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Supply Chain Risk Management In Palm Sugar Small And Medium Enterprises (Smes)

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Abstract

This study develops a supply chain risk management framework for the organic lontar palm sugar supply chain in Palmira Indonesia, Karangasem, Bali. The research is driven by critical operational instabilities, notably a 20% discrepancy between recorded and physical inventory and frequent production delays caused by inconsistent raw material supply. To address these challenges, the study employs an integrated methodology combining the Supply Chain Operations Reference (SCOR) model, Failure Mode and Effects Analysis (FMEA), and the House of Risk (HOR) framework. The supply chain was systematically mapped across five core processes: Plan, Source, Make, Deliver, and Return, identifying a total of 55 risk events and 60 potential risk agents. The results of HOR Phase I analysis indicate that risk exposure is highly concentrated; Pareto analysis reveals that 13 priority risk agents, representing only 21.6% of the total identified agents, account for 80.04% of the total Aggregate Risk Potential (ARP). The most critical agents identified include raw material scarcity (ARP = 2032), weak implementation of standard operating procedures (ARP = 1876), machinery and equipment failure (ARP = 1508), and limited technical capability of suppliers (ARP = 1440). In HOR Phase II, 17 targeted mitigation actions were formulated and prioritized based on their Effectiveness-to-Difficulty (ETD) ratios. The analysis identifies the establishment of periodic evaluation schedules (ETD = 9595) and the standardization of

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SOPs across all workstations (ETD = 8639) as the most impactful strategies for operational stabilization. These findings provide a structured diagnostic and a practical roadmap for small-scale agro-industrial systems to minimize disruption-driven waste, enhance product conformity, and improve the overall reliability of value-added organic supply chains.

Keywords: supply chain; risk management; palm sugar; SCOR; FMEA; House of Risk.

INTRODUCTION

Supply chain risk management in small agro-industrial systems depends not only on process efficiency inside the processing unit but also on the reliability of the supply chain that feeds, coordinates, and distributes production. Karangasem Regency is one of the principal lontar-growing areas in Bali, and Subdistrict Kubu, particularly Tianyar Village, constitutes an important production base for lontar-derived products. In this setting, lontar sap is transformed into molded palm sugar and further processed into crystalline organic palm sugar, creating value-added opportunities for farmers, processors, and downstream traders. However, the continuity of production remains vulnerable to material shortages, operational inconsistency, and coordination problems that can increase waste, rework, and service failure.

The production of organic lontar palm sugar is not a stand-alone activity. It depends on the synchronized interaction of upstream suppliers, processing units, logistics arrangements, and final distribution channels. Material, information, and financial flows must align if production is to be timely, quality-consistent, and commercially viable. In practice, however, preliminary field observations indicate recurring mismatches between recorded inventories and actual stock, delayed production due to insufficient raw materials, inconsistent process execution, and weaknesses in quality control. These symptoms suggest that the problem is not limited to a single operational bottleneck but is embedded in the structure of the supply chain itself.

This vulnerability is consistent with broader evidence from agro-food and biomass-related supply chains. Risk assessment has become increasingly important in agro-food systems because these chains operate under complexity, uncertainty, and interdependence across production, distribution, and consumption stages (Paillin et al., 2024). Reviews of biomass and biofuel supply chains likewise identify uncertainty, risk,

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and resilience as central concerns in network design and management (Gital & Bilgen, 2024; Habibi et al., 2023). In practical terms, agro-industrial systems that depend on variable biological inputs cannot be managed solely through production planning; they require explicit risk management mechanisms.

The problem is especially acute in small and medium agro-industrial enterprises. Compared with larger industrial organizations, such firms often face thinner inventories, weaker monitoring systems, less formalized procedures, narrower supplier bases, and more limited managerial slack. In supply chains of this type, even modest disturbances may propagate quickly from upstream sourcing to internal operations and then to delivery performance. Several recent case studies in Indonesian agro-food systems support this point. Empirical studies indicate that raw material constraints and labor-related disruptions frequently emerge as dominant sources of risk in agro-food systems (Citraresmi & Rahmawati, 2020; Dzulfikri et al., 2024). In addition, process inconsistency and weak quality control have been identified as critical contributors to operational inefficiency and product non-conformity (Kristanto & Kurniawati, 2023; Marlina & Hadiguna, 2023). These findings suggest that risk in small agro-industrial systems is not isolated, but distributed across multiple stages of the supply chain.

In the case of organic lontar palm sugar, the vulnerability is intensified by the natural variability of feedstock supply. Sap-based production systems are inherently exposed to environmental fluctuation, harvesting uncertainty, and limitations in supplier capability. Beyond that, internal operations may still be weakened by human error, irregular standard operating procedure (SOP) implementation, fragile machinery reliability, and incomplete inventory control. Such conditions reduce operational efficiency, raise the likelihood of quality deviations, and ultimately threaten business continuity.

Although supply chain risk management is a mature field, the applied literature shows that many studies still rely on relatively fragmented methodological designs. Paillin et al. (2024) found that semi-quantitative approaches dominate agro-food supply chain risk assessment and spans a diverse methodological landscape, indicating that no single approach has become standard across contexts. More importantly, some studies emphasize identification and assessment without carrying the analysis forward into a structured mitigation design, while others propose mitigation options without clearly linking them to the hierarchical structure of process-level risks.

This gap has been identified explicitly in recent work on sustainable supply chains. Akhmad et al. (2026) argue that many previous studies discuss risk assessment

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and mitigation separately, thereby weakening the ability to develop structured mitigation priorities. A similar insight appears in food supply chain studies that integrate SCOR mapping with risk prioritization and mitigation design, where the strength of the framework lies in connecting supply chain activities, risk events, risk agents, and preventive actions into one coherent decision structure (Ahmad & Susanty, 2019; Keumalasari et al., 2025; Utama et al., 2025).

Existing studies are also uneven in terms of sectoral focus. Previous studies have applied integrated risk management approaches, including SCOR–HOR frameworks, across a range of sectors. Applications have been reported in construction procurement and agro-food contexts (Ahmad & Susanty, 2019; Citraresmi & Rahmawati, 2020). Similar approaches are also used in small-scale food processing industries (Dzulfikri et al., 2024; Kristanto & Kurniawati, 2023). More recent studies extend these frameworks to other resource-based supply chains, such as patchouli and aquaculture systems (Keumalasari et al., 2025; Thuy et al., 2023). However, organic lontar palm sugar has not yet been analyzed through a similarly integrated framework, even though it exhibits many of the same structural features that make agro-food supply chains risk-prone: raw material perishability or variability, dispersed upstream actors, process dependence on manual routines, and quality-sensitive outputs.

A second gap concerns the translation of risk diagnosis into actionable priorities for small agro-industrial firms. Studies using HOR frequently show that a relatively small number of risk agents account for a large share of total exposure, thereby justifying targeted mitigation rather than diffuse intervention (Ahmad & Susanty, 2019; Marlina & Hadiguna, 2023; Thuy et al., 2023). Yet the value of that logic depends on connecting prioritized risk agents to realistic interventions that fit the resource constraints of the focal organization. In the lontar palm sugar context, such interventions must be feasible for small-scale operations and compatible with supplier conditions, not merely conceptually sound.

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Objectives

Against this background, the objectives of this study are threefold: (1) to identify risk events and risk agents across the organic lontar palm sugar supply chain; (2) to prioritize dominant sources of risk by integrating severity, occurrence, and event–agent relationships; and (3) to formulate mitigation strategies that are both operationally relevant and practically implementable.

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The contribution of the study is methodological and substantive. Methodologically, it develops an integrated SCOR–FMEA–HOR workflow that links process mapping, risk identification, prioritization, and mitigation design in a single sequence. This is consistent with recent arguments that effective supply chain risk management benefits from frameworks that connect assessment and mitigation rather than treating them separately (Akhmad et al., 2026). Substantively, the study extends the application of structured risk-mitigation design to the organic lontar palm sugar supply chain, a context that is economically relevant for rural agro-industry yet underrepresented in the risk-management literature.

RESEARCH METHODS

This study employed a descriptive-quantitative design supported by methodological triangulation. The empirical basis consisted of direct observation, in-depth interviews, documentary examination, and risk-scoring questionnaires administered to supply chain actors involved in the organic lontar palm sugar business. The purpose of the design was not to estimate causal effects econometrically, but to diagnose the structure of supply chain risk, prioritize dominant risk agents, and formulate targeted mitigation options.

A descriptive-quantitative orientation is appropriate for this context for two reasons. First, agro-food supply chain risk research often relies on semi-quantitative approaches because the managerial need is to structure uncertainty and support decisions even where full statistical data are limited (Paillin et al., 2024). Second, integrated applied frameworks such as SCOR combined with HOR or FMEA are frequently designed to support operational prioritization rather than hypothesis testing (Ahmad & Susanty, 2019; Keumalasari et al., 2025; Kristanto & Kurniawati, 2023).

Analytical Framework

The analytical framework consisted of six stages: SCOR mapping, FMEA-based identification of risk events, occurrence and correlation scoring, HOR phase I prioritization, Pareto selection, and HOR phase II mitigation design. The overall flow of the analysis was as follows:

Input data and field evidence → SCOR process mapping → FMEA-based risk event identification and severity scoring → occurrence and correlation scoring → HOR phase I and ARP calculation → Pareto-based selection of priority agents → HOR phase II and mitigation prioritization.

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Table 1. Integrated analytical flow

Stage	Method	Main output
1	SCOR	Process map across Plan–Source–Make–Deliver–Return
2	FMEA	List of risk events and severity scores
3	Risk scoring	Occurrence scores and event–agent relationship matrix
4	HOR phase I	Aggregate Risk Potential (ARP) and rank of risk agents
5	Pareto selection	Priority risk agents accounting for dominant exposure
6	HOR phase II	Mitigation actions and effectiveness-to-difficulty priorities

SCOR-based supply chain mapping

The use of SCOR to structure supply chain processes is well established in applied research. It has been used to map activities and identify potential risk exposure in both industrial and agro-food contexts (Ahmad & Susanty, 2019; Nguyen et al., 2018). In more recent studies, SCOR has been combined with risk prioritization approaches to support decision-making in sustainability-oriented and small-scale supply chains (Keumalasari et al., 2025; Thuy et al., 2023).

In the present study, SCOR served two purposes. First, it clarified which actors and activities constituted the focal chain. Second, it ensured that risk identification did not remain generic but was tied to concrete process stages. This is important because mitigation strategies should correspond to where disruption emerges, not merely to its downstream symptoms.

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FMEA-based identification of risk events

After the process map was established, potential failures or disruptions at each stage were identified using the logic of FMEA. FMEA was used to define risk events that is, observable disruptions or failure modes that could affect continuity, quality, timing, or coordination. Each risk event was then assigned a severity score reflecting the seriousness of its consequences for the chain.

This use of FMEA is consistent with previous studies in which severity scoring helps convert qualitative operational problems into structured risk profiles that can later be combined with HOR-based prioritization (Keumalasari et al., 2025; Lintang Trenggonowati et al., 2020). In the context of organic lontar palm sugar, the identified risk events covered stock inaccuracy, delayed or insufficient raw material supply, poor raw material quality, machine disruption, human error in production, quality non-conformity, delivery disturbance, and return-related issues.

Risk agents, occurrence, and correlation

Risk events describe what can go wrong, but mitigation requires identifying why those disruptions arise. Accordingly, the study identified risk agents as the causal factors or sources that trigger one or more risk events. Each risk agent was assigned an occurrence score representing the likelihood of its appearance.

The next step was to assess the relationship between each risk event and each risk agent. This produced the correlation matrix required for HOR phase I. Through this step, the study was able to capture the fact that one risk agent may trigger multiple risk events and that some agents therefore have wider systemic influence than others. This multi-event logic is one reason why HOR is useful for supply chain settings characterized by interdependence (Nguyen et al., 2018; Sukwadi & Caesar, 2022)

House of Risk phase I

HOR phase I was used to prioritize risk agents by calculating Aggregate Risk Potential (ARP). The logic of ARP is to combine the occurrence of each risk agent with the severity of the events it influences and the strength of the relationship between them. This allows a more structured prioritization than looking only at event severity or agent frequency separately.

The calculation followed the standard expression:

$$ARP_j = O_j \sum (S_i \times R_{ij})$$

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where ARP_j is the aggregate risk potential of agent j, O_j is its occurrence score, S_i is the severity of event i, and R_{ij} is the relationship score between event i and agent j. This formulation is widely used in HOR-based risk assessment and supports the ranking of agents whose mitigation is likely to generate the greatest reduction in total exposure (Ahmad & Susanty, 2019; Citraresmi & Rahmawati, 2020; Marlina & Hadiguna, 2023).

Pareto selection

After ranking the agents by ARP, the study used a Pareto logic to select the relatively small subset of agents responsible for the dominant share of risk exposure. This step is important because small agro-industrial enterprises usually face tight resource constraints and cannot address all possible risk sources simultaneously. Prior research using HOR has similarly applied Pareto-style selection to focus managerial attention on the most consequential agents (Ahmad & Susanty, 2019; Dzulfikri et al., 2024; Thuy et al., 2023).

House of Risk phase II

HOR phase II was then used to formulate and prioritize preventive actions for the priority agents. Each potential mitigation action was assessed through two dimensions: total effectiveness in controlling the selected risk agents and difficulty of implementation. The effectiveness of an action was obtained by considering how strongly the action could address high-priority agents.

The equations used were:

$$TE_k = \sum ARP_j \times E_{jk}$$

$$ETD_k = \frac{TE_k}{D_k}$$

where TE_k is total effectiveness, E_{jk} represents the relationship between risk agent j and mitigation action k, and D_k denotes the implementation difficulty of the mitigation action. The ratio ETD_k therefore indicates which actions provide the best balance between expected impact and implementation burden. This effectiveness to difficulty logic is central to HOR phase II and is designed to support pragmatic managerial prioritization (Kasemset et al., 2014; Utama et al., 2025).

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RESULTS

The supply chain map shows that the organic lontar palm sugar system consists of three main groups of actors: upstream suppliers, the focal processing unit, and downstream distribution actors. Upstream suppliers produce the main raw material derived from lontar sap, commonly in the form of molded palm sugar or related intermediate input. The focal processing unit then converts this input into crystalline organic palm sugar. The final product is distributed either directly to consumers or through intermediary retail channels.

Beyond physical product movement, two other flows are central to the functioning of the chain. The first is the information flow, which includes demand communication, production requirements, delivery schedules, and price-related information. The second is the financial flow, which moves in the opposite direction from downstream to upstream. The quality of coordination across these three flows strongly influences the continuity and reliability of the system.

Using SCOR, the chain can be described as follows: (1) Plan includes demand estimation, production planning, material requirement planning, and delivery scheduling. This stage is strategically important because errors at the planning stage generate downstream consequences in sourcing, production, and distribution; (2) Source covers supplier selection, raw material scheduling, inbound receipt, incoming quality inspection, supplier performance evaluation, and procurement arrangements. This stage is critical because it directly influences both material availability and raw material quality; (3) Make includes production scheduling, processing operations, and quality inspection of the product. This is the operational core of the chain and the stage at which product quality is materially determined; (4) Deliver comprises warehouse handling, packaging and dispatch, delivery method selection, physical distribution, and billing. This stage affects timeliness, product condition upon arrival, and customer satisfaction; and (5) Return includes handling of non-conforming raw materials from suppliers and customer returns or complaints related to product defects or mismatches.

Taken together, the SCOR map confirms that the chain is relatively compact in actor structure but still highly exposed to process-level disruption. Each SCOR stage has its own risk profile, and the interdependence among stages means that upstream problems can easily propagate into internal operations and downstream service.

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Risk identification and classification

The FMEA-based identification process showed that risk events are distributed across all five SCOR stages. Although the specific manifestations differ by activity, the events can be grouped into several major categories: raw material risk, operational risk, quality risk, distribution risk, and managerial/coordination risk.

Raw material risk includes scarcity of supply, variability in input quality, and irregular delivery schedules. These risks are particularly important in biologically based supply chains, where feedstock availability is affected by conditions beyond direct managerial control. Reviews of biomass supply chain uncertainty similarly emphasize supply variability and disruption exposure as central challenges for planning and resilience (Gital & Bilgen, 2024; Habibi et al., 2023).

Operational risk includes machinery breakdown, poor process discipline, labor error, and incomplete adherence to SOPs. These risks are internal to the processing unit but interact strongly with upstream and downstream pressures. Similar operational concerns are reported in shallot SMEs, soy sauce production, and other food-oriented supply chains, where labor negligence, process inconsistency, and equipment issues feature prominently in risk profiles (Citraresmi & Rahmawati, 2020; Dzulfikri et al., 2024; Marlina & Hadiguna, 2023).

Quality risk includes contamination, deviation from expected product standards, and quality inconsistency caused by either poor raw material quality or process failure. In a value-added food product, such risk has immediate commercial implications because quality nonconformity undermines market acceptance and customer trust.

Distribution risk includes delivery delay, transport-related damage, and warehousing or dispatch errors. While these risks occur closer to the customer end of the chain, they are often amplified by earlier failures in planning or production.

Managerial and coordination risk includes weak supplier capability, incomplete communication, stock-record mismatch, and insufficient information integration. These risks are particularly significant in small agro-industrial systems because formalized management systems are often limited. Studies in patchouli, frozen food, and integrated food supply chains similarly highlight coordination and governance weaknesses as recurring risk sources (Keumalasari et al., 2025; Kristanto & Kurniawati, 2023)).

The classification indicates that the organic lontar palm sugar chain is exposed not to isolated technical failures, but to a multi-source risk environment. The same conclusion is evident in broader agro-food risk reviews, which classify supply chain risks

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into internal, external, and macro-level categories and emphasize their interconnected nature (Paillin et al., 2024).

Prioritized risk agents in HOR phase I

The HOR phase I analysis revealed that the distribution of risk is highly concentrated. Not all agents contribute equally to total exposure; rather, a limited subset accounts for the largest aggregate risk potential. This pattern is consistent with the logic found in other HOR-based studies, where a small number of agents often dominate the ARP distribution and therefore warrant immediate managerial attention (Ahmad & Susanty, 2019; Marlina & Hadiguna, 2023; Thuy et al., 2023). The House of Risk (HOR) Phase I was applied to determine the priority level of risk agents based on their Aggregate Risk Priority (ARP) values. This approach enables the identification of the most critical sources of risk that significantly affect supply chain performance. The ranking of risk agents based on ARP values is presented in Table 2.

Table 2. Ranking of Risk Agent

Code	ARP	%	Kum. %	rank
A6	2032	10,03%	10,03%	1
A23	1876	9,26%	19,29%	2
A21	1508	7,44%	26,74%	3
A18	1440	7,11%	33,85%	4
A8	1341	6,62%	40,47%	5
A4	1330	6,57%	47,03%	6
A16	1232	6,08%	53,12%	7
A20	1224	6,04%	59,16%	8
A13	1104	5,45%	64,61%	9
A3	906	4,47%	69,08%	10
A12	812	4,01%	73,09%	11
A39	760	3,75%	76,84%	12
A43	648	3,20%	80,04%	13

The results indicate that several risk agents have significantly higher ARP values, suggesting their dominant contribution to overall supply chain risk. In particular, the top-ranked risk agents represent the most critical sources that require immediate attention.

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To further identify the most influential risk agents, a Pareto analysis was conducted based on the cumulative percentage of ARP values. Pareto diagram of HOR I presented in Figure 1.

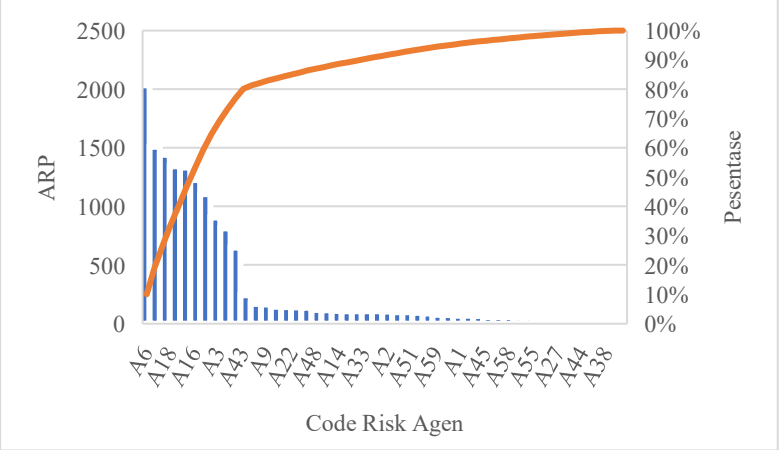


Figure 1. Pareto Diagram HOR I

The analysis shows that approximately 80% of the total risk is contributed by the top-ranked risk agents. Based on this result, 13 risk agents were selected as priority risks, as they account for 80.04% of the cumulative ARP value. These priority risk agents represent the most critical sources of disruption across the supply chain, affecting production, coordination, and financial stability. Based on Pareto analysis, 13 risk agents were selected as priority are presented in Table 3.

Table 3. Risk agent priority

Rank	Code	Risk agent
1	A6	Raw material scarcity
2	A23	Weak implementation of SOPs
3	A21	Disruptions or failures in machinery and equipment
4	A18	Suppliers lack financial management and communication technology capability
5	A8	Delayed client payments and outstanding debts
6	A4	Human error
7	A16	Insufficient monitoring and evaluation

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8	A20	Inadequate quality inspection
9	A13	Suppliers set high prices without proper cost calculation and pricing planning
10	A3	Errors in information and communication
11	A12	Suppliers set prices without market validation
12	A39	Lack of regular inspection
13	A43	Unsafe handling and placement of goods by logistics providers

The priority risk structure indicates that supply chain vulnerability is shaped by a combination of upstream supply constraints, internal operational weaknesses, and coordination inefficiencies. Raw material scarcity emerges as the most critical risk, directly threatening production continuity and demand fulfillment, particularly in biologically dependent systems. This is reinforced by weak SOP implementation, human error, inadequate quality control, and lack of regular inspection, all of which reflect insufficient process discipline and increase the likelihood of inconsistent outputs and undetected defects. Operational reliability is further challenged by machinery breakdown and limited managerial capability of suppliers, indicating that both technical and managerial capacities are still fragile. Financial instability, reflected in cash-flow constraints, constrains the ability to maintain operations and respond to disruptions. On the coordination side, ineffective information flow and communication errors contribute to misalignment across actors, while insufficient monitoring and evaluation practices reduce the system's ability to detect and respond to risks early. Additionally, pricing-related issues such as suppliers setting high prices without systematic cost calculation and the lack of market validation introduce inefficiencies and reduce planning accuracy. Finally, improper handling and unsafe placement of goods during transportation highlight logistical vulnerabilities that can directly degrade product quality. Overall, these risks are interconnected, indicating that improving supply chain resilience requires integrated strengthening of supply stability, operational discipline, financial capacity, and coordination mechanisms. These results indicate that supply chain risk is not driven by a single dominant factor, but by the interaction between supply instability, internal process weaknesses, and coordination inefficiencies. Table 4 summarizes the priority agents and their principal implications.

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Table 4. Priority risk agents and principal supply chain implications

Priority risk agent	Main SCOR locus	Principal implication
Raw material scarcity	Source / Plan	Production interruption and unmet demand
Weak implementation of SOPs	Make / Plan	Process inconsistency and quality deviation
Disruptions or failures in machinery and equipment	Make	Output stoppage and production delay
Suppliers lack financial management and communication technology capability	Source	Inconsistent quality, timing, and coordination
Delayed client payments and outstanding debts	Plan / Source / Make	Reduced operational flexibility and delayed response
Human error	Make	Process variability, rework, and reduced operational efficiency
Insufficient monitoring and evaluation	Plan / Make	Late detection of deviations and increased risk escalation
Inadequate quality inspection	Make	Defects passing downstream and compromised product quality
Suppliers set high prices without proper cost calculation and pricing planning	Source / Plan	Cost instability and reduced procurement efficiency

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Errors in information and communication	Plan / Source / Make	Decision errors, misalignment, and coordination inefficiency
Suppliers set prices without market validation	Source	Uncompetitive pricing and inefficient cost structure
Lack of regular inspection	Make	Inconsistent process control and increased quality risk
Unsafe handling and placement of goods by logistics providers	Deliver	Product damage and loss during transportation

The concentration of risk on a limited number of dominant agents observed in this study is consistent with patterns reported in agro-food supply chains. In particular, raw material constraints and supplier-related issues are frequently identified as major contributors to overall risk exposure (Citraresmi & Rahmawati, 2020; Dzulfikri et al., 2024). Comparable patterns are also evident in fisheries and aquaculture systems, where interdependent risk structures tend to amplify the influence of key agents (Nguyen et al., 2018; Thuy et al., 2023). The implication is that the chain's vulnerability is rooted primarily in upstream stability and internal operational control.

Mitigation strategies in HOR phase II

HOR phase II translated the priority agents into a set of preventive actions. Because the chain operates under SME-type resource constraints, the main criterion was not technical desirability alone, but the balance between expected effectiveness and implementation difficulty. Based on the priority risk agents identified in the House of Risk (HOR) Phase I, mitigation strategies were developed using the HOR Phase II approach to determine the most effective actions for reducing supply chain risk. This approach ensures that mitigation efforts are focused on actions that provide the greatest impact with relatively manageable implementation effort. Based on the 13 prioritized risk agents, 17 mitigation actions were developed through interviews with expert respondents, taking into account the costs and resources required for their implementation. These seventeen mitigation actions are presented in Table 5.

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Table 5. Mitigation risk

No	Mitigation action	Code	D
1	Establish buffer stock	M1	3
2	Improve productivity and increase the population of lontar sap plants	M2	5
3	Ensure sufficient availability of machinery and equipment spare parts	M3	3
4	Collaborate with relevant stakeholders to conduct outreach and training programs	M4	5
5	Conduct regular training for workers	M5	5
6	Align employee capabilities with assigned job roles	M6	5
7	Develop and display SOPs for each task and machine in the work area	M7	3
8	Implement a reward and punishment system and prioritize key clients	M8	4
9	Establish a fixed schedule for periodic evaluation	M9	3
10	Develop formal and professional work contracts	M10	3
11	Establish quality standards aligned with the company's acceptable price level	M11	4
12	Form a Quality Control (QC) team	M12	4
13	Obtain real-time market price information through farmer group social media communication	M13	3
14	Establish a periodic maintenance management schedule	M14	3
15	Engage external auditors to assess the company's financial and operational health	M15	5
16	Package products using protective materials	M16	3
17	Provide dedicated in-house delivery personnel	M17	4

Note: D = Difficulty score (1 = very easy, 5 = very difficult)

The results indicate that mitigation actions with higher effectiveness-to-difficulty (ETD) values should be prioritized, as they provide greater impact in reducing risk with relatively lower implementation effort. This prioritization demonstrates that not all mitigation strategies contribute equally to risk reduction, and actions that combine high

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effectiveness with manageable implementation difficulty offer the most efficient approach to improving supply chain resilience. These findings highlight the importance of focusing resources on targeted mitigation efforts rather than applying broad, non-specific strategies, while also providing a structured and prioritized approach to addressing the most critical risk agents identified in the supply chain. The prioritized mitigation actions, along with their effectiveness (TE), difficulty (D), and effectiveness-to-difficulty ratio (ETD), are presented in Table 6.

Table 6. Prioritized mitigation actions

Rank	Code	Mitigation	ETD
1	M9	Establish a fixed schedule for periodic evaluation	9595
2	M7	Develop and display SOPs for each task and machine in the work area	8639
3	M5	Conduct regular training for workers	7089
4	M1	Establish buffer stock	6096
5	M13	Obtain real-time market price information through farmer group social media communication	4956
6	M3	Ensure sufficient availability of machinery and equipment spare parts	4380
7	M10	Develop formal and professional work contracts	3990
8	M2	Improve productivity and increase the population of lontar sap plants	3658
9	M12	Form a Quality Control (QC) team	3523
10	M8	Implement a reward and punishment system and prioritize key clients	2993
11	M4	Collaborate with relevant stakeholders to conduct outreach programs	1837
12	M11	Establish quality standards aligned with the company's acceptable price level for suppliers	1827
13	M15	Engage external auditors to assess the company's operational and financial condition	1636
14	M17	Provide dedicated in-house delivery personnel	1458
15	M6	Align employee capabilities with assigned job roles	1383

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16	M14	Establish a periodic maintenance management schedule	1326
17	M16	Package products using primary and secondary protective packaging	648

The results indicate that mitigation actions with higher effectiveness-to-difficulty (ETD) values should be prioritized, as they provide greater impact in reducing supply chain risk with relatively lower implementation effort. The ranking shows that actions related to monitoring, standardization, and workforce capability, such as periodic evaluation scheduling, SOP implementation, and regular training, dominate the top positions. This suggests that strengthening internal process control is more critical than relying solely on external interventions. Additionally, supply-related actions such as buffer stock and real-time market information remain important, indicating that both upstream stability and internal operational discipline must be addressed simultaneously. Overall, the findings demonstrate that targeted and prioritized mitigation strategies are more effective than broad, non-specific approaches. The analysis generated four broad clusters of mitigation.

First, supply stabilization measures were prioritized to address raw material scarcity and supplier-related weakness. These measures include buffer stock arrangements, closer coordination with suppliers, more structured delivery scheduling, and stronger long-term supplier relationships. Comparable studies in agro-food supply chains also identify supplier partnerships, collaboration, and more systematic recording of material needs as highly relevant preventive actions (Akhmad et al., 2026; Dzulfikri et al., 2024).

Second, operational control measures were prioritized to reduce internal process inconsistency. These include strengthening SOP implementation, improving work discipline, routine supervision, and practical training for workers. Studies on halal food, patchouli, and other food chains similarly emphasize training, better operational standards, and disciplined implementation as key risk-reduction levers (Keumalasari et al., 2025; Kristanto & Kurniawati, 2023).

Third, equipment reliability measures were prioritized in response to machine-related risk. Preventive maintenance, scheduled checking, and faster response to machine abnormalities are central to reducing production interruption. The importance of such measures is consistent with applied risk-management studies in agro-industry

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and manufacturing contexts that treat process reliability as a major determinant of risk exposure (Asrol et al., 2024; Sukwadi & Caesar, 2022).

Fourth, information and coordination measures were prioritized to improve stock visibility, planning accuracy, and communication across actors. These measures include more disciplined inventory recording, better synchronization between planning and actual stock, and clearer communication with suppliers and distribution partners. In food security procurement and broader food supply chain settings, better information visibility and monitoring have likewise been treated as central elements of risk control (Alfazah et al., 2020). Table 3 synthesizes the prioritized mitigation package.

Table 7. Prioritized mitigation package

Mitigation focus	Main preventive actions	Primary risk agents addressed
Supply stabilization	Buffer stock, structured delivery scheduling, stronger supplier coordination and longer-term supplier relationships	Raw material scarcity; limited supplier managerial capability
Operational discipline	SOP reinforcement, worker training, routine supervision, clearer work instructions	Weak SOP implementation
Equipment reliability	Preventive maintenance, scheduled machine checks, rapid response to abnormalities	Machinery breakdown
Financial and information control	Better inventory recording, tighter stock monitoring, improved cash-flow planning and communication across actors	Cash-flow constraints; stock mismatch; planning inconsistency

Taken together, the mitigation results indicate that resilience in the organic lontar palm sugar chain cannot be built through one type of intervention alone. Technical, managerial, and relational actions must be combined. This pattern is consistent with

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recent integrated frameworks that link structured prioritization with coordinated mitigation rather than isolated corrective actions (Akhmad et al., 2026; Utama et al., 2025).

DISCUSSION

The results suggest that the organic lontar palm sugar supply chain is vulnerable because risk is both process-distributed and causally concentrated. Risk events arise in planning, sourcing, production, delivery, and return, yet a comparatively small set of agents appears to account for a substantial share of the chain's exposure. This pattern should be read as a structured semi-quantitative diagnosis rather than as a fully validated dynamic model of system behavior.

Within that diagnostic frame, upstream instability and internal process discipline emerge as the two most influential vulnerability clusters. Raw material scarcity and supplier capability represent the upstream side, while weak SOP implementation and machinery breakdown represent the internal operational side. Cash-flow constraints connect the two by limiting the firm's ability to buffer, coordinate, or respond quickly to disruption.

This interpretation aligns with the broader literature on agro-food supply chain risk, particularly in emphasizing the role of supply uncertainty and coordination complexity in shaping system resilience (Gital & Bilgen, 2024; Habibi et al., 2023; Paillin et al., 2024). Building on this perspective, the findings suggest that supply chain risk in small agro-industrial systems is not driven by isolated factors, but by the interaction between upstream uncertainty and internal operational capacity. Upstream instability particularly raw material variability has been consistently identified as a primary source of disruption in agro-food supply chains (Citraresmi & Rahmawati, 2020; Dzulfikri et al., 2024). At the same time, internal process weaknesses, including inconsistent implementation of standard operating procedures, increase the likelihood of inefficiency and quality deviation (Keumalasari et al., 2025; Marlina & Hadiguna, 2023). This interaction implies that disruptions originating from supply variability are more likely to propagate in systems with limited process discipline.

For the lontar palm sugar context, the analysis indicates that the most damaging disruptions are not attributable solely to supply variability or solely to internal inefficiency. Rather, supply uncertainty enters a system whose process discipline and managerial controls have limited absorptive capacity. In supply chain risk management terms, this means that disruption prevention is closely tied to loss prevention: irregular supply and

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weak routines jointly increase the probability of downtime, quality deviation, rework, and avoidable material loss.

Why integration matters

The combined use of SCOR, FMEA, and HOR is analytically useful because each method addresses a different problem. SCOR clarifies where activities are located in the chain, FMEA identifies what can go wrong and how serious the consequences may be, and HOR helps rank which causal agents and preventive actions deserve earlier managerial attention. The value claimed here is therefore practical and diagnostic, not comparative proof that the integrated framework outperforms every alternative design.

This integration is especially useful in small agro-industrial systems where the managerial challenge is not only to detect risk but also to move from diagnosis to action under tight resource constraints. In such settings, an ordered mitigation package can be more valuable than a highly sophisticated but operationally inaccessible model.

The results also support the practical relevance of integrated approaches already observed in other Indonesian food supply chain studies. Utama et al. (2025) show that identifying risks, weighting them, and designing mitigation in one framework improves the effectiveness of halal supply chain risk management. Asrol et al. (2024) similarly demonstrate that risk assessment linked to broader supply chain performance modelling can support agro-industrial decision-making. The present study extends that applied logic to the organic lontar palm sugar sector.

Implications for managing organic lontar palm sugar supply chains

The first managerial implication is that supply stabilization should be treated as a strategic rather than merely operational issue. Because raw material scarcity is the most influential risk agent, mitigation should begin by reducing supply volatility through stronger supplier relationships, clearer scheduling, and selective buffering. This is consistent with findings in agrifood case studies where supplier partnerships and better needs recording are prioritized as preventive actions (Dzulfikri et al., 2024)

The second implication is that risk management in this chain must directly address work discipline and routine execution. Weak SOP implementation is not a secondary problem; it is one of the most influential drivers of total exposure. Formalizing procedures without ensuring daily compliance is therefore insufficient. The real managerial requirement is procedural discipline supported by training, monitoring, and accountability.

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The third implication concerns equipment reliability. In a small-scale processing environment, machinery breakdown has disproportionate consequences because redundancy is limited. Preventive maintenance is therefore not a peripheral technical matter but a core risk-management activity. It affects continuity, quality, and delivery simultaneously.

The fourth implication is relational. Limited supplier capability means that downstream processors cannot rely only on transaction-based procurement. Where upstream actors have managerial or technical limitations, collaborative improvement becomes part of risk mitigation. This does not necessarily imply a sophisticated digital supply system; in SME contexts, even relatively simple coordination routines, predictable delivery schedules, and clearer expectations can materially reduce risk.

The fifth implication is financial. Cash-flow constraints amplify other risks because they narrow the firm's response options. In practice, this means that operational resilience cannot be separated from financial management. Firms that face recurrent raw material fluctuation and machine dependence need minimum financial slack if they are to absorb disruption.

Theoretical implications

First, it supports the proposition that risk in agro-industrial supply chains can be treated as systemic yet still prioritizable. The presence of many possible disruptions does not automatically imply analytical diffusion; semi-quantitative agent-based ranking can still provide a workable basis for decision support in SME contexts.

Second, it illustrates the continued relevance of semi-quantitative risk frameworks in contexts where detailed longitudinal data are unavailable but structured operational decisions are still required. The contribution here is best understood as methodological fit for context rather than as evidence that semi-quantitative tools resolve all inferential concerns.

Third, it extends the empirical reach of integrated SCOR FMEA HOR logic to a traditional agro-industrial product based on a regionally embedded biological resource. The contextual value lies in showing how a familiar risk-management architecture can be adapted to a culturally rooted rural value chain with supply chain risk management implications.

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Limitations

Several limitations should be recognized: (1) First, the study relies on expert-based scoring for severity, occurrence, and event agent relationships. Although triangulation through observation and interviews improves credibility, the scoring process remains partly judgment-based. This limitation is common in HOR and FMEA applications in applied supply chain settings; (2) Second, the study is geographically specific to Karangasem and to the focal supply chain under investigation. The results are therefore analytically transferable rather than statistically generalizable. Supply chain structures for other agro-industrial products may differ in actor composition, regulatory environment, or scale; (3) Third, the analysis is cross-sectional. It captures the current configuration of risks and mitigation priorities, but does not model dynamic change over time. This matters because supply risk, especially in biologically based systems, may shift with seasonality, market changes, and external shocks; and (4) Fourth, the current study prioritizes mitigation actions qualitatively through HOR logic but does not estimate the monetary value of disruption reduction or the detailed economic trade-offs among alternative actions.

Directions for future research

Future research can build on the present study in several directions: (1) One direction is to incorporate dynamic modelling so that the evolution of risk over time can be examined. Reviews of uncertainty and resilience in biomass supply chains suggest that more advanced modelling of disruption propagation and resilience behavior remains a major research need (Gital & Bilgen, 2024; Habibi et al., 2023); (2) A second direction is to enrich prioritization through multistakeholder or fuzzy decision approaches. Utama et al. (2025) show that structured fuzzy screening and prioritization can improve decision accuracy under uncertainty. Such extensions may be especially useful if a future study includes a larger and more diverse respondent base; (3) A third direction is to quantify the economic impacts of the highest-priority agents and mitigation actions. This would strengthen managerial decision-making by linking risk priorities to cost, loss avoidance, and return on mitigation investment; (4) A fourth direction is to compare multiple agro-industrial products or regions. Cross-case analysis could reveal whether raw material scarcity and internal process discipline are consistently dominant in traditional bioresource-based SMEs or whether different products produce different risk structures; and (5) A fifth direction is to explore whether monitoring dashboards or lightweight digital systems could improve planning visibility and communication. Food-security

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procurement studies indicate that supply chain monitoring tools can support risk visibility and control (Alfazah et al., 2020). While highly sophisticated systems may be impractical for small firms, simplified digital recording and coordination tools could still reduce stock mismatch and planning inaccuracy.

CONCLUSION

This study developed and applied a supply chain risk management framework to the organic lontar palm sugar supply chain in Karangasem, Bali. The application indicates that vulnerability is distributed across planning, sourcing, production, delivery, and return activities, but concentrated in a limited set of dominant agents led by raw material scarcity, weak SOP implementation, machinery breakdown, limited supplier managerial capability, and cash-flow constraints.

The results further suggest that performance improvement in this chain is unlikely to emerge from isolated corrective actions. The prioritized mitigation package therefore combines supply stabilization, stronger supplier coordination, preventive maintenance, tighter process discipline, better inventory visibility, and improved cash-flow planning. Framed through supply chain risk management, these actions matter because they address disruption-driven waste, rework, delay, and avoidable inefficiency rather than only downstream service symptoms.

The principal contribution of the study is a structured diagnostic application for SME-scale agro-industry. By linking process mapping, risk diagnosis, prioritization, and mitigation design, the framework helps translate fragmented operational problems into ordered managerial action. Its inferential reach remains limited by the semi-quantitative and context-specific nature of the evidence, but it offers a credible basis for supply chain risk management improvement and for future validation in comparable agro-industrial settings.

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