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Sustainability Risk Analysis of the Halal Feed Supply Chain for Ruminant Commodities Through the Integration of the SCOR-FMEA Method

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ABSTRACT

Ruminant commodities play a strategic role in maintaining the stability of meat and milk supply for society. In this context, feed serves not only as a key determinant of livestock productivity but also as a critical foundation for environmental sustainability and compliance with halal standards throughout the supply chain. This study aims to map and priorities risks in the ruminant feed supply chain through the integration of the SCOR and FMEA methods. The novelty of this research lies in the integration of sustainability risks with halal-related risks within the supply chain framework. The study was conducted in Gendro Village, Pasuruan Regency. Data were collected through expert assessments of severity, occurrence, and detection levels, taking into account economic, environmental, and socio-halal aspects. The SCOR framework was applied to systematically map sustainability and halal risks along the supply chain, while FMEA was used to determine risk priorities based on the Risk Priority Number (RPN). The findings indicate that the highest RPN values occur in the planning process, particularly in traceability system planning (R5), and in the production process related to product tracking and record-keeping activities (R20). In addition, the study reveals several halal compliances risks that are difficult to detect, including document verification, segregation practices, and line clearance procedures. In practical terms, the identified risk priorities and proposed improvements can be directly implemented by farmers, enabling improvements in feed quality, reductions in losses, preservation of halal integrity, and enhancement of supply chain resilience through realistic and low-cost interventions. Overall, this study contributes a risk prioritization model that integrates economic, environmental, and halal dimensions and links mitigation actions to SCOR processes, making it applicable to ruminant feed supply chains as well as other commodity-based supply chains.

1. Introduction

The ruminant livestock industry, particularly dairy and beef cattle, plays a strategic role in meeting national food needs by providing essential meat and milk products. The ruminant feed supply chain plays an important role in increasing livestock productivity, animal health, and maintaining the stability of meat and milk production. In reality, this supply chain is fragmented based on the actors involved according to the scale of their business, such as forage farmers, feed ingredient suppliers, distributors, and farmer groups. This has an impact on the vulnerability of the animal feed supply chain to various operational risks, such as inconsistent raw material quality, uncontrolled moisture content, inadequate storage facilities, and weak documentation practices. These problems result in feed spoilage, production inefficiencies, and economic losses at the farmer level.

This industry is crucial for food security as it provides high-quality, nutrient-rich food that is vital for human nutrition (Davis & White, 2020; Guyader et al., 2016; Place, 2024). Economically, in Malaysia, the livestock sector contributes 12.4% of the agricultural GDP, with ruminants contributing 12.1% of the livestock GDP, and meat demand is expected to increase from 1.4 million MT in 2010 to 1.8 million MT in 2020 (Nor & Rosali, 2015). The livestock industry is one of the important pillars in supporting national food security due to its role in providing high nutritional value animal protein sources for the community. Data from 2024 shows that the agricultural sector contributes around 6.3% to Malaysia's Gross Domestic Product (GDP), with the livestock sub-sector growing by 3.3% (Department of Statistics Malaysia [DOSM], 2024). However, this improvement in performance has not been able to fully meet national demand, meaning that domestic meat production still falls short of market demand. Malaysia requires around 200,000 tons of beef annually, yet local production only accounts for 47,000 tonnes, or less than 20% of total needs, with a national target to increase production to 100,000 tonnes by 2030 (Ainsworth et al., 2021; Elbehri & Chestnov, 2021).

In line with this, the Malaysia Trade Statistics Review (MTSR) 2024 reported that Malaysia's livestock industry continues to expand positively, with a 23.2% increase in trade value, reaching RM1.4 billion in 2023. The growth of this sector reflects the increasing demand from both households and industry for livestock and livestock products. To date, the poultry sub-sector, particularly chicken and eggs, still dominates production and trade, with export values reaching RM726.7 million and RM671.2 million, respectively, demonstrating its role as the mainstay of the national protein supply. In contrast, the ruminant sub-sector still faces high dependence on imports, particularly for cattle, goats, and sheep, with import values exceeding RM135 million in 2023. This situation underscores the need to strengthen domestic production capacity, not only to ensure food security and sustainability, but also to reduce dependence on global markets that are vulnerable to fluctuations.

In Indonesia, the livestock sector contributes 1.58% to the Gross Domestic Product (GDP), as reported by the Coordinating Ministry for Economic Affairs. On a global scale, the livestock sector plays a significant role in the world's agricultural economy and is a source of livelihood for around 1.3 billion people (Thamil Vanan & Divya Lakshmi, 2020). In terms of sustainability, a number of studies show that the livestock industry has improved its environmental performance through increased production efficiency, reduced resource use, and reduced greenhouse gas emissions per unit of food produced (Abbasi & Zhang, 2024; Lee et al., 2024; Su et al., 2024). Furthermore, livestock activities also make a strategic contribution to integrated agricultural systems, including through the provision of organic fertilizers and the application of integrated farming approaches that strengthen the interconnection and synergy between crop and livestock businesses (Irfan, 2022).

One of the key elements in improving livestock productivity is the availability of high-quality, sustainable feed that meets halal standards. For example, alfalfa stands out for its superior nutritional profile, including easily digestible protein, calcium, phosphorus, and high carotene content, which significantly increases milk and meat production in livestock (Tokhetova, 2024). Various studies show that Moringa oleifera has great potential as animal feed due to its essential nutrients, such as amino acids, vitamins, and minerals, which contribute to improved growth performance, milk production, and overall animal health (Ali & Khatun, 2025). Properly regulating the composition and levels of amino acids in feed has been proven to improve feed utilization efficiency through the optimization of protein synthesis in the body, which ultimately leads to increased livestock productivity while reducing the environmental impact of livestock farming (Paul et al., 2020). Therefore, the implementation of sustainable feed production practices is an urgent necessity to reduce negative impacts on the environment, including greenhouse gas emissions, water pollution, and land conversion. On the other hand, compliance with halal standards in feed processing and production cannot be ignored, especially to meet the growing needs of Muslim consumers (Herdiana, 2025; Megat, 2025). Such compliance requires the consistent application of hygiene, traceability, and quality control principles throughout all stages of production. Strengthening risk management systems, such as HACCP, supported by the use of modern tracking technology, has the potential to increase transparency and compliance in the supply chain.

However, the ruminant feed supply chain still faces various structural challenges, including dependence on imported raw materials, price volatility, and the complexity of meeting sustainability and halal certification requirements. Dependence on imported feed causes supply chain disruptions and increased costs due to global market volatility (Pastorelli et al., 2023). Price fluctuations have an impact on feed operating costs and a decline in overall profits (Jafari et al., 2025). Ruminant livestock production is also associated with high greenhouse gas emissions and involves complex procedures to ensure compliance with Sharia (Islamic) law (Salami et al., 2019; Zainuddin et al., 2019). These conditions require supply chain management that is not only efficient but also capable of meeting sustainability demands and compliance with halal supply chain principles. On the other hand, the animal feed supply chain also faces pressures related to sustainability and halal compliance. Feed spoilage, the lack of organic waste, inefficient use of resources, and reprocessing and redistribution that produce emissions are problems faced in terms of sustainability. Practices that are not fully aligned with halal principles throughout the animal feed supply chain have the potential to create opportunities for contamination. This situation can ultimately complicate the process of proving and verifying the halal status of products.

Sustainable supply chains emphasize the integration of economic, social, and environmental aspects in every stage of material, information, and financial flows. In the context of halal supply chains, sustainability encompasses not only efficiency and environmental impact but also sharia compliance, which adds value and provides assurance for Muslim consumers. Therefore, risk management in halal-based and sustainable ruminant feed supply chains is a crucial issue for research. Previous studies have shown that FMEA has been used in the context of food and agricultural supply chain risk management to determine risk priorities, and SCOR for process mapping. However, most studies use sustainability, operational risk, and halal compliance aspects in separate contexts, or place halal standards as binary compliance requirements.

Research that explicitly integrates halal principles into the risk assessment structure especially in community-based ruminant feed supply chains is still limited. This situation results in halal risks receiving less attention in priority setting. To address this limitation, this study was designed by integrating SCOR FMEA as a systematic framework for mapping the supply chain process from upstream to downstream and facilitating the structured identification and prioritization of risks based on severity, frequency, and detectability. By incorporating economic, environmental, and halal impacts into the severity dimension, this integration allows halal-related risks to be evaluated not only as compliance issues but as factors that exacerbate the overall risk consequences throughout the supply chain.The SCOR model is a reliable tool for managing and improving supply chain operations. Its structured approach to process modelling, performance measurement, and performance comparison makes it valuable for companies aiming to improve the efficiency and effectiveness of their supply chains. However, overcoming integration challenges and exploring the structural relationships between processes can further optimize the application of this model (Kusrini & Miranda, 2021; Maas et al., 2023). Meanwhile, Failure Mode and Effect Analysis (FMEA) is an effective method for analyzing the severity, likelihood, and detectability of emerging risks (Zuniawan, 2020). The integration of SCOR and FMEA provides a comprehensive approach to risk mapping and mitigation, as it connects supply chain activities with the most critical risk priorities.

Although there has been much research on supply chain risk management, studies that specifically integrate the perspective of halal supply chain sustainability in ruminant feed commodities are still very limited. In fact, sustainability issues in ruminant farming are closely related to resource use efficiency, waste reduction, emission reduction, and improved welfare for local farmers. Thus, this study is expected to contribute academically and practically to enriching the literature on supply chain risk management, particularly in the halal and sustainable animal feed sector. Based on this description, this study aims to analyze risks in the ruminant animal feed supply chain from a halal supply chain sustainability perspective through the integration of the SCOR-FMEA method. The results of this study are expected to serve as a reference for strategic decision-making for stakeholders, including the feed industry, farmers, government, and halal certification agencies, in realizing a more resilient, competitive, sustainable, and sharia-compliant supply chain. Accordingly, this study aims to analyses and priorities risks in the ruminant feed supply chain from a sustainability and halal perspective using the integrated SCOR–FMEA method. The study seeks to generate practical risk maps and mitigation recommendations that are operational, replicable, and directly applicable to farmer communities, enabling them to improve feed quality, reduce losses, strengthen halal integrity, and enhance the resilience of community-based ruminant feed supply chains.

2. Method

2.1. State of The Art

The concept of sustainability in the halal supply chain (HSC) is multifaceted, encompassing economic, social, and environmental dimensions. In Indonesia's halal beef supply chain, cattle farmers bear the highest costs but earn lower profits than beef retailers, indicating economic inequality that affects sustainability. On the other hand, cattle farmers contribute significantly to job creation throughout the supply chain, highlighting the social impact of the halal supply chain (Mahbubi & Uchiyama, 2020). Cattle farms in the halal beef supply chain produce higher carbon emissions and use more fresh water, posing environmental challenges (Primadasa et al., 2025). This makes effective management of operational and logistics costs crucial for economic sustainability in the halal supply chain, especially for small and medium-sized enterprises (SMEs).

In ruminant commodities, halal food safety risk mapping shows critical points of vulnerability from upstream to downstream; the FMEA approach is commonly used to prioritize failure modes and corrective actions, while earlier exploratory studies mapped halal risk factors in Indonesian chicken meat. The principle of halal product assurance in Indonesia itself is standardized in Law No. 33/2014 (BPJPH), which requires process/material compliance throughout the supply chain. Specifically, the results of previous studies related to this study are presented in Table 1.

Table 1. Previous studies

Authors, Years	Context	Methods	Key Findings	Relevance to this Research
(Susanty et al., 2021)	Sustainability of Indonesia's beef supply chain	Sustainability status measurement & indicators	Sustainability status varies between nodes; targeted policy intervention based on measurable indicators is needed.	Reinforcing the importance of sustainability indicators in the ruminant sector as a basis for prioritizing upstream risks (feed) (Susanty et al., 2021)
(Mashur et al., 2022)	Feed bank for beef cattle (Indonesia)	MDS and development strategy analysis	Feed banks effectively mitigate feed shortages during the dry season; sustainability status can be mapped for policy recommendations.	Demonstrating that feed management is the key lever for ruminant supply chain resilience

Authors, Years	Context	Methods	Key Findings	Relevance to this Research
				(Mashur et al., 2022)
(Ahmad et al., 2026)	Indonesian halal chicken meat supply chain	Identification of critical halal points & design of mitigation strategies	Identifying critical points that could potentially compromise halal integrity from upstream to downstream and offering integrated mitigation strategies.	Providing an adaptable halal risk framework for ruminant feed processes (Ahmad et al., 2026)
(Hasibuan et al., 2021)	Ready-to-drink beverage industry	SCOR–FMEA Integration	Process mapping with SCOR and RPN-based risk prioritization guide operational mitigation actions.	Confirming the methodological suitability of SCOR–FMEA for agro-food; applicable to ruminant feed (Hasibuan et al., 2021)
(Hashimoto et al., 2025)	Tofu–tempeh agroindustry	SCOR for performance measurement	SCOR effectively maps processes and KPIs in the local food agroindustry.	Providing examples of SCOR-based operation mapping in food; a foundation for mapping feed processes (Hashimoto et al., 2025)
(Bosona & Gebresenbet, 2023)	Blockchain-based food traceability (international review)	Systematic review	Blockchain improves traceability, transparency, and efficiency in cross-commodity food supply chains.	Enabling transparency and halal/sustainability compliance in the feed process (Bosona & Gebresenbet, 2023)
(Sidarto & Hamka, 2021)	Halal poultry traceability case	Blockchain implementation in the poultry industry Blockchain implementation in the poultry industry	The blockchain system strengthens farm-to-fork transparency and halal data integrity.	Evidence of field practices in Indonesia; relevant for feed traceability and halal compliance (Sidarto & Hamka, 2021)
(Thanomsin et al., 2025)	Corn supply chain	FMEA in the feed supply chain	FMEA highlights key risks in corn supply and guides supply chain performance improvements.	Corn is the main component of the ration; the findings are directly relevant to ruminant feed
(Afsharnia & Rohani, 2025)	Halal Supply Chain Management (HSCM) improvements can align with global	Applied DEMATEL method with input from 25 industry experts to examine causal relationships among sustainability factors in HSCM.	Sustainable Procurement (SP) is the primary driving (causal) factor, influencing Green Logistics (GL), Halal Certification (HC), Supply Chain Transparency (SCT), and Waste Management (WM). Halal Certification &	Provides a direct framework for prioritizing interventions knowing which factors drive others helps in planning policy, managerial

Authors, Years	Context	Methods	Key Findings	Relevance to this Research
	sustainability/ SDGs		Supply Chain Transparency are highly dependent on SP and GL.	strategies in HSCM for sustainability.
(Deptuła et al., 2025)	Halal value chain competes globally, looks at elements that contribute to or hinder competitiveness in different segments of the chain (food, services, certification, logistics).	Qualitative/documentary analysis using secondary data, applies Porter's Value Chain framework and Porter's Diamond Model to identify drivers of competitiveness.	Global market for Halal products shows strong growth potential. The key competitiveness determinants are standardization/harmonization of certification; logistics and infrastructure; coordination along the value chain; improved access to finance for MSMEs; strong marketing/export networks. Barriers include inconsistent standards internationally; cost burdens for smaller players; weak value-chain linkages.	Useful for identifying competitiveness levers in the Halal value chain. The findings help define what factors firms or governments should target to improve global competitiveness.
(Shuhaimi et al., 2025)	Explores the development and global significance of Malaysia's halal food sector, highlighting persistent challenges that hinder competitiveness and growth.	Qualitative study based on literature review and secondary data. Content and thematic analyses were conducted to identify recurring issues and policy gaps in the halal food ecosystem.	Small and medium enterprises (SMEs) face high certification costs and bureaucratic complexity. Inconsistent domestic and international standards limit export potential. Food safety, traceability, and transparency remain weak due to limited technological adoption (e.g., Blockchain, IoT).	Highlights the importance of regulatory efficiency, technology integration, and consumer awareness in strengthening halal industry competitiveness

2.2. Design, Scope, and Analysis Units

This study uses an explanatory mixed-methods design with a case study on the ruminant feed supply chain (raw materials feed mills distributors farmer groups). The unit of analysis is the SCOR process (Plan, Source, Make/Transform, Deliver/Order-Fulfil, Return, Enable/Orchestrate) along with risk events in each process. Primary data: focus group discussions (FGD) with experts (feed mill managers, ingredient suppliers, cooperative/farmer group coordinators, and halal auditors) and FMEA questionnaires. Secondary data: Production SOPs and quality logs, halal/HACCP audit records, supply chain operational data (lead time, scrap/NC, complaints, delivery accuracy), and regulations/standards. Sampling: purposive sampling of 12 cross-cutting expert respondents.

2.3. Data Collection Techniques

Data collection was conducted through interviews and questionnaires. Interviews were conducted with various parties, including farmers, who are suppliers of animal feed raw materials, halal auditors, and village officials. As seen in Table 2 and Table 3, the questionnaire used in the study used a scale of 1-10.

Table 2. FMEA Scale for Occurrence and Detection

Occurrence (O)		Detection (D)	
Scale	**Description**	**Scale**	**Description**
1-2	Rare/Incidental	1-2	Very easy to detect
3-4	Sometimes	3-4	Easy to detect
5-6	Currently	5-6	Currently
7-8	Frequently	7-8	Difficult to detect
9-10	Very often	9-10	Almost undetectable

Table 3. FMEA scale for severity

Economic Impact (S_Ec)		Environmental Impact (S_En)		Socio-Halal Impact (S_SH)	
Skala	Description	Skala	Description	Skala	Description
1-2	Very small	1-2	Very small	1-2	Very small
3-4	Small	3-4	Small	3-4	Small
5-6	Significant	5-6	Significant	5-6	Significant
7-8	High	7-8	High	7-8	High
9-10	Very High	9-10	Very High	9-10	Very High

2.4. Data Processing Techniques

Severity (S) was constructed as a composite measure reflecting three equally important dimensions: economic impact (S_Ec), environmental impact (S_En), and socio halal impact (S_SH). As seen in Eq. (1) and Eq. (2), to ensure balanced representation of sustainability and halal considerations, equal weights were assigned to each dimension, such that $W\_Ec = W\_En = W\_SH = 1/3$. Accordingly, the composite severity score was calculated as:

Risk Priority Number (RPN):

$$RPN = S^* \times O \times D \quad (1)$$

With the S* value obtained from:

$$S = (1/3 \times S\_Ec) + (1/3 \times S\_En) + (1/3 \times S\_SH) \quad (2)$$

This weighting scheme reflects the conceptual assumption that economic performance, environmental impact, and halal integrity are equally critical in assessing risk severity within a sustainable halal feed supply chain. As seen in Table 4, RPN results are used for risk clustering, with the following conditions.

Table 4. Risk clusters

Cluster	RPN
Very low risk	1-250
Moderate risk	250-500
High risk	500-1000

Source: (Jafari et al., 2025)

3. Results and Discussion

Based on the data collection results, data related to actors in each process in the animal feed supply chain was obtained. As seen in Table 5, the actors for each process.

Table 5. Actors involved in the animal feed supply chain

Process SCOR	Actor
Plan	Farmer/Farmer Group
Source	Forage farmer
	Distributor of concentrates and vitamins
Production	feed mill operator
Distribution	Feed storage farmer
Return	Farmers, distributors

Next, risky activities were identified for each actor and their impact on the sustainability of the halal supply chain as follows Table 6.

Table 6. Risk activity in the animal feed supply chain

Actor	Risk Event	Economic	Environment	Socio- Halal	Code
Farmer/Farmer Group	Inaccurate ration forecasting	Overfeeding/underfeeding, inflated feed costs, decreased milk/body weight productivity	Feed wastage, increased organic waste	Supply instability, complaints from members/partners	R1

Actor	Risk Event	Economic	Environment	Socio- Halal	Code
	Not establishing buffer stocks/feed banks for the dry season	Stockouts, costly emergency purchases, inefficient material substitutions	Overcutting of vegetation, land pressure, additional transport emissions	Animal stress; declining group reputation	R2
	Improper silage/hay planning (high moisture content, incorrect harvest time)	Nutritional value decreases, scrap batches, production losses	Failed fermentation, leachate/odor; mycotoxin risk	Complaints about feed quality	R3
	Failure to verify the halal status of premixes/additives and suppliers	Replacement/withdrawal fees; operational disruptions	-	Halal non-conformity (SJPH), potential recall, audit findings	R4
	Weak traceability planning (lot & recording)	Difficult to isolate the problem, recall costs increase	Widespread recalls increase waste	Low transparency; consumer confidence declines	R5
Forage farmer	Improper harvesting (high moisture content/late)	Yield and nutritional value decrease; scrap/damage increases	Lindi/odor from failed fermentation	Risk of mold; recurring quality complaints	R6
	Inadequate drying/storage (poor circulation, damp piles)	Loss of quality, price drops; potential for local recalls	Organic waste & increased emission potential	Mycotoxins; non-compliance with hygiene/HACCP	R7
	Pesticide/herbicide residues above the limit	Batch rejected; testing & replacement costs	Soil/water pollution	Failed “tayyib” (feed safety); trust declined	R8
	Contamination by foreign objects/impurities (soil, plastic, metal; feces/urine)	Damage to equipment and livestock health, which increases costs	Inorganic waste is increasing	Violations of hygiene/halal standards; potential complaints	R9
	Traceability & labeling of weak forage	Difficult to isolate the problem, resulting in increased recall costs	Widespread recalls increase waste	Low transparency; halal audits at risk of findings	R10
Distributor of concentrates/vitamins	Unverified halal product/invalid COA	Rejection/return; customer downtime	-	Non-conformity halal (SJPH); potensi recall	R11
	Inappropriate warehouse/transport conditions (temperature/humidity, light)	Potency & stability decrease	Wasted energy	Potential early expiry; decreased credibility	R12
	Cross-contamination in warehouse (mixing non-halal/other chemicals)	Loss of value & disposal costs	Waste from contaminated products	Halal & hygiene violations; audit findings	R13
	Counterfeit/adulterated products	Financial losses; liability risk	Batch disposal increasing waste	Food safety & halal integrity threatened; loss of trust	R14
	Poor stock & FEFO management (insufficient buffer, expiry)	Stockouts/overstock; forced discounting	Waste from expired products	Poor customer service; weak traceability documentation	R15

Actor	Risk Event	Economic	Environment	Socio- Halal	Code
Feed-processing farmer	Formulation/dosing errors (uncalibrated scales, incorrect micro-dosing)	Worsened FCR, decreased milk/body-weight production, batch rework/scrap increasing costs	Feed wasted and energy used inefficiently	Noncompliance with ration specifications; potential member complaints	R16
	Cross-contamination & poor equipment hygiene	Batches rejected, cleaning downtime, loss of internal customer trust	Increased water/cleaning chemicals; more wash waste	Risk of halal noncompliance (impurity/cross-contact) and hygiene; audit findings	R17
	Finished product moisture out of spec (silage/pellets too wet; insufficient cooling/drying)	Nutritional value decreases	Organic waste & potential emissions/odour from failed fermentation	Does not meet 'thayyib' (safety) aspects; animal health impacted	R18
	Unstable process parameters (mixing time, pelleting temperature, particle size)	High quality variability; decreased livestock performance; quality claims	Excessive energy consumption; low efficiency	Inconsistent with COA; operational reliability questioned	R19
	Weak traceability & batch recording	Slow investigations; increased recall costs; lost production time	Widespread recalls increase waste	Low transparency; SJPH/halal & HACCP compliance at risk of failed verification	R20
Feed-storing farmer	Uncontrolled moisture & ventilation	Moldy feed and stock losses, decreased livestock performance	Increased organic waste; potential emissions/odour from spoilage	Mycotoxin risk, not 'thayyib'; complaints/audit findings	R21
	Pest attacks & physical contamination (rats, insects, sand/gravel)	Loss of quantity/quality; higher control costs	Increased pesticide use; residue risks	Impurity contamination (animal excreta) violating hygiene/halal	R22
	FIFO/FEFO failure & mislabelling	Expired/scrap products; recall and rework costs	Widespread recalls increase waste	Weak traceability; decreased partner trust	R23
	Poor packaging integrity (torn, water seepage, damaged pallets)	Loss of value; repacking costs; quality claims	Increased packaging waste; potential environmental contamination	Warehouse hygiene violations; cross-contamination risk	R24
	Weak segregation & housekeeping (mixed with non-halal/chemical)	Batch rejection; supply disruptions	Disposal of contaminated batches → increased waste	Halal non-conformity (SJPH/HACCP); potential recall and sanctions	R25
Farmer/Distributor	Delayed reporting of complaints/NC (kept in use until depleted)	Reduced milk/body-weight production; animal health costs	Spoiled feed increasing organic waste	Late traceability; continued risk of halal/food-safety non-conformity	R26
	Incomplete return documentation (lot/batch)	Investigations & recalls costly/time-consuming	Broader recalls increasing waste	Low transparency; audit findings	R27
	Weak backward traceability (supplier lots not linked)	High recall costs, slow response time	Expanded recalls increasing waste	Low accountability; risk of audit failure	R28

Actor	Risk Event	Economic	Environment	Socio- Halal	Code
	Undocumented evidence of destruction/rework	Potential sanctions/legal costs	Unrecorded waste and poor handling	Non-compliance with SJPH/HACCP; halal integrity risk	R29
	Improper temporary storage of returns (humid, open)	Product value further decreases; rework opportunities lost	Odour/leachate; pests	Not 'thayyib'; recurring complaints	R30

Based on these risky activities, a risk assessment was then conducted using the scale in Table 6. The results of the risk assessment and WRPN are as follows.

Table 7. Risk assessment of the animal feed supply chain

Process SCOR	Code	S_Ec	S_En	S_SH	S	O	D	RPN	Description
Plan	R1	7	4	4	5	7	7	245	Very low risk
	R2	8	6	5	6.33	7	6	265.86	Moderate risk
	R3	7	8	7	7.33	6	6	263.88	Moderate risk
	R4	6	2	9	5.67	4	8	181.44	Very low risk
	R5	7	6	7	6.67	6	7	280.14	Moderate risk
Source	R6	6	6	6	6	6	5	180	Very low risk
	R7	7	7	7	7	7	6	294	Moderate risk
	R8	8	8	8	8	4	8	256	Moderate risk
	R9	7	6	9	7.33	5	7	256.55	Moderate risk
	R10	6	5	7	6	6	7	252	Moderate risk
	R11	7	3	9	6.33	4	8	202.56	Very low risk
	R12	6	5	5	5.33	6	5	159.9	Very low risk
	R13	7	6	9	7.33	5	7	256.55	Moderate risk
	R14	9	6	9	8	3	9	216	Very low risk
	R15	7	6	5	6	6	6	216	Very low risk
Make	R16	8	5	6	6.33	6	6	227.88	Very low risk
	R17	7	5	9	6.33	5	7	221.55	Very low risk
	R18	7	7	8	7.33	6	6	263.88	Moderate risk
	R19	6	4	5	5	5	5	125	Very low risk
	R20	7	6	7	6.67	6	7	280.14	Moderate risk
Distribusi	R21	7	7	8	7.33	7	6	307.86	Moderate risk
	R22	6	6	8	6.67	6	6	240.12	Very low risk
	R23	6	6	6	6	5	7	210	Very low risk
	R24	5	5	6	5.33	5	5	133.25	Very low risk
	R25	7	6	9	7.33	5	7	256.55	Moderate risk
Return	R26	6	5	6	5.67	6	6	204.12	Very low risk
	R27	6	5	6	5.67	6	7	238.18	Very low risk
	R28	7	6	7	6.67	5	8	266.8	Moderate risk
	R29	7	5	8	6.66	4	8	213,12	Very low risk
	R30	6	6	6	6	6	6	216	Very low risk

Based on Table 7, it is known that there are two clusters of animal feed risks based on supply chain sustainability, namely very low risk and moderate risk. The risk assessment results show that there are two risks that cause a higher Risk Priority Number (RPN), namely risks related to moisture and weaknesses in tracking and documentation. Similar results have been shown in previous food and feed supply chain studies, where uncontrolled moisture content and tracking limitations were identified as sources of damage, mycotoxin contamination, and repeated and difficult-to-detect delayed corrective actions. This consistency indicates that moisture control and tracking represent structural vulnerabilities in community-based feed supply chains rather than context-specific issues.

The highest risk in the planning process is found in R5 (traceability planning). In the sourcing process, the highest risks are found in R9 (contamination by foreign objects/impurities) and R13 (cross-contamination in the warehouse). In the making process, the highest risk is found in R20 (weak traceability & batch recording). The highest risk in the distribution process is in R21 (uncontrolled moisture content & ventilation), and the return process has the highest risk in R28 (weak backwards traceability (supplier lots not connected). Overall, the highest risk is found in R21. From a sustainability perspective, the dominance of moisture- and traceability-related risks has direct implications for resource efficiency and waste generation. Moisture failures increase feed spoilage and organic waste, while weak traceability often expands recall scopes and leads to unnecessary disposal of feed batches. These effects not only increase operational costs but also undermine environmental performance and economic resilience at the farmer level, highlighting the importance of targeted risk mitigation for sustainable feed supply chains.

The risk profile of the ruminant feed supply chain indicates that the Risk Priority Number (RPN) is more strongly driven by the frequency of occurrence and the difficulty of early detection than by the severity of impacts alone. This pattern is particularly evident in risks related to moisture control and traceability. When warehouse humidity, material drying, or final product moisture are not properly maintained, disturbances occur relatively often, while early warning signs are difficult to capture before quality deterioration or safety issues arise. As a result, the values of O (occurrence) and especially D (detection) tend to remain at medium–high levels, elevating the RPN even though the aggregate severity (combined economic–environmental–halal impacts) is not always extreme.

Upstream, the quality of materials from suppliers is heavily influenced by rudimentary drying and storage practices. Excessive moisture, poor ventilation, or inconsistent sanitation increase the risk of fungal growth and physical contamination, leading to waste and higher organic residues. These problems cascade into midstream and downstream processes: mixing, pelleting, and cooling become unstable, and final storage at the farmer level is even more prone to quality degradation if ventilation, palletizing, and packaging integrity are poorly managed. In tropical climates and community-based facilities, the combination of “frequent events” and “difficult detection” in moisture-related issues almost always results in a surge of RPN.

Another prominent source of risk comes from traceability and documentation. The lack of standardized lot planning, inconsistent batch recording, and weak backward traceability during returns slow down the organization’s ability to isolate problems when deviations occur. Mathematically, this is reflected in high D scores because detection failures are only revealed after impacts materialize, driving RPN upward even if frequency is not as high as moisture-related risks. At the same time, the halal lens, particularly in premix/additives, segregation, and line clearance, shows that incomplete halal documentation or noncompliance with procedures often does not immediately appear in daily operations but can escalate during audits. This condition also maintains high D values. If halal penalties are explicitly applied in RPN calculations, such risks will naturally rise in priority ranking.

From a sustainability perspective, these findings are consistent with three critical impacts. Economically, stockouts, rework, recalls, and emergency shipments represent tangible cost leakages. Environmentally, feed spoilage and large-scale recalls contribute to organic waste and potential emissions from additional drying and transport processes. Socio-halal impacts include the integrity of processes, livestock health risks related to mycotoxins, and the trust of partners and consumers, all of which depend on robust documentation governance and hygiene practices. Since the severity score (S) is calculated as the average of three sub-severity measures (economic, environmental, halal), this approach maintains balance in evaluation, ensuring that risks with significant halal implications but moderate frequency remain visible rather than being overshadowed by purely economic metrics. In terms of halal governance, several risks show relatively high detection scores, indicating that halal non-conformities are often latent and only identified during audits or traceability investigations. By explicitly incorporating halal impact into the severity assessment, this study demonstrates that halal-related risks can significantly influence overall risk prioritization. This finding reinforces the need to strengthen halal governance through systematic document verification, segregation, and gatekeeping mechanisms integrated into daily operations, rather than treating halal compliance solely as an administrative requirement.

The managerial implications are immediate and can be implemented gradually. Strengthening quality gates at the raw material intake, setting commodity-specific moisture specifications, and conducting supplier drying audits will reduce the frequency of risk events. In processing and storage, monitoring humidity with hygrometers/data loggers, inspecting packaging integrity at intake, and enforcing ventilation and FEFO discipline will reduce undetected problems, thereby lowering D. In the realm of traceability, uniform lot codes from upstream to downstream and simple digital recording that links Certificates of Analysis (COA) and halal certificates to each lot movement will accelerate problem isolation when complaints or returns occur. These three levers, reducing O at the source, lowering D through monitoring and recordkeeping, and protecting halal integrity via document gatekeeping jointly suppress RPN for top-tier risks without requiring costly facility upgrades.

Finally, it must be acknowledged that the current scoring of O and D relies on expert judgment and thus retains some subjectivity. However, the structured data already established opens avenues for future improvement: moisture records and non-conformity histories can be used to calibrate O and D empirically, while risk prioritization can be refined through thresholding, quantile/Pareto analysis, or statistical clustering. Thus, the SCOR–FMEA framework enriched with a sustainability–halal lens not only provides a sharp risk portrait of current conditions but also establishes a replicable pathway for continuous improvement across other farmer clusters.

4. Conclusion

This study integrates the SCOR–FMEA framework with a sustainability halal perspective to analyses and priorities risks in a community-based ruminant feed supply chain. The main findings show that overall risk prioritization is driven more strongly by the frequency of occurrence and the difficulty of early detection than by severity alone. Two dominant risk patterns consistently emerge across SCOR processes: moisture-related failures (from upstream sourcing to final storage) and weaknesses in traceability and documentation. In addition, halal compliance risks particularly those related to verification of premix and additive documentation, segregation, and line clearance tend to exhibit high detection difficulty, indicating that non-conformities are often identified late in the process. From a theoretical perspective, this study contributes to the supply chain risk management and halal supply chain literature in two key ways. First, it extends the application of SCOR–FMEA by embedding sustainability and halal considerations directly into the severity dimension, rather than treating halal as a separate or purely compliance-based criterion. This integrated severity construct allows halal-related impacts to meaningfully influence risk prioritization alongside economic and environmental dimensions. Second, the study provides empirical evidence from a community-based feed supply chain context, which remains underrepresented in existing research that predominantly focuses on large-scale or industrial operations.

The practical implications of the findings are particularly relevant for farmer communities and small-scale feed operators. The results suggest that effective risk reduction can be achieved through pragmatic and low-cost interventions, such as defining commodity-specific moisture thresholds, strengthening drying and storage practices, improving intake inspection, and implementing simple lot-based traceability systems. Strengthening halal governance through systematic document verification and gatekeeping at critical control points can further reduce latent halal risks and enhance trust among stakeholders. Collectively, these measures support improved feed quality, reduced waste, better resource efficiency, and more resilient and halal-compliant supply chains at the community level. Despite these contributions, this study has several limitations. The assessment of occurrence and detection relies on expert judgement, which introduces a degree of subjectivity. In addition, the analysis is based on a single case study, which may limit the generalizability of the findings. Future research is therefore encouraged to incorporate data-driven calibration of risk parameters using sensor-based moisture monitoring, historical non-conformity records, or digital traceability data. Expanding the study to multiple regions or supply chain configurations, as well as integrating quantitative environmental assessment tools such as life cycle analysis, would further strengthen the robustness and applicability of the proposed framework.

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