UDC 65.012
DOI: 10.15587/1729-4061.2025.316197

ENHANCING THE HALAL POTATO CHIPS SUPPLY CHAIN: INNOVATIVE RISK MITIGATION STRATEGIES FOR SUSTAINABLE GROWTH

Siti Asmaul Mustaniroh
Corresponding author
Associate Professor*
E-mail: asmaul_m@ub.ac.id
Sucipto Sucipto
Professor*
Yuyun Pujiastuti
Postgraduate Alumnae*
Nadya Prabaningtias
Postgraduate Alumnae*
Rita Saputri
Undergraduate Student*
Maharani Pertiwi Koentjoro
Assistant Professor
Laboratory of Integrated Science and Technology**
Rizka Aulia Rahma
Postgraduate Alumnae
Department of Food Technology and Biotechnology**
*Department of Agroindustrial Technology**
**Universitas Brawijaya
Veteran str., 10-11, Malang, Indonesia, 65145

Consumer trust is an important asset in the distribution of the halal supply chain. The object of this research is the halal supply chain for micro-scale potato chip enterprises, involving suppliers, producers, and retailers. The final product's halal status may be at risk caused by factors like sourcing raw materials, production processes, storage, distribution, and halal management at various supply chain phases. The problem to be solved is to develop a comprehensive institutional model of the potato chip supply chain, identify and assess these halal-related risks, map risk agents based on risk events, and develop alternative mitigation strategies to minimize potential threats. To accomplish this, an integrated methodology, including the House of Risk (HoR) and Interpretive Structural Modelling (ISM) methodologies, is implemented. The findings reveal the identification of 69 risk events and 70 risk agents, all associated with planning, purchasing, production, and distribution. Thirty priority risk agents requiring immediate attention were determined using the Pareto Diagram and ISM. Based on the ISM analysis, risk agents were categorized into independent and dependent variables within the potato chip business cluster.

The integration of HoR and ISM effectively prioritizes risk agents and uncovers their interrelationships, enabling robust mitigation strategies. The approved approach provides a comprehensive risk assessment framework, allowing producers to control the main risk factors affecting halal product integrity, and enhance consumer trust. These findings are particularly valuable for micro-scale potato chip enterprises to strengthen their halal supply chain integrity, improve risk management practices, and increase competitiveness in halal markets

Keywords: halal, supply chain, micro-scale enterprises, risk mitigation, institutional supply chain, HoR, ISM

Received 27.11.2024
Received in revised form 21.01.2025
Accepted 05.02.2025
Published 28.02.2025

How to Cite: *Mustaniroh, S. A., Sucipto, S., Pujiastuti, Y., Prabaningtias, N., Saputri, R., Koentjoro, M. P., Rahma, R. A. (2025). Enhancing the halal potato chips supply chain: innovative risk mitigation strategies for sustainable growth. Eastern-European Journal of Enterprise Technologies, 1 (13 (133)), 17–26. https://doi.org/10.15587/1729-4061.2025.316197*

1. Introduction

The significance of Micro, Small, and Medium Enterprises (MSMEs) in national economic development, particularly in employment generation, Gross Regional Domestic Product (GRDP) growth, export capacity, and capital formation, is well-established. In Indonesia, MSMEs dominate the business landscape, contributing nearly 100 % of all enterprises but accounting for only 58–61 % of the gross domestic product. In 2023, approximately 64 million MSMEs were operational, with over 15 % involved in the agro-industrial sector, including horticulture. The projected growth of horticultural MSMEs in 2024 is anticipated to reach 10 %, driven by increased domestic and international demand for locally produced items such as organic vegetables and herbal plants [1].

Indonesia holds substantial potential for developing potato chip products, supported by strategic initiatives such as cluster mapping, capital acceleration strategies, marketing, and strategic alliances to enhance competitiveness [2]. The mapping of potato chip MSMEs clusters encompasses core industries (potato chip MSMEs), supplier industries (potato farmers and collectors), supporting industries (producers of food additives, packaging, machinery, and equipment), and buyers (distributors and consumers). The formation of these clusters has had a positive impact on strengthening business capacity and competitiveness, thereby serving as an effective tool for regional economic development policies. Potato chip production has consistently increased, driven by rising demand and an average potato consumption growth rate of 13.95 % [2]. However, to sustain and accelerate the growth of the potato chip agroindustry, improving supply

chain efficiency is essential. Enhanced supply chain management not only increases regional product competitiveness but also bolsters the agroindustry's role in regional economic advancement.

The development of the potato chip processing industry has intensified competition among businesses, necessitating continuous improvement in product competitiveness. Supply chain management (SCM) plays a crucial role in addressing this challenge, as it enables the integration of strategic, defensive, and operational activities to enhance a company's overall competitiveness [3]. One of the most important but little-studied of these is the halal supply chain, especially in industries that produce food like potato chips. Effective management of halal supply chains is imperative to mitigate risks of contamination and disruptions, ensuring the integrity of halal-certified products. Failure to address these risks undermines market trust and operational efficiency.

Even though the potato chip market is growing and MSMEs are important in Indonesia, the intricacy of managing the halal supply chain in this industry is not adequately handled. Risks such as contamination and supply chain disruptions threaten halal integrity, undermining market trust and operational efficiency. Most existing research focuses on production and marketing concerns, sometimes overlooking the critical element of halal integrity, which is critical for Muslim consumers. Hazards, including contamination and supply chain interruptions, jeopardize the integrity of halal, eroding customer confidence and business productivity. Though it is still not sufficiently addressed, effective management of halal supply chains is essential in industries that manufacture food, like the potato chip industry.

Therefore, studies that are devoted to improving the quality of halal supply chain management are of scientific relevance.

2. Literature review and problem statement

In the paper [4], potatoes are identified as a valuable horticultural crop with significant potential for development due to their high economic value, particularly as raw materials in the food industry. To produce high-quality potato chips, the raw potatoes must meet specific quality standards and criteria [5]. Research by [6] has shown that obtaining halal certification is an effective strategy for enhancing product competitiveness in the potato chip industry, which is experiencing an increase in competition. Products with a halal certification offer assurance that the ingredients and production processes adhere to Islamic Sharia law. The stringent monitoring of production also minimizes the risk of contamination with non-permissible substances, ensuring superior standards of hygiene and safety. Halal-certified products are of greater consumer value, which has the potential to boost profits for businesses [6].

However, despite these advantages, there are unresolved issues related to the maintenance of halal integrity throughout the supply chain [4]. Ensuring halal quality is crucial to reduce supply chain vulnerabilities, thus necessitating the improvement of the Halal Supply Chain Model for different product and market combinations [5]. Certified products may lose their halal designation as a result of cross-contamination. The primary challenge encountered in the halal supply chain of potato chips is the presence of risks that may compromise the halal integrity of the final product. These risks manifest themselves at numerous phases of the supply chain, such as the procurement of raw materials, production processes, storage, distribution, and halal management [6]. The reason for this may be due to the absence of effective identification and mitigation of these risk agents.

The study by [7] emphasizes that the supply chain is essential to effectively manage these processes in order to reduce costs and improve customer satisfaction. Halal supply chain management instills the halal concept into the food chain to meet consumer needs by integrating all parties involved in production and distribution, which is an important part of maintaining halal integrity and consumer trust. But there were unresolved issues related to the identification of specific risk factors within the halal supply chain that could compromise product integrity.

The reason for this may be the complexities involved in mapping and analyzing the multitude of risk agents and events across different stages of the supply chain. There is a persistent risk of contamination by non-halal materials at various phases of the halal supply chain, such as food processing, packaging, transportation, warehousing, and sales [8]. Key aspects of effective supply chain management include strong stakeholder relationships, trust among partners to foster long-term collaboration, and robust risk management to ensure seamless operations and distribution. A flexible and adaptive supply chain is better positioned to respond to market demand fluctuations and external conditions, enhancing business continuity [9].

Previous approaches, such as the use of standard risk assessment tools, have been employed in supply chain risk management [10]. However, these methods often lack the ability to prioritize risks effectively and understand the interrelationships between risk agents. In the agro-industrial sector, facing supply chain complexities, it is imperative to promptly identify hazards in supply chain management in order to improve competitiveness and market share. The likelihood and impact of these risks within supply chain entities can be identified, assessed, and addressed through strategic risk management steps to enhance logistics efficiency. In halal food supply chains, contamination with non-halal substances can occur due to the use of equipment or facilities that do not meet halal standards or deviations in production processes that violate the Shariah principle. There is a persistent risk of contamination by non-halal materials at various phases of the halal supply chain, such as food processing, packaging, transportation, warehousing, and sales [11]. The probability of halal products being compromised and becoming haram is elevated by these risks. Therefore, it is essential to conduct thorough identification across raw material procurement, production processes, storage, and distribution to ensure the integrity of halal products is maintained until they reach consumers.

A way to overcome these difficulties can be the integration of advanced risk assessment methodologies that can both prioritize risks and map their interrelationships. The House of Risk (HoR) technique is a useful tool for managing supply chain risk in the halal industry. It assists in identifying important points that may compromise the halal integrity of products across the supply chain and in developing suitable risk mitigation methods [12]. Prioritizing risks that need to be addressed right now is made possible by the HoR method, which offers an organized and methodical approach to risk identification and management.

But there were unresolved issues related to the need for understanding the interrelationships between risk agents to develop effective mitigation strategies. Therefore, it is required to determine risk mitigation strategies by integrating

the Interpretive Structural Modelling (ISM) method and identifying the interrelationships between risk agents. The integration of HoR and ISM methods provides a more comprehensive and effective approach to risk management by enhancing the identification, analysis, mapping, and mitigation of risks. ISM helps understand the interconnections between various risk agents by mapping their structural relationships, offering deeper insights into how one risk agent can influence others and improving overall risk interaction analysis.

All of this points to the need for research on the integration of HoR and ISM approaches in order to enhance product integrity and consumer trust by identifying, prioritizing, and mitigating risks in the supply chain for halal potato chips.

3. The aim and objectives of the study

The aim of the study is to develop innovative risk mitigation strategies for the regional economic development and sustainable growth goals.

To achieve this aim, the following objectives are accomplished:

– to develop a comprehensive institutional model for the halal potato chip micro-enterprise supply chain;

– to identify and analyze priority risk agents within the halal potato chip supply chain based on specific risk events;

– to prioritize and evaluate the identified risk agents, using the House of Risk (HoR) methodology, ensuring a structured approach to assuring halal compliance throughout the supply chain;

– to develop a structural model for mitigating institutional risks using the Interpretive Structural Modelling (ISM) approach, thereby enhancing halal compliance and sustainability across the potato chip micro-enterprise supply chain.

4. Materials and methods

4. 1. Object and hypothesis of the study

The object of this research is the halal supply chain within the potato chip micro-scale enterprises that are sampled in Indonesia. The study focuses on the institutional structure of this supply chain, which involves multiple stakeholders such as suppliers, producers, and retailers. The hypothesis of this study suggests that the halal integrity of the final product in the potato chip business cluster is vulnerable to various risks throughout the supply chain, including raw material sourcing, production, storage, distribution, and halal management. By identifying and mapping risk agents to specific risk events, it is possible to develop effective mitigation strategies to minimize these risks and ensure the preservation of halal standards. Furthermore, applying House of Risk (HoR) and Interpretive Structural Modelling (ISM) methodologies will help prioritize these risk agents and provide a structured approach for institutional risk mitigation.

This research operates under several assumptions. It assumes that all stakeholders in the supply chain, including producers, suppliers, and retailers, either have or are pursuing halal certification and are committed to maintaining halal standards throughout. Supply chain practices are presumed to be standardized, with any deviations considered potential risks. The risks identified in the small-scale potato chip industry are expected to be generalizable to similar business clusters. Additionally, it is assumed that sufficient data is available for the HoR and ISM methodologies and that stakeholders actively participate in the risk identification and mitigation process. Lastly, market conditions are expected to remain stable throughout the study.

This work adopts several simplifications. It assumes uniform stakeholder behavior in adhering to halal standards and standardizes supply chain processes across all stages, minimizing variations. The risks identified in the potato chip micro-scale enterprises are generalized to similar business contexts without considering specific regional differences. The study also presumes that market conditions remain stable throughout and that sufficient and reliable data is available for the HoR and ISM methodologies.

4. 2. Data collection

The research methodology employed a quantitative approach through the analysis of empirical data collected during 2023, to identify risks that emerge at each stage of the supply chain (suppliers, manufacturers, and retailers). The objects and respondents of this research are suppliers (1 person), manufacturers (3 people), and retailers (1 person) who understand the halal supply chain.

4. 3. House of Risk

The House of Risk (HoR) [9, 13] methodology was employed to identify, evaluate, and prioritize risk agents and risk events in the halal potato chip supply chain. The HoR framework was divided into two phases:

1. Phase 1. Identifying risk events and agents, and calculating Aggregate Risk Potential (ARP) values.

2. Phase 2. Developing mitigation strategies based on priority risk agents.

In Phase 1, the following steps were conducted:

1. Conduct risk event identification in the institutional supply chain of potato chips among suppliers, producers, and retailers (as mentioned in Table 1).

2. Identify risk events and risk agents.

3. Assess the severity level of risk events on a scale of 1–10.

4. Assess the occurrence level of risk agents on a scale of 1–10.

5. Correlation assessment between risk events and risk agents. Correlation values use a scale of 0, 1, 3, and 9 indicating no correlation, low correlation, moderate correlation, and high correlation.

6. Calculate the Aggregate Risk Potential (ARP) value using the formula:

$$ARPj = Oj \times \sum Si \cdot Rij, \quad (1)$$

ARPj – aggregate risk potential from risk agent *j*;

Oj – occurrence from risk agent *j*;

Si – severity from risk event *i*;

Rij – correlation between risk event *i* and risk agent *j*.

ARP represents the risk potential of agent, *O* is the occurrence rate of agent, *S* is the severity of event, and *R* is the correlation between event and agent.

7. Arrange the ARP values in ascending order to prioritize the risk occurrences and risk agents that require attention.

8. The Pareto 80/20 chart was used to identify priority risk agents that contribute to 80 % of the total risk.

4. 4. Interpretive Structural Modelling (ISM)

The Interpretive Structural Modelling (ISM) [13] method was utilized to analyze the relationships between prioritized

risk agents from HoR Phase 1. The following steps were performed:

1. Establish contextual relationships among risk agents.

2. Use symbols (*V*, *A*, *X*, *O*) to construct a Structural Self Interaction Matrix (SSIM).

– *V*: Variable influences/triggers variable;

– *A*: Variable is influenced/triggered by variable;

– *X*: Variables influence each other;

– *O*: Variables have no relationship.

3. Convert SSIM into the Reachability Matrix (RM) and test it using the transitivity rule.

4. Develop the Driver Power-Dependence (DPD) matrix, categorizing risk agents into four quadrants:

– autonomous: low driver power and low dependence;

– dependent: low driver power and high dependence;

– high driver power and low dependence. The ISM approach enabled the identification of independent and dependent risk agents, providing insights for effective mitigation planning.

The risk events in Table 1 illustrate potential issues that may disrupt halal compliance in the provision of raw materials, production processes, and distribution flows.

Risk agents are aspects that contribute to halal non-compliance at each stage and the potential that may arise and result in several risk events.

Table 1

Risk events and risk agents in the halal supply chain

Supply chain actors	Examples of risk events	Examples of risk agents
Supplier	E5: delayed delivery of raw materials	A7: poor supplier communication practices
Producer	E1: lack of halal-certified raw materials	A1: non-adherence to halal material usage protocols
Retailer	E29: improper storage conditions	A32: inadequate retailer awareness of halal compliance

5. Results of prioritizing halal supply chain risk agents using House of Risk and determining mitigation strategies with Interpretive Structural Modelling

5. 1. Comprehensive institutional model for the halal potato chip micro-enterprise supply chain

The development of a comprehensive institutional model for the potato chip supply chain explained the interactions within key stakeholders. This institutional framework serves as the foundational step for subsequent risk identification and mitigation, ensuring that all parties maintain halal compliance throughout the supply chain.

Fig. 1 illustrates the roles of the three primary partners: supplier, producer, and retailer whose coordinated actions ensure the seamless flow of products. In this model, potatoes are ordered from the supplier by the producer, who then processes them into chips and delivers the final product to the retailer.

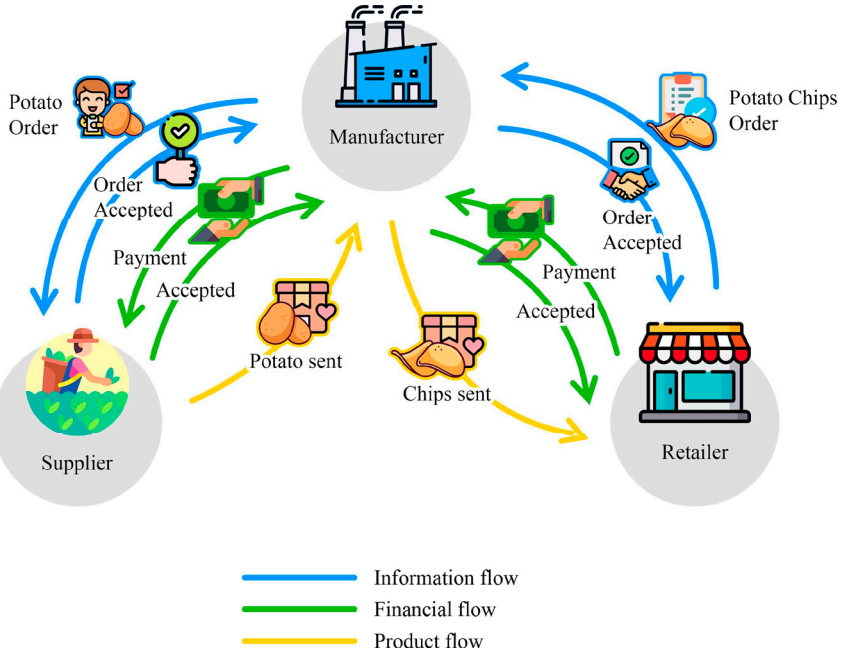

Fig. 1. Structure of the halal supply chain institutional model

The model emphasizes three integrated flows: information flow (blue, representing requests and confirmations), financial flow (green, representing payments and receipts), and product flow (yellow, representing the movement of raw materials and finished goods). The information flow is a representation of the communication that is required for both halal compliance and operational efficiency. The supply chain's underlying financial transactions are highlighted by the financial flow. The product flow guarantees that the items' integrity is maintained at every stage and illustrates the actual movement of the goods. By integrating these three processes, producers, suppliers, and retailers can effectively coordinate to guarantee seamless product distribution [10]. This model clearly demonstrates the structured interaction among suppliers, producers, and retailers, highlighting the critical channels of communication, financial transactions, and product movements essential for maintaining halal integrity.

5. 2. Identification of potential risk agents based on specific risk events in the halal potato chip supply chain

Identification of risk events in the halal potato chip supply chain activities was conducted through interviews with supply chain actors (suppliers, producers, retailers) with a total of 5 respondents who are experts in the halal supply chain. The results revealed 69 risk events and 70 risk agents that affect the halal status of potato chips. The focus was on planning (plan), sourcing (source), production (make), and delivery (deliver) activities. All identified risk events and risk agents are detailed in Table 2.

These risk events represent potential problems that interfere with halal compliance in raw materials, production, and distribution. The risk agents are factors that cause halal non-compliance at each stage and have the capacity to trigger multiple risk events.

Table 2

Identification of risk events as the basis for determining risk agents

Supply chain actors	Risk events	Examples of risk events	Risk agents total	Examples of risk agents
Supplier	E5, E9, E41, E48, E53, E58, E61, E65	Quality of potatoes not meeting halal standards, delays in delivery	A7, A11, A43, A49, A54, A59, A62, A66	Lack of supplier knowledge about halal standards, absence of supplier certifications
Manufacturer	E1, E2, E3, E4, E6, E7, E8, E10, E11, E12, E13, E14, E15, E16, E17, E18, E19, E20, E21, E22, E23, E24, E25, E26, E27, E28, E30, E32, E34, E36, E38, E39, E40, E42, E43, E45, E46, E49, E51, E54, E56, E57, E59, E62, E63, E66, E68, E69	Improper cleaning of equipment, use of non-halal certified additives	A1, A2, A3, A4, A5, A6, A8, A9, A10, A12, A13, A14, A15, A16, A17, A18, A19, A20, A21, A22, A23, A24, A25, A26, A27, A28, A29, A30, A31, A33, A36, A38, A40, A41, A42, A44, A46, A47, A50, A52, A55, A57, A58, A60, A63, A64, A67, A69, A70	Lack of training for workers, improper documentation of raw materials
Retailer	E29, E31, E33, E35, E37, E44, E47, E50, E52, E55, E60, E64, E67	Cross-contamination during storage, mixing halal and non-halal products	A32, A34, A35, A37, A39, A45, A48, A51, A53, A56, A61, A65, A68	Lack of separate storage spaces for halal products, insufficient retailer education on halal compliance

According to the findings of the risk identification, there have been eight risk occurrences at suppliers, forty-eight at producers, and thirteen at retailers. Potential problems that interfere with halal compliance in raw materials, production, and distribution are known as risk events in the supply chain for halal potato chips. Parties that cause halal non-compliance at every step of the process are known as risk agents in the supply chain for halal potato chips. They have the capacity to cause many risk events.

The Aggregate Risk Potential (ARP) ranking value is used to analyze risk occurrences and risk agents in order to prioritize risk mitigation methods based on the 80 % Pareto diagram. Due to their substantial contribution to the entire risk potential and direct correlation with the degree of impact on a company's supply chain, risk agents with the highest ARP values are given priority for mitigation. Appendix 2 displays the findings of the Pareto diagram analysis's cumulative ARP computation.

5. 3. Prioritization and evaluation of risk agents using the House of Risk (HoR) methodology

The Aggregate Risk Potential (ARP) ranking was used to analyze risk events and risk agents to prioritize risk mitigation strategies based on the 80 % Pareto diagram. The severity (*S*), occurrence (*O*), and correlation (*C*) levels were assessed to calculate the ARP value for each risk agent using the HoR phase 1 method. The ARP value is calculated by multiplying the occurrence rate by the correlation strength between the risk agent and the risk event, as well as the risk impact (severity). Fig. 2 illustrates the Pareto diagram used to determine the priority of risk agents, and Table 3 lists the 30 priority risk agents identified for micro-enterprises.

Because of their significant contribution to the overall risk potential and their direct relationship to the extent of supply chain effect, these priority risk agents need to be mitigated.

Based on the analysis using the Pareto principle, there are 30 priority risk agents in micro-enterprises, present at the supplier, producer, and retailer levels. High-level risk agents in the hierarchy are prioritized for mitigation because of their substantial impact on other risk agents. In order to map the links between risk agents, the ISM analysis uses the priority results of risk agents from HoR phase 1. The mitigation plan should concentrate on the risk agent with the highest ARP from HoR if it significantly affects the ISM structure. Because risk agents with a high ARP but few ISM connections imply particular and non-contagious threats, internal controls might be the focus of mitigation methods. The integration of ISM analysis and HoR phase 1 data offers a more thorough method of risk identification and mitigation. By concentrating on managing high-impact risk agents and perhaps lowering overall risk, the combination of ARP priorities and risk hierarchy linkages allows for developing more effective and efficient mitigation measures. Because managing these risk agents can lessen the total risk impact, mitigation efforts should concentrate on risk agents that are driving factors in ISM and have a high ARP in HoR.

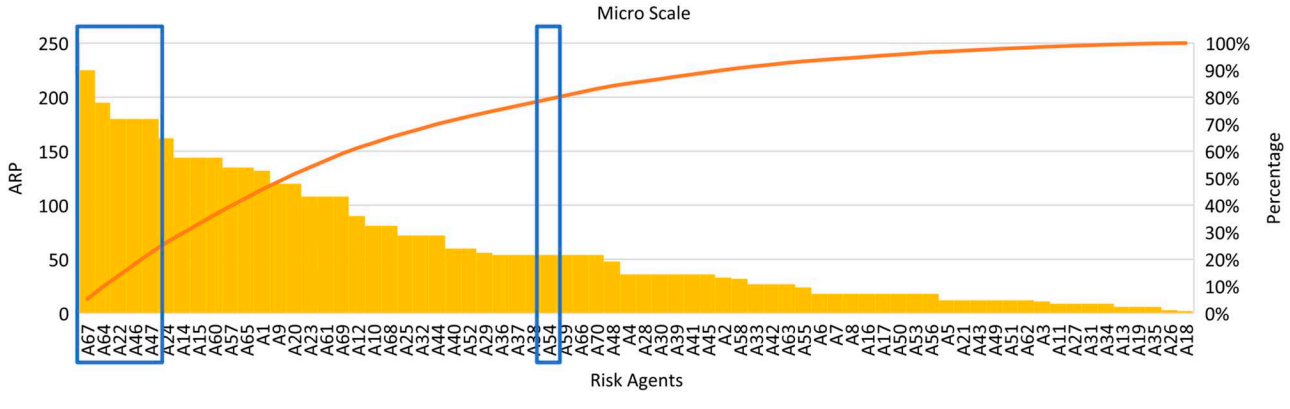

Fig. 2. Pareto diagram in micro-scale business

Table 3

Priority risk agents for micro-enterprises

No.	Agent Code	ARP	Cum* ARP	%
1	A67	225	225	5.3
2	A64	195	420	9.9
3	A22	180	600	14.1
4	A46	180	780	18.3
5	A47	180	960	22.5
6	A24	162	1122	26.3
7	A14	144	1266	29.7
8	A15	144	1410	33.1
9	A60	144	1554	36.5
10	A57	135	1689	39.6
11	A65	135	1824	42.8
12	A1	132	1956	45.9
13	A9	120	2076	48.7
14	A20	120	2196	51.5
15	A23	108	2304	54.1
16	A61	108	2412	56.6
17	A69	108	2520	59.1
18	A12	90	2610	61.2
19	A10	81	2691	63.1
20	A68	81	2772	65.0
21	A25	72	2844	66.7
22	A32	72	2916	68.4
23	A44	72	2988	70.1
24	A40	60	3048	71.5
25	A52	60	3108	72.9
26	A29	56	3164	74.2
27	A36	54	3218	75.5
28	A37	54	3272	76.8
29	A38	54	3326	78.0
30	A54	54	3380	79.3

*Note: * – cumulative ARP.*

5. 4. Development of a structural model for institutional risk mitigation using interpretive structural modelling (ISM)

The prioritized risk agents from the HoR analysis were further examined using the ISM approach to understand the interrelationships between them and to develop a structural model for institutional risk mitigation. A Structural Self-Interaction Matrix (SSIM) was constructed to understand the interrelationships between risk elements among the risk agents. The contextual relationships among the risk agents were established by organizing them into a Structural Self-Interaction Matrix (SSIM) to conduct a MICMAC analysis and develop a partition level matrix. The risk agents were categorized according to their Driver Power (*DP*) and Dependence (*D*) values using the MICMAC analysis, as shown in Fig. 3.

According to the ISM study, risk agents A20, A46, A47, and A57 have a high degree of driving power and influence other risk agents. On the other hand, variations in other risk agents have an impact on risk agents A1, A10, A15, A23, and A44, which are dependent variables. The partition levels, illustrated in Fig. 4, demonstrate the hierarchical structure of the risk agents, which aids in prioritizing the formulation of effective risk mitigation strategies.

In order to improve halal compliance and sustainability throughout the potato chip micro-enterprise supply chain, businesses can employ mitigation techniques that target the underlying sources of risks by concentrating on the independent risk agents found through ISM. Risk agents A20, A46, and A47 are the most important key factors to consider in prioritizing independent supply chain risk mitigation strategies, and their changes affect other sub-elements/systems as a whole.

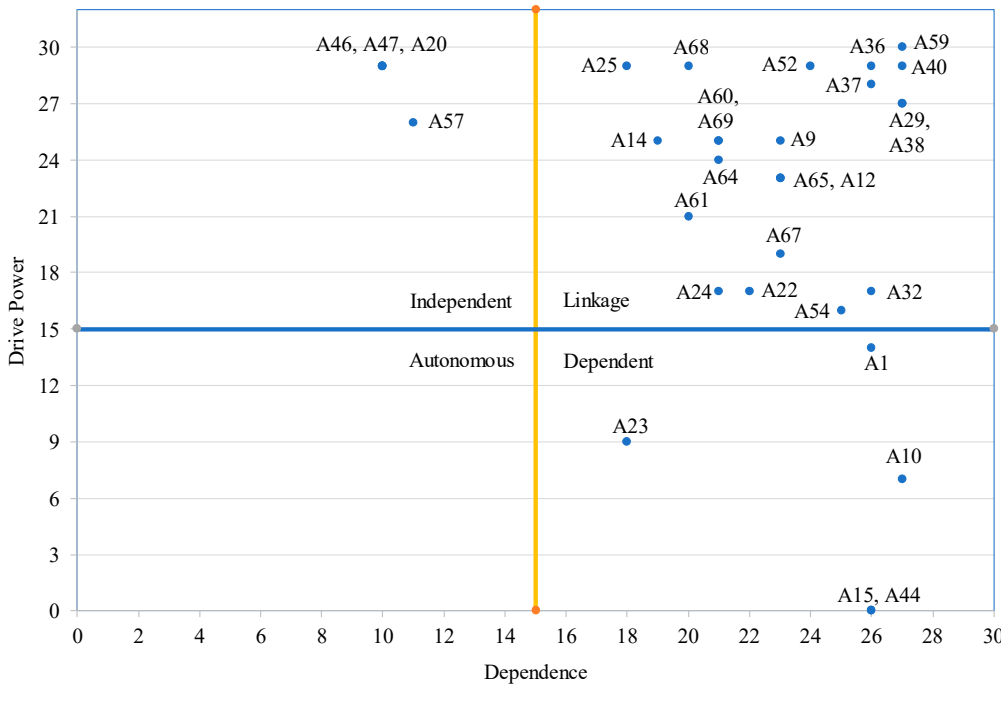

Fig. 3. MICMAC analysis

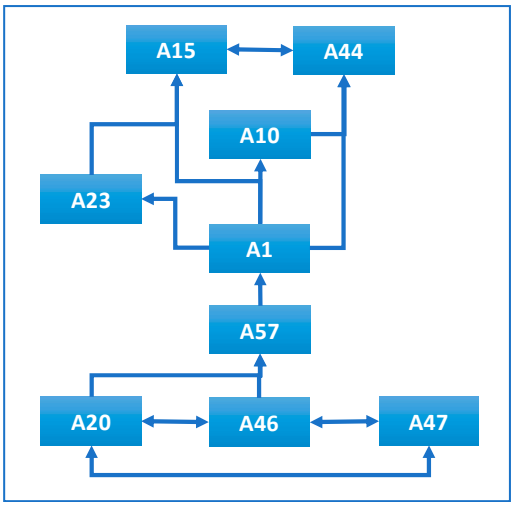

Fig. 4. Partition levels of the risk agents' hierarchical structure

6. Discussion of results focuses on relation to the prioritization of halal supply chain risk agents through House of Risk Phase 1 and mitigation strategies using the Interpretive Structural Methodology

Maintaining halal integrity across the supply chain requires strict control over raw materials, production processes, and distribution. The halal supply chain for potato chips involves three key players: suppliers, producers, and retailers, whose coordination ensures compliance with halal standards. Suppliers provide raw materials, including potatoes from farmers, intermediaries, and wholesalers, ensuring quality, quantity, and timely delivery [2]. Challenges include the lack of a return policy for substandard potatoes, emphasizing the need for strict quality controls.

Retailers link producers to consumers through marketing and sales. The integrity of halal products is the responsibility of retailers in the halal supply chain [14], as non-halal products can contaminate halal products at any point during handling until the product is delivered to the customer. They handle information on orders and market demand, while financial transactions vary between consignment and direct sales. Micro-enterprises focus on local retailers, while small enterprises utilize wholesalers for broader distribution, expanding market reach [4]. Overall, effective coordination between suppliers, producers, and retailers ensures the halal status of potato chips, safeguarding consumer trust and upholding market competitiveness.

The study systematically identified 69 risk events and 70 risk agents in the halal potato chip supply chain, focusing on planning, sourcing, production, and delivery activities. These risk events represent potential problems that interfere with halal compliance in raw materials, production, and distribution. The risk agents are factors that cause halal non-compliance at each stage and have the capacity to trigger multiple risk events. By employing the House of Risk (HoR) and Interpretive Structural Modelling (ISM) methodologies, 30 priority risk agents were identified, accounting for 80 % of the total risk potential, as shown in Fig. 2 (Pareto Diagram) and Table 2.

This study's findings are explained by the thorough use of the Interpretive Structural Modelling (ISM) and House of Risk (HoR) Phase 1 approaches to rank and examine risk factors in the supply chain for halal potato chips. Fig. 2 (Pareto Diagram) highlights the importance of these agents in jeopardizing halal integrity by showing that 30 priority risk agents account for 80 % of the risk potential. These priority risk agents are listed in Table 3, which were determined by using the HoR approach to calculate their Aggregate Risk Potential (ARP) values. The high ARP values suggest that the halal compliance of the supply chain is significantly impacted by these risk agents.

The ISM methodology further elucidated the interrelationships among the prioritized risk agents, categorizing them into independent and dependent variables based on their driving power and dependence, as depicted in Fig. 3 (MICMAC Analysis) and Fig. 4 (Partition Level). Risk agents A20, A46, A47, and A57 are identified as independent variables with high driving power, meaning they significantly influence other risk agents. In contrast, risk agents A1, A10, A15, A23, and A44 are dependent variables, affected by changes in other agents. This hierarchical structuring allows for strategic risk mitigation, where addressing independent risk agents can lead to a cascading effect, thereby mitigating dependent risks and enhancing overall halal compliance and sustainability.

The integration of HoR and ISM methodologies offers a comprehensive framework for prioritizing and understanding the interdependencies among risk agents, which is a distinctive feature compared to previous research. This strategic approach facilitates the development of effective mitigation strategies that not only address high-impact risk agents but also consider their influence on the broader supply chain ecosystem. Quantitative evaluations, such as the Aggregate Risk Potential (ARP) values, provided an objective basis for prioritizing risk agents, ensuring that mitigation efforts are efficient and effective.

The risk agents A1, A10, A15, A23, and A44 are in Quadrant II (dependent), have a low driving force but a high dependency, which means that other risks are probably what caused them to emerge [13]. Four risk agents are classified as independent: A20, A46, A47, and A57 significantly impact other risk agents, and their changes have an effect, particularly on risk agents in the dependent quadrant, which in turn influence the occurrence of other risk agents.

A1, There are serious concerns in the halal potato chip supply chain since manufacturers are not committing to using ingredients that are branded as halal. The lack of planning in the usage of halal-certified raw materials and the upkeep of halal potato chip manufacturing facilities are the causes of this predicament. Consumer trust can be damaged by non-halal contamination, certification loss, and even legal infractions resulting from non-compliance with raw material selection. Long-term effects include losing the steadily increasing halal market share and seeing a drop in consumer loyalty. Socialization, the recurring implementation of regulations for the use of halal-certified raw materials, and internal audits that concentrate on halal raw material compliance are among the mitigation techniques that need to be put into place. The research findings contradict [15] regarding the importance of producers being able to build consumer trust and maintain the integrity of halal products. The halal food supply chain can become more transparent and accountable through the use of technologies like blockchain. By guaranteeing confirmed halal ingredients and preventing contamination, the research findings are consistent with [16] and highlight how implementing blockchain technology for halal potato chips can boost confidence. This tactic mitigates the consequences of insufficient manufacturer dedication to halal practices, safeguarding consumer trust and preserving market competitiveness.

A10, The halal potato chip supply chain lacks processes for keeping track of raw material purchases and receipts, which may lead to low traceability concerns and the possible use of non-halal raw materials. This damages the reputation and faith of customers by making it harder to confirm whether materials are halal, increasing the chance of cross-contamination, and causing the loss of halal certification. The research findings are in line with [17], which highlights how strong traceability systems improve compliance and halal integrity. For the halal potato chip supply chain to guarantee high traceability and avoid the use of non-halal components, thorough documentation procedures for raw material procurement and receipt must be put in place.

The research findings are consistent with [16], the introduction of digital technologies, such as supply chain management systems built on blockchain, can improve record-keeping's accountability and transparency. The mitigation strategy that must be put into practice is the establishment of a systematic and uniform record-keeping system and the regular auditing of documentation.

A15, producers who fail to use dishwashing soap with a halal label risk consumer confidence, suffer financial losses, and run the danger of facing legal consequences related to halal certification. Using halal-labeled facilities is essential to maintaining product integrity, in accordance with [6]. All production equipment needs to be hygienic, free of non-halal pollution, and in accordance with Sharia law. To preserve the halal status of finished goods and uphold consumer confidence, internal regulations requiring halal-certified facilities must be established in effect. Developing internal procedures requiring the use of halal-certified raw materials, better supervision of the production process, and educating producers on the significance of halal standards are all examples of risk mitigation techniques.

A23, the standard of hygiene and sanitation in the process of making halal potato chips is impacted by the producer's lack of commitment to offer sinks surrounding the production area. There is a greater chance of cross-contamination between equipment and raw materials, which might damage the product's quality and halal status. Reputational damage, a decline in customer trust, and transgressions of halal standards are among possible effects. The findings of this investigation are consistent with [18], which states that inadequate infrastructure and hygienic facilities raise the possibility of product contamination with non-halal or unsanitary materials, lowering the standard of sanitation throughout the manufacturing process. The integrity of halal products is greatly dependent on the application of halal quality assurance procedures, which include the provision of suitable hygienic and sanitation facilities. Strict sanitation regulations, sufficient sink facilities, and frequent employee education regarding the significance of cleanliness in the manufacture of halal food are examples of risk mitigation techniques. Manufacturers who are dedicated to establishing sufficient hygienic facilities in the manufacturing area will be better equipped to preserve the halal status of their goods, win over more customers, and eventually obtain a competitive edge in the marketplace.

A44, the primary trust that consumers have in products is their halal certification, which may be threatened by producers' lack of procedures for employing halal-labeled ingredients. Along with potentially legal infractions regarding halal laws, the impact also includes monetary losses and reputational harm. This is consistent with [18] in that there are confusing protocols for using ingredients branded as halal, which represents a significant risk to a product's ability to meet halal certification requirements. Consumer trust is the cornerstone of SMEs' economic advantage in the halal market, and this damages it in addition to affecting product certification. Developing a systematic halal management system is a crucial way to guarantee the integrity and uniformity of the product. Establishing accurate and stringent procedures for the selection of raw materials, ensuring that all production materials have a valid halal certification, and educating manufacturers on the significance of halal standards are all necessary components of the risk mitigation plan. This study is in line with [19] that the application of the halal supply chain management model, which prioritizes traceability, transparency, and commitment to halal standards through the production, distribution, and storage aspects of the supply chain, increases customer confidence in the halal integrity of products. This strategy also makes the global market more competitive.

A20, in the halal potato chip supply chain, one of the most important problems is the absence of worker training about the halal production process. Employees' ignorance of halal standards can lead to cross-contamination, a decline in customer confidence, and even market loss, particularly in customer segments where product halalness is a sensitive issue. Adverse effects include the loss of halal certification and monetary losses caused by product recalls. Insufficient training can lead to non-compliance with rules, contamination hazards, and a lack of knowledge of halal standards, as this study supports [20]. The training aims to improve certification knowledge, the application of stringent hygiene requirements, and awareness of the halalan toyyiban idea. Insufficient training affects the authenticity of halal products and damages consumer confidence. Regular training and certification programs for employees that emphasize process control, cleanliness procedures, and awareness of halal raw materials are the mitigation approach that has been established in effect.

A46, the integrity of the supply chain for halal potato chips may be threatened by producers' lack of expertise and proficiency in adopting halal product processes. Producers who lack knowledge of halal standards risk a chance of choosing the wrong raw materials and processing methods, which could lower the product's quality and certification. This study supports [20], which states that one of the most significant barriers to guaranteeing commitment to halal standards is manufacturers' awareness and ability to apply halal principles. The integrity of the supply chain is seriously threatened by the producers' lack of expertise and proficiency in implementing halal production procedures. Inconsistently satisfying halal regulations during production is sometimes a challenge for producers without prior experience. Loss of customer confidence, a decline in sales, and consequences for halal label infractions are among the possible effects. The training and development of human resources and the creation of an internal audit system centered on commitment to relevant halal standards are two risk mitigation strategies that can be used to guarantee the continuity of the halal supply chain. This is required to improve knowledge and skills in managing production in accordance with international halal standards.

A47, a major risk in the supply chain for halal potato chips could result from producers who lack to provide workers (employees) with halal training. Insufficient training can result in operational mistakes, the risk of cross-contamination, and failure to comply with halal requirements if employees lack knowledge of halal standards and procedures. The findings of this study support [20]'s claim that a lack of training can

result in non-compliance with certification standards, a lack of knowledge of halal processes, and an increased risk of contamination. This could damage the company's competitiveness, decrease consumer trust, and affect the integrity of halal products. To guarantee that the entire supply chain satisfies halal requirements and preserves the product's reputation in the international market, structured training is required. The elimination of halal certification, a reduction in product quality, and the potential loss of markets that prefer halal goods are some of the effects. The development of frequent employee training programs, a focus on hygienic procedures and the handling of halal products, and internal audits to verify commitment to halal standards are the suggested mitigating techniques.

A57, the sustainability of the supply chain for halal potato chips is potentially threatened by producers' lack of commitment and responsibility in involving halal and thoyyib elements into the production process. Research in accordance with [21] emphasizes the significance of producer commitment and responsibility in integrating halal and thayyib features in the production process. Without this commitment, the risk of disregard with halal standards grows. With damaged products, a reduction in product quality, and the discontinuation of halal certification, this lack of commitment could risk the sustainability of the halal supply chain. Lack of knowledge and dedication might lead to producers not meeting halal standards, which would compromise the integrity of the product and decrease consumer confidence. The primary effects are the loss of markets that are sensitive to halal designation and a decline in consumer trust. Consequently, the sustainability of the halal product supply chain depends on improving halal literacy and an encouraging mindset toward halal practices. This can be achieved by implementing demanding internal policies that concern halal compliance, training employees, and conducting frequent audits to make sure halal standards are being met. This study is in line with [22] that halal certification compliance drives product innovation and consumer trust, significantly enhancing market performance. This study offers strategic insights for companies to leverage halal certification as a competitive advantage.

However, this study has limitations, including variables such as hygiene and raw material recording practices, as well as a focus on small-scale companies, which may hinder the formulation of general conclusions.

Recommendations for further research include the need to consider the integration process of advanced technologies such as blockchain to improve traceability and transparency in the halal supply chain. Furthermore, exploring the impact of differences in corporate culture and external influences on risk management practices is an important factor to study.

7. Conclusions

1. The development of the comprehensive Halal Supply Chain Institutional Model provides a clear depiction of the interactions among suppliers, producers, and retailers. This model forms the foundational framework for effective risk management by clearly delineating the integrated flows of information, finances, and products, thereby ensuring consistent halal compliance and operational efficiency within the potato chip micro-enterprise supply chain.

2. This study systematically identified various risk events and risk agents in the halal potato chip supply chain, focusing on planning, sourcing, production, and delivery activities. The various risks that may compromise the items' halal integrity have been fully appreciated thanks to this comprehensive identification. When compared to other research, this result is unique due to its comprehensive coverage of supply chain phases and its more detailed identification of risk agents. The comprehensive information collected by important supply chain participants explains this outcome, emphasizing critical issues that require action.

3. The determined risk agents were classified according to their Aggregate Risk Potential (ARP) values by applying the House of Risk (HoR) technique. The need for targeted mitigation methods on these agents is highlighted by the Pareto analysis, which showed that 30 priority risk agents account for 80 % of the total risk potential.

4. The Interpretive Structural Modelling (ISM) method was used to create a structural model for institutional risk mitigation. This analysis categorizes risk agents into dependent and independent variables in the potato chips business cluster. Dependent risk agents are triggered by other variables, while independent agents are determined to have crucial driving forces in controlling the system. This approach facilitates the development of efficient mitigation methods by revealing the interdependencies among risk agents. Specifically, addressing independent risk agents such as A20, A46, A47, and A57 can lead to a cascading effect that mitigates dependent risks, thereby enhancing sustainability and halal compliance. This finding differs from other research in that it allows for a more strategic approach to risk mitigation by mapping the interdependencies amongst key issues in addition to identifying them.

Conflict of interest

The authors hereby declare that there are no conflicts of interest, whether financial, personal, authorship-related, or otherwise, that could have influenced the conduct of this study or the results presented in this paper.

Financing

This research was financed by the Faculty of Agricultural Technology, Universitas Brawijaya for Associate Professor Doctoral Grant 2023.

Use of artificial intelligence

The authors affirm that no artificial intelligence technologies were utilized in the development of this work.

Acknowledgments

The authors express their sincere gratitude to the Faculty of Agricultural Technology at Universitas Brawijaya, with a special emphasis on the Department of Agro-industrial Technology, for their invaluable support and resources that contributed to the successful completion of this research. The guidance and support of these distinguished institutions and individuals were indispensable to the accomplishment of this investigation.

References

1. Tambunan, T. (2019). Recent evidence of the development of micro, small and medium enterprises in Indonesia. Journal of Global Entrepreneurship Research, 9 (1). https://doi.org/10.1186/s40497-018-0140-4
2. Wahdania, N. Z., Mustaniroh, S. A., Santoso, I., Purwaningsih, I. (2021). Clustering of potato chips SMEs in Batu City, Indonesia. IOP Conference Series: Earth and Environmental Science, 924 (1), 012060. https://doi.org/10.1088/1755-1315/924/1/012060
3. Maharijaya, A., Nur Salma, L., Amarilis, S. (2020). Produksi dan Kualitas Umbi Beberapa Genotipe Kentang (Solanum tuberosum L.) Koleksi IPB untuk Olahan Keripik Kentang. Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy), 48 (3), 275–282. https://doi.org/10.24831/jai.v48i3.32979
4. Rasi, R. Z., Masrom, N. R., Omar, S. S., Ahmad, M. F., Sham, R. (2017). Withdrawn article: Designing Halal Supply Chain: Malaysia's Halal Industry Scenarios. MATEC Web of Conferences, 135, 00040. https://doi.org/10.1051/matecconf/201713500040
5. Emrouznejad, A., Abbasi, S., Sıcakyüz, Ç. (2023). Supply chain risk management: A content analysis-based review of existing and emerging topics. Supply Chain Analytics, 3, 100031. https://doi.org/10.1016/j.sca.2023.100031
6. Tarei, P. K., Thakkar, J. J., Nag, B. (2020). Benchmarking the relationship between supply chain risk mitigation strategies and practices: an integrated approach. Benchmarking: An International Journal, 27 (5), 1683–1715. https://doi.org/10.1108/bij-12-2019-0523
7. Deng, X., Yang, X., Zhang, Y., Li, Y., Lu, Z. (2019). Risk propagation mechanisms and risk management strategies for a sustainable perishable products supply chain. Computers & Industrial Engineering, 135, 1175–1187. https://doi.org/10.1016/j.cie.2019.01.014
8. Wu, D., Olson, D. L. (2008). Supply chain risk, simulation, and vendor selection. International Journal of Production Economics, 114 (2), 646–655. https://doi.org/10.1016/j.ijpe.2008.02.013
9. Ahmad, T. L., Susanty, A. (2019). House of Risk Approach for Assessing Supply Chain Risk Management of Material Procurement in Construction Industry. IOP Conference Series: Materials Science and Engineering, 598 (1), 012060. https://doi.org/10.1088/1757-899x/598/1/012060
10. Ali, M. H., Suleiman, N., Khalid, N., Tan, K. H., Tseng, M.-L., Kumar, M. (2021). Supply chain resilience reactive strategies for food SMEs in coping to COVID-19 crisis. Trends in Food Science & Technology, 109, 94–102. https://doi.org/10.1016/j.tifs.2021.01.021
11. Ab Talib, M. S., Abdul Hamid, A. B., Zulfakar, M. H. (2015). Halal supply chain critical success factors: a literature review. Journal of Islamic Marketing, 6 (1), 44–71. https://doi.org/10.1108/jima-07-2013-0049
12. Marucheck, A., Greis, N., Mena, C., Cai, L. (2011). Product safety and security in the global supply chain: Issues, challenges and research opportunities. Journal of Operations Management, 29 (7-8), 707–720. https://doi.org/10.1016/j.jom.2011.06.007
13. Natalia, C., Br. Hutapea, Y. F. T., Oktavia, C. W., Hidayat, T. P. (2020). Interpretive Structural Modeling and House of Risk Implementation for Risk Association Analysis and Determination of Risk Mitigation Strategy. Jurnal Ilmiah Teknik Industri, 19 (1), 10–21. https://doi.org/10.23917/jiti.v19i1.9014
14. Bonne, K., Verbeke, W. (2007). Religious values informing halal meat production and the control and delivery of halal credence quality. Agriculture and Human Values, 25 (1), 35–47. https://doi.org/10.1007/s10460-007-9076-y
15. Ahamed, N. N., Vignesh, R., Alam, T. (2023). Tracking and tracing the halal food supply chain management using blockchain, RFID, and QR code. Multimedia Tools and Applications, 83 (16), 48987–49012. https://doi.org/10.1007/s11042-023-17474-4
16. Blossey, G., Eisenhardt, J., Hahn, G. (2019). Blockchain Technology in Supply Chain Management: An Application Perspective. Proceedings of the 52nd Hawaii International Conference on System Sciences. https://doi.org/10.24251/hicss.2019.824
17. Masudin, I., Rahmatullah, B. B., Agung, M. A., Dewanti, I. A., Restuputri, D. P. (2022). Traceability System in Halal Procurement: A Bibliometric Review. Logistics, 6 (4), 67. https://doi.org/10.3390/logistics6040067
18. Nurjamjam, S. (2018). The Influence of Halal Certification and Halal Quality Assurance Practices on Business Competitive Advantage: Case Study of MSMEs in West Java. Indonesian Journal of Halal Studies (IJHS), 1 (1), 69–80. Available at: https://ejournal.uinsalatiga.ac.id/index.php/ijhs/article/view/1664
19. Tieman, M., van der Vorst, J. G. A. J., Che Ghazali, M. (2012). Principles in halal supply chain management. Journal of Islamic Marketing, 3 (3), 217–243. https://doi.org/10.1108/17590831211259727
20. Hashim, H. I. C., Shariff, S. M. M. (2016). Halal Supply Chain Management Training: Issues and Challenges. Procedia Economics and Finance, 37, 33–38. https://doi.org/10.1016/s2212-5671(16)30089-2
21. Alfarizi, M., Ngatindriatun (2022). Commitment to Halal Practices of Indonesian Culinary MSMEs in the Production Chain: The Impact of Halal Literacy and Attitudes. JSEAIS: Journal of Southeast Asian Islam and Society, 1 (1). Available at: https://e-journal.lp2m.uinjambi.ac.id/ojp/index.php/JSAIS/article/view/1767
22. Salindal, N. A. (2018). Halal certification compliance and its effects on companies' innovative and market performance. Journal of Islamic Marketing, 10 (2), 589–605. https://doi.org/10.1108/jima-04-2018-0080