin variability, production pathways, and manufacturing system integrity. Particular attention is given to emulsifiers, hydrocolloids, fermentation-derived flavor enhancers, recombinant proteins, blood-related components, and processing aids, all of which may involve animal-derived inputs, fermentation substrates, or genetically engineered systems. Beyond ingredient-level evaluation, the review highlights the importance of cross-contamination control, segregation practices, and traceability across shared production facilities. A structured Halal Critical Control Point (HCCP) framework is proposed to operationalize compliance assessment across raw material sourcing, fermentation media, enzyme production, solvent usage, and manufacturing systems. As plant-based innovation advances through biotechnology and precision fermentation, a system-based and science-driven Halal governance approach is essential to ensure compliance, consumer trust, and regulatory coherence.

Keywords: *Plant-Based, Food Systems, Halal Compliance, Origin Variability, Fermentation-Derived Ingredients, Recombinant Enzymes, Critical Control Points, Cross-Contamination*

INTRODUCTION

Plant-based foods are gaining increasing interest in both food development, which involves food technology and innovation, and consumer preference. Plant-based meat is expected to reach approximately USD 34 billion by 2027 (Trivedi, 2026). The rapid growth of plant-based foods is driven by increasing consumer preference for plant-centric diets, along with factors ranging from concerns about animal welfare and environmental sustainability to ethical considerations and health issues. Here, plant-based foods are foods made from plant ingredients designed and intended to mimic animal-based foods (Nolden & Forde, 2023). Therefore, plant-based food products commonly include alternatives to meat, cheese, milk, and eggs, formulated from plant-derived ingredients. These products typically utilize plant-derived proteins, lipids, carbohydrates, and functional ingredients to replicate the nutritional, structural, and sensory properties of animal-based foods.

However, there are several limitations associated with the use of plant-based proteins as alternatives to animal proteins, not only in terms of food development but also regarding their effects on the human gastrointestinal tract (Kaur et al., 2022) as well as Halal compliance concerns.

Despite rapid innovation in plant-based food systems, Halal compliance challenges related to ingredient origin variability and complex production pathways remain insufficiently structured. The growing use of multi-origin additives, fermentation-derived materials, recombinant enzymes, and processing aids calls for a systematic, risk-oriented evaluation beyond formulation analysis.

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However, current literature lacks a systematic ingredient-level and system-level Halal assessment of plant-based food systems, particularly in relation to source verification, processing pathways, and cross-contamination risks. Therefore, this review assesses Halal compliance considerations in plant-based food ingredients, focusing on origin variability, production system control, and manufacturing integrity. A structured Halal Critical Control Point (HCCP) framework is proposed to operationalize compliance across raw material sourcing, fermentation, enzyme production, solvent use, and cross-contamination management. This review aims to support science-based, system-level approaches to Halal governance in emerging plant-based food technologies.

LITERATURE REVIEW

With respect to ingredients, since animal-based foods are typically rich in protein, plant-derived protein sources are widely used as alternatives. It has been reported that the protein content of plant-based sources, that is, cereals (6%–15%), legumes (20%–38%), pseudocereals (11%–23%), nuts (18%–38%) and seeds (9%–30%) is comparatively higher than milk (3%–5%), whereas approximately similar to meat (23%) (Thakur et al., 2023).

From a product development perspective, plant-based protein alternatives generally exhibit lower diversity and content of essential and non-essential amino acids, as well as differences in protein quality, odor, and texture compared to animal-derived proteins. To overcome these limitations, protein complementation strategies, such as blending cereal- and legume-based proteins, are commonly employed to improve amino acid balance (Guidi et al., 2022; Jareonsin et al., 2024; Liu et al., 2020). In addition, processing technologies including extrusion, fermentation, and enzymatic modification have been shown to enhance digestibility, functional properties, and textural characteristics of plant-based proteins. Sensory challenges related to undesirable odors and flavors can be mitigated through fermentation and flavor-masking strategies, while the incorporation of functional ingredients such as hydrocolloids and plant-based lipids further improves texture and mouthfeel.

Bibliometric analyses indicate a scarcity of studies on Halal food ingredients and additives, suggesting that ingredient-related Halal concerns, including those associated with plant-based foods, remain insufficiently explored (Nazaruddin et al., 2023). This gap is particularly important, as plant-based foods are often perceived by consumers as inherently Halal due to their plant-derived origin (Al-Teinaz, 2020; Riaz & Chaudry, 2018). However, to mimic the sensory and functional properties of animal-based products, plant-based foods typically require the incorporation of various food additives (Arinzechukwu et al., 2025; Kyriakopoulou et al., 2021; McClements & Grossmann, 2021). The use of these additives raises concerns, as their sources and processing methods must be carefully verified. Although food additives are considered safe within established regulatory limits, Halal compliance requires additional consideration. In the context of Halal, both the origin and processing methods of food additives are critical, as additives may be derived from animal, plant, microbial, genetically modified, mineral, or chemically synthesized sources (Al-Mazeedi et al., 2013; Al-Teinaz, 2020; Ermis, 2017; Saeed, 2023).

RESEARCH METHODS

This study was conducted as a structured narrative review adopting a semi-systematic approach. To enhance transparency and reproducibility, selected elements of the PRISMA were adapted (Figure 1). Scientific databases including Scopus, PubMed, ScienceDirect (Elsevier), and Google Scholar were systematically searched for articles published between 2010 and 2026. The search terms included combinations of the following keywords: “plant-based food,” “plant-based protein,” Halal compliance,” and “Halal food additives,” The Google Scholar was used as a supplementary search tool to identify additional relevant studies through citation tracking and to

capture recently published literature not indexed in the primary databases. The search results were screened for relevance, and duplicate records were removed to ensure consistency across sources. In addition, only peer-reviewed journal articles published in English were included. Conference papers, non-scientific reports, and articles lacking relevance were excluded. Titles and abstracts were screened for relevance, followed by full-text evaluation. In addition to the literature search, practical insights from industrial and laboratory experience in plant-based product development were incorporated to contextualize scientific findings; however, conclusions were primarily based on peer-reviewed evidence.

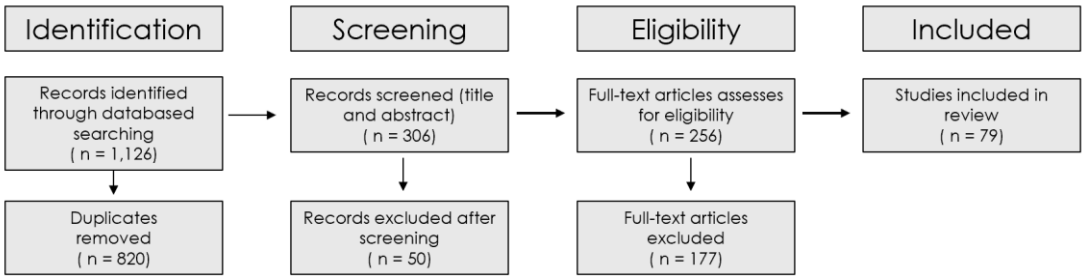


Figure 1. PRISMA flow diagram for this review

FINDINGS AND DISCUSSION

Food additive in the plant-based product

Food additives play a fundamental technological role in plant-based food systems, where they are used to stabilize emulsions, enhance texture, improve flavor, and replicate the structural properties of animal-derived products. The increasing complexity of plant-based formulations has led to the incorporation of diverse additives, including emulsifiers, hydrocolloids, enzymes, colorants, and flavor enhancers.

Although many of these additives are plant- or microbially derived, their Halal status cannot be determined solely by apparent botanical origin. Several additives exhibit origin variability, with potential derivation from plant, animal, microbial, recombinant, or synthetic production pathways. In addition, fermentation substrates, carrier materials, and processing conditions may further influence compliance status.

From a Halal governance perspective, the primary challenge is not the use of additives per se, but the *opacity of origin and production pathways* for ingredients that can be plant-, animal-, microbial-, mineral-, or synthetically derived. Because risk is driven by origin variability and process inputs (e.g., fermentation media, carriers, solvents, and shared facilities), a risk-oriented mapping is required. Table 1 summarizes representative high-relevance additives used in plant-based foods according to origin variability, production pathway, dominant Halal compliance concern, and indicative risk level. Among the additive categories, blood-derived and heme-related ingredients represent a distinct high-severity case due to their origin-based prohibition in Halal jurisprudence.

Blood-Derived and Heme Proteins: Safety and Halal Compliance Considerations

The extraction of compounds from animal blood poses a high risk of pathogen contamination in food products. Although blood-derived products are recognized as potential functional ingredients and can be incorporated into edible foods, their safety and regulatory considerations remain critical (Bahru, 2021; Ofori & Hsieh, 2012). This category represents a high-severity risk

because permissibility is constrained by origin (blood), regardless of downstream purification, and because it intersects with both safety and biotechnology-based workarounds. In modern food technology, hemoglobin and myoglobin have been investigated as carriers for iron fortification in food supplements, specialized diets, and bioactive food development due to their high heme-iron content (Jarzębski et al., 2023). Hemoglobin derived from animal blood, in particular, has attracted attention as a highly bioavailable iron source. Beyond nutritional applications, myoglobin, a heme protein naturally present in vertebrate muscle, plays a significant role in flavor and color development. The incorporation of myoglobin into plant-based formulations has been shown to increase the formation of aldehydes while reducing hydrocarbons, resulting in a volatile profile more similar to that of conventional meat (Devaere et al., 2022). However, from a Halal compliance perspective, compounds derived from blood are considered non-permissible, regardless of their level of purification, as their origin itself is prohibited. To address technological needs while avoiding animal-derived sources, plant-based expression systems have been explored. For example, myoglobin has been successfully expressed in the leaves of *Nicotiana benthamiana* (Carlsson et al., 2020) demonstrating potential for plant-based food and related industries. Nevertheless, in the context of Halal compliance, the genetic engineering process, the origin of the inserted gene, and the overall production system must also be carefully evaluated.

Halal Compliance Challenges in Plant-Based Food Ingredients

Beyond explicitly prohibited materials such as blood-derived ingredients, a broader compliance challenge arises from origin variability across commonly used additives.

Source Verification

Source verification represents a fundamental requirement in ensuring Halal compliance in plant-based food ingredients. Although plant-based products are generally perceived as inherently permissible, the Halal status of an ingredient depends not only on its apparent botanical origin but also on the source of its raw materials, food additives, processing aids, carrier substances (Jarzębski et al., 2023), and intermediate compounds. In many cases, food additives and functional ingredients may be derived from multiple origins, including plant, animal, microbial, or synthetic sources, each of which requires careful evaluation.

For example, emulsifiers such as mono- and diglycerides (INS 471) may originate from either vegetable oils or animal fats (Additives et al., 2017; Kara & Bor, 2019). Although microalgal fermentation has been explored as a potential alternative source of INS 471, current evidence indicates that this approach remains at the research stage, and microalgae-derived INS 471 is not yet widely available for industrial application (Ferreira et al., 2021). For many modern ingredients, however, source' is determined not only by raw material origin but also by how the ingredient is produced, particularly for fermentation-based manufacturing.

Fermentation Substrates and Culture Media

Similar considerations apply to fermentation-derived ingredients, whose Halal status depends largely on the composition of the substrate and culture media used during production (Ermis, 2017; Harunaningtyas & Rohana, 2025; Karahalil, 2020). Xanthan gum, a high-molecular-weight exopolysaccharide synthesized via aerobic fermentation by *Xanthomonas* species, is typically produced using carbohydrate substrates such as glucose, sucrose, or corn syrup as carbon sources (Khosravi et al., 2026; Miranda et al., 2020). These substrates are generally plant-derived and therefore considered acceptable from a Halal perspective. However, nitrogen sources used in the fermentation medium, including peptone and yeast extract, require careful evaluation. Peptone is a protein hydrolysate that may be derived from animal sources (e.g., whey, casein, or meat) or

plant proteins (e.g., soy or wheat) (Miranda et al., 2020). In particular, porcine-derived peptone is commercially available and would not be permissible to produce Halal-certified xanthan gum. Therefore, traceability and verification of nitrogen sources and other fermentation media components are essential to ensure Halal compliance. Even when the ingredient is fermentation-derived, Halal assurance can still be compromised by manufacturing inputs that are not label-declared, including enzymes and processing aids.

Processing Aids and Manufacturing Inputs

Processing aids represent a critical yet frequently overlooked aspect of Halal compliance in plant-based food production. Unlike food additives, which are typically declared on product labels, processing aids are substances used during manufacturing to facilitate processing but are not intended to remain in the final product at functional levels. Despite their limited presence in the finished food, the origin and composition of processing aids must be evaluated, as their use may affect the Halal status of the product (Awulachew, 2021; Nath et al., 2025).

In plant-based food, processing aids may include enzymes, anti-foaming agents, filtration agents, extraction solvents, and purification chemicals (Aminlari, 2022; Fu et al., 2023; Short et al., 2021; Tangyu et al., 2019). Enzymes such as proteases, lipases, and transglutaminase are commonly employed to modify protein structure, enhance texture, or improve functional performance in meat analogues and dairy alternatives (Arief & Manab, 2024; Sun et al., 2025; Wen et al., 2022; Yu et al., 2025). These enzymes may be derived from microbial fermentation, plant sources, animal tissues, or recombinant expression systems, and therefore require careful source verification. In particular, enzymes extracted from porcine or non-Halal slaughtered animal tissues would not be permissible.

In modern food biotechnology, many industrial enzymes are produced through recombinant expression systems, whereby genes encoding specific enzymes are inserted into microbial hosts such as *Escherichia coli* or *Aspergillus* species. While these enzymes are not directly animal-derived, their Halal status requires evaluation of gene origin, host organism, fermentation media, and downstream purification processes (Ladole et al., 2026; Mohite et al., 2026; Srivastava, 2019; Yao et al., 2026). Recombinant production therefore introduces an additional layer of traceability requirements within Halal compliance assessment. Therefore, Halal evaluation of plant-based foods must integrate ingredient origin with production inputs (fermentation media, recombinant hosts/genes, solvents, and processing aids) and facility-level controls, as summarized in Figure 2.

Table 1. Origin variability, production pathways, and Halal compliance control points of food additives used in plant-based foods

Food additive	INS	Technological function	Typical application in plant-based foods	Origin variability and production pathway	Key Halal compliance concern	Risk level*	References
Colorants							
Carmine (cochineal)	120	Colorant (red pigment)	Plant-based meat analogues, sausages, beverages, confectionery (to mimic red meat color)	Animal-derived (extracted from Dactylopius coccus insects)	Animal origin (insect-derived); majority scholarly opinion considers non-permissible;	High	(Juhrich et al., 2025)

					source verification required		
Iron oxides	172	Colorant (red, yellow, black pigments)	Meat analogues (color adjustment), supplements	Mineral or synthetic	Generally permissible; verification of purity and processing aids required	Low	(Divya et al., 2025; Wu et al., 2024)
Leghemoglobin (heme analog)	–	Flavor and color enhancer (heme functionality)	Plant-based burgers (meat-like flavor and browning)	Recombinant fermentation (gene encoding soy leghemoglobin expressed in microbial host, e.g., yeast)	Gene origin, host organism, fermentation substrate, downstream processing; recombinant pathway requires full traceability	Moderate-high	(Meng et al., 2025; Rana et al., 2026; Yao et al., 2025)
Gelling Agents / Structuring Agents							
Lecithin	322	Emulsifier	Plant-based dairy alternatives, chocolate analogues, spreads	Multi-origin (soy, sunflower, egg-derived)	Animal origin (egg); cross-contact; source verification required	Moderate-high	(Patel et al., 2026; Son et al., 2025; Tay et al., 2025)
Mono-di-glyceride	471	Emulsifier	Meat analogues, bakery products, dairy alternatives	Multi-origin (vegetable oils, animal fats, synthetic; emerging microalgal research)	Animal fat origin must be verified; potential porcine-derived fat	Moderate-high	(Ferreira et al., 2021; Kara & Bor, 2019)
Carrageenan	407	Thickening / gelling agent	Plant-based milk, yogurt alternatives, processed meat analogues	Seaweed-derived (red algae); extraction process dependent	Solvent use; processing aids; purification verification	Low	(Dimakopoulou-Papazoglou et al., 2025; Mata et al., 2025; Zhang et al., 2025)
Xanthan gum	415	Thickening agent	Meat analogue binder, dairy alternative stabilizer	Microbial fermentation (Xanthomonas spp.); substrate and nitrogen source dependent	Fermentation substrate; nitrogen source (e.g., peptone origin); media verification required	Low	(Khosravi et al., 2026; Miranda et al., 2020)
Methyl cellulose and its derivatives	461	Texturizer, thermal gel-forming agent	Meat analogues (thermal gel structure), plant-based	Chemically modified cellulose (plant-derived cellulose subjected to etherification	Verification of chemical reagents used during modification	Low	(Dahal et al., 2025; Han et al., 2025; Peñaranda et al., 2025; Siri

		burgers, nuggets, and structured protein systems	reactions)	(e.g., methylating agents, solvents); processing aid assessment		et al., 2026)
Enzymes						
Transglutaminase	_	Protein cross-linking enzyme	Texture improvement in meat analogues; protein structuring; binding agent	Microbial fermentation / Animal tissue extraction / Recombinant production	Animal-derived enzyme source; gene origin (recombinant forms); fermentation substrate and media verification	Moderate–high	(Wen et al., 2022; Yu et al., 2025)
Lipase	_	Lipid hydrolysis; flavor development	Flavor enhancement in plant-based cheese alternatives; fat modification in meat analogues	Microbial fermentation / Plant-derived / Animal-derived (pancreatic)	Porcine-derived pancreatic lipase; fermentation substrate; recombinant gene origin	Moderate–high	(Kara & Bor, 2019)
Protease	_	Protein hydrolysis; texture modification	Protein modification in meat analogues; digestibility improvement; texture control	Microbial fermentation / Plant-derived / Animal-derived	Animal tissue origin; fermentation media components; recombinant production pathway	Moderate	(Sakai et al., 2025)
Flavorings						
Monosodium glutamate	621	Flavor enhancer		Microbial fermentation	Fermentation/ substrate source	Moderate-high	(Sakai et al., 2025)
Yeast extract	_	Flavor enhancer (umami source)	Meat analogue flavor base; savory formulations; seasoning blends	Fermentation-derived (Saccharomyces spp.); substrate-dependent	Fermentation substrate source; autolysis processing; possible alcohol use during fermentation	Moderate	(Li, 2024; Pisco, 2024; Shen, 2024; Vasisht et al., 2025)
Myoglobin	_	Flavor and color contributor (heme functionality)	Experimental meat analogues; iron fortification;	Animal blood-derived / Recombinant expression systems	Blood-derived material (non-permissible); recombinant gene origin;	High	(Carlsson et al., 2020; Meng et al., 2025; Qian et al., 2025)

			flavor simulation		host organism and media verification		
Sweeteners (for dairy alternatives)							
Glycerol	422	Humectant, sweetener, solvent	Plant-based dairy alternatives, protein beverages, desserts, confectionery	Multi-origin (vegetable oils via transesterification, animal fats, synthetic, or biodiesel by-product purification)	Animal fat origin (possible porcine-derived glycerol); processing pathway verification; residual impurities	Moderate–high	(Aung & Nam, 2024; Rudge et al., 2025)
Sorbitol	420	Sweetener, humectant	Dairy alternatives, reduced-sugar beverages, protein bars	Hydrogenation of glucose (plant-derived starch source); synthetic production	Generally low risk; verification of glucose source and processing aids recommended	Low	(Antunes et al., 2025; Dragomir et al., 2025)
Steviol glycosides	960	High-intensity natural sweetener	Plant-based milk, yogurt alternatives, beverages	Plant extraction (Stevia rebaudiana); purification and crystallization processes	Solvent extraction (e.g., ethanol origin and residual level); purification processing verification	Low–moderate	(Mekdade et al., 2025; O'Sullivan et al., 2025)
Preservative							
Sodium benzoate	211	Preservative		Synthetic	Generally low risk	Low	(Calvo, 2025; Khalifa et al., 2025)
Iron fortification							
Hemoglobin	–	Iron fortification; heme-iron source	Experimental iron-fortified meat analogues; dietary supplements	Animal blood-derived; heme extraction and purification	Blood-derived ingredient (non-permissible in Halal); safety and pathogen risks; origin itself not permissible regardless of purification	High	(Meng et al., 2025; Yao et al., 2025)

*Risk level is qualitative and based on variability of source origin, fermentation inputs, processing conditions, and cross-contact potential.

Solvents used in extraction or purification processes, such as ethanol, may present further compliance considerations depending on their origin and residual levels (Alzeer & Abou Hadeed, 2016; Najiha et al., 2010; Pauzi et al., 2019). Although processing aids are often removed or reduced to negligible quantities in the final product, Halal evaluation focuses not only on residual presence but also on the permissibility of the substances used throughout the manufacturing process.

Regulatory frameworks typically distinguish processing aids from food additives based on their technological function and residual presence in the final product. However, Halal certification frameworks may evaluate both categories under broader principles of permissibility and production integrity. Furthermore, shared production facilities and potential cross-contact with non-Halal materials represent additional compliance risks, particularly in multi-product manufacturing environments where enzymes or solvents may be handled concurrently.

Compliance assessment in plant-based food ingredients therefore requires a multidimensional evaluation that extends beyond primary ingredient classification. In addition to evaluating the apparent origin of raw materials, certification bodies must consider fermentation inputs, processing aids, solvent use, genetic modification, and manufacturing integrity. To systematize these considerations, a structured framework for Halal evaluation of ingredient sources in plant-based foods is proposed (Figure 1).

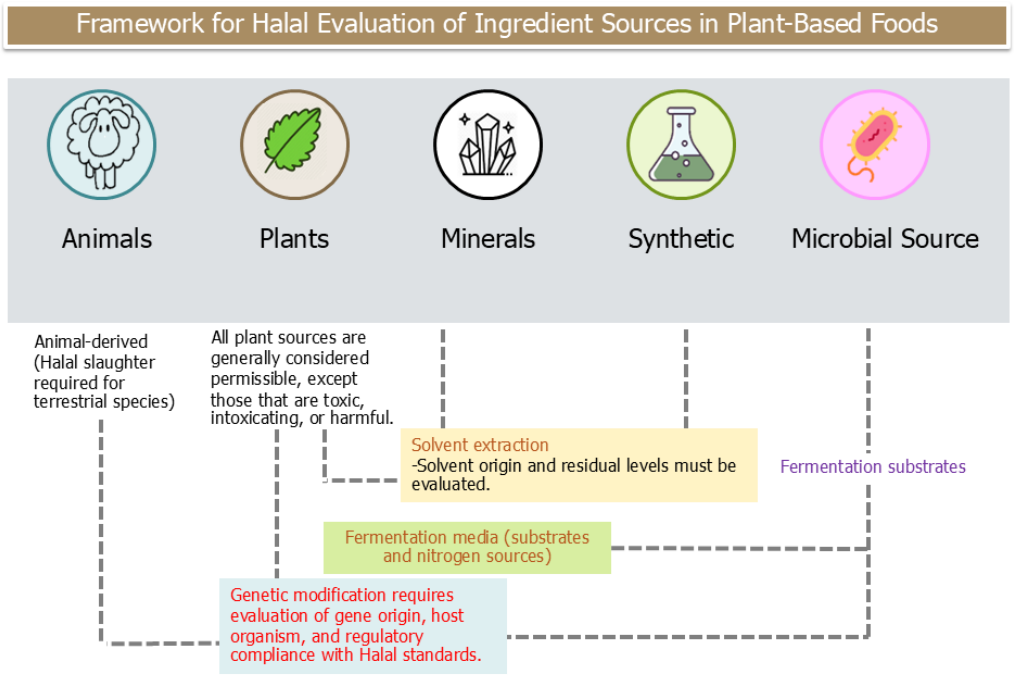


Figure 2. Framework for Halal Evaluation of Ingredient Sources in Plant-Based Foods.

This framework illustrates the classification of ingredient sources and the principal compliance control points—including fermentation substrates, fermentation media composition, solvent use, processing aids, and genetic modification—that must be evaluated to determine the Halal status of plant-based food ingredients. The model emphasizes that Halal assessment extends beyond primary ingredient origin and requires verification across the production chain.

Cross-Contamination and Manufacturing Systems

Beyond ingredient origin and processing inputs, cross-contamination represents a critical consideration in Halal compliance for plant-based foods. Many production facilities manufacture

both conventional meat products and plant-based analogues using shared equipment and processing lines. Without appropriate segregation or validated cleaning procedures, residual non-permissible materials may compromise the Halal integrity of otherwise compliant formulations.

In addition to equipment sharing, risks may arise from common storage, transportation, and handling systems, particularly when raw materials or finished products are processed within integrated supply chains. Therefore, Halal certification requires not only verification of ingredient origin but also assurance of manufacturing integrity through documented cleaning validation, segregation protocols, and traceability across the production chain (Kurniawan et al., 2026; Lau et al., 2016; Supian, 2018).

While ingredient-level evaluation remains central to Halal compliance, a production-system perspective is equally necessary. Compliance cannot be assured solely through formulation analysis; rather, a structured identification of Halal Critical Control Points (HCCPs) is required to operationalize verification throughout the production lifecycle.

In plant-based foods, compliance risk does not arise from a single source but from multiple interacting pathways, including raw material variability, fermentation inputs, enzyme production methods, solvent usage, and shared manufacturing environments. To systematize these considerations, Table 2 presents a structured framework of Halal Critical Control Points in plant-based food production systems, identifying key control focus areas, associated risk sources, affected ingredient categories, and required verification actions.

Table 2. Halal Critical Control Points (HCCP) in Plant-Based Food Production Systems

HCCP	Control Focus	Key Risk Source	Examples of affected Ingredient Categories	Required Verification Action
HCCP 1	Raw Material Origin Verification • Ingredients • Food additives • Processing aids	Multi-origin sources	Glycerol can be derived from either plant oil (organic glycerol) or animal-based fat.	Supplier halal certification and/or laboratory testing
HCCP 2	Fermentation Media Assessment • tryptone	Nitrogen source variability	Xanthan gum, MSG, Yeast extract	Media documentation review, Supplier halal certification
HCCP 3	Enzyme Production Pathway	Animal tissue or recombinant gene origin	Lipase, Transglutaminase	Gene origin and host verification
HCCP 4	Solvent & Processing Aid Control	Ethanol and chemical reagents	Steviol glycosides, carrageenan	Solvent type and origin and residual analysis

HCCP	Control Focus	Key Risk Source	Examples of affected Ingredient Categories	Required Verification Action
HCCP 5	Manufacturing Integrity	Cross-contact risk, All categories	All categories	Cleaning validation and segregation

CONCLUSIONS

The rapid expansion of plant-based foods has introduced new technological pathways that challenge conventional assumptions regarding Halal compliance. Although plant-based products are often perceived as inherently permissible, this review demonstrates that Halal integrity cannot be determined solely by botanical origin. Instead, compliance depends on a multidimensional assessment encompassing ingredient origin variability, fermentation substrates and media composition, recombinant enzyme production, solvent usage, processing aids, and manufacturing system integrity.

The analysis highlights that risk in plant-based foods frequently arises from multi-origin ingredients, fermentation-derived materials, recombinant biotechnology applications, and shared production environments. In particular, emulsifiers, glycerol, mono- and diglycerides, enzymes, heme analogs, and fermentation-derived flavor enhancers require systematic source verification. Furthermore, cross-contamination risks within integrated manufacturing facilities necessitate production-level controls beyond formulation assessment.

To address these complexities, this study proposes a structured Halal Critical Control Point (HCCP) framework tailored to plant-based foods. By integrating raw material verification, fermentation media assessment, enzyme production pathway evaluation, solvent and processing aid control, and manufacturing segregation practices, the framework provides a practical mechanism for operationalizing Halal compliance across the production chain.

Future research should focus on standardizing risk classification criteria for emerging biotechnological ingredients, developing traceability tools for recombinant and fermentation-derived materials, and harmonizing Halal regulatory approaches across jurisdictions. As plant-based food innovation continues to evolve, a system-based, science-driven approach to Halal governance will be essential to ensure consumer trust, regulatory coherence, and sustainable market growth.

LIMITATION & FURTHER RESEARCH

Despite providing a structured framework for Halal evaluation of plant-based food ingredients, several limitations should be acknowledged. First, the proposed Halal Critical Control Point (HCCP) framework is conceptually derived from existing literature and regulatory principles rather than empirical validation within industrial settings. Future research should assess its practical applicability through case studies, certification audits, and industry-based implementation analyses.

Second, the classification of risk levels in this review is based on documented origin variability and known compliance challenges; however, quantitative risk assessment models specific to Halal compliance in plant-based systems remain underdeveloped. Future work may integrate probabilistic risk modeling, traceability metrics, and supply-chain data analytics to enhance objectivity in risk categorization.

Finally, emerging technologies—including precision fermentation, synthetic biology, and genetically engineered heme analogs—introduce novel compliance questions concerning gene origin, host systems, and production substrates. Continued interdisciplinary collaboration between food scientists, regulatory authorities, and Shariah scholars will be essential to develop science-based and globally coherent governance frameworks.

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