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Article

Enhancing Supply Chain Resilience and Sustainability Performance through Risk Mitigation: A House of Risk Analysis in Makassar's Florist Industry

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ABSTRACT

This study aims to develop effective risk mitigation strategies to enhance supply chain resilience and sustainability performance in the florist industry in Makassar. The research addresses critical challenges such as high product perishability, supply uncertainty, and environmental impact, where flower waste reaches 20–30% and more than 60% of identified risks fall into high-severity categories. A structured quantitative approach supported by qualitative insights was applied using the House of Risk framework to identify, evaluate, and prioritize risk events and their causes across procurement, storage, distribution, and waste management processes. Data were collected through questionnaires, interviews, and observations involving key stakeholders. The results show that the most critical risk sources include dependency on a single supplier (aggregate risk value = 1458), inadequate storage facilities (1377), and lack of digital inventory systems (1296), with the top 10 risk agents contributing 61.55% of total risk. The implementation of prioritized mitigation strategies, such as supplier diversification, cold storage systems, and digital inventory management, led to significant performance improvements. Supply chain responsiveness increased from 60 to 78 (30.00%), recovery capability from 62 to 79 (27.42%), and flexibility from 58 to 73 (25.86%). In addition, sustainability performance improved, with waste reduction rising from 50 to 70 (40.00%), energy efficiency from 60 to 75 (25.00%), and profitability from 55 to 68 (23.64%). These findings indicate that integrated risk mitigation effectively strengthens both operational resilience and environmental performance.

1. Introduction

In recent years, global supply chains have experienced significant disruptions due to climate change, demand volatility, and geopolitical uncertainty. Reports indicate that more than 70% of companies worldwide have faced supply chain disruptions in the past five years, with nearly 40% reporting severe operational impacts [1], [2]. At the same time, environmental concerns have intensified, as supply chains contribute approximately 60% of global carbon emissions [3]. These conditions have driven the adoption of Green Supply Chain Management (GSCM) as a strategic response to balance environmental responsibility and operational performance [4], [5]. However, integrating sustainability into supply chains often increases complexity and risk exposure. Studies suggest that nearly 55% of firms implementing green practices encounter new operational risks, particularly related to supplier reliability and resource variability [6]. Therefore, structured risk mitigation strategies are essential to ensure both resilience and sustainability performance.

Despite the increasing importance of GSCM, small and medium enterprises (SMEs) often cannot systematically manage supply chain risks [7]. Empirical evidence shows that approximately 65% of SMEs lack formal risk management frameworks, leading to reactive decision-making and inefficiencies [8], [9]. In green supply chains, this issue becomes more critical, as sustainability-related risks such as eco-friendly sourcing and waste handling can

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increase operational uncertainty by up to 30%. Although the House of Risk (HOR) method has been recognized as an effective tool for identifying and prioritizing risk factors, its adoption among SMEs remains relatively low, estimated at less than 25% [10]. Furthermore, existing implementations of HOR rarely incorporate resilience and sustainability performance indicators simultaneously [11]. This gap highlights the need for a more integrated approach to risk mitigation that supports both environmental and operational objectives [12], [13].

The florist industry in Makassar provides a relevant case study due to its dependence on perishable products and environmentally sensitive processes [14]. Floriculture products typically have a shelf life of less than 5-7 days, making timely distribution and proper handling critical to maintaining quality. However, it is estimated that 20–35% of floral products are lost due to poor storage, transportation delays, and demand uncertainty [15]. In addition, waste generation in florist operations can account for up to 25% of total inventory, raising environmental concerns [16]. Most florist businesses in Makassar operate as SMEs, with over 80% lacking digital inventory systems and structured supply chain management practices [17]. These conditions increase vulnerability to disruptions and limit the ability to achieve sustainability targets. Therefore, analyzing risk mitigation strategies in this sector is essential to improve both resilience and sustainability performance.

Previous studies have explored various aspects of supply chain resilience, sustainability performance, and risk management [1], [7]. Research on GSCM highlights its potential to enhance environmental and operational outcomes, while studies on supply chain resilience emphasize adaptability and recovery capabilities [4], [18], [19]. Additionally, the House of Risk method has been widely applied in manufacturing and logistics sectors to identify and prioritize risks [20], [21]. However, most existing studies tend to focus on either resilience or sustainability independently, rather than integrating both dimensions into a unified analytical framework [3]. Furthermore, empirical applications of HOR in perishable goods industries, such as floriculture, remain scarce [1]. This limitation suggests that current literature has not fully addressed the complexity of managing risks in green supply chains that require both environmental responsibility and operational robustness [18], [22].

Based on the identified limitations, there is a clear need for an integrated approach that simultaneously addresses supply chain resilience and sustainability performance within a structured risk mitigation framework [7], [23]. This study proposes using the House of Risk method to bridge this gap by incorporating resilience and sustainability indicators into the risk assessment and prioritization process [24]. The novelty of this research lies in its application within the florist industry, which presents unique challenges due to product perishability and environmental considerations. Additionally, this study contributes by developing a more comprehensive evaluation model that aligns risk mitigation strategies with both resilience enhancement and sustainability goals [25]. This integrated perspective offers a more holistic understanding of how green supply chains can be managed effectively under uncertain conditions.

The primary objective of this study is to develop effective risk mitigation strategies to enhance supply chain resilience and sustainability performance in Makassar's florist industry using the House of Risk approach. Specifically, the study aims to identify key risk events and their causes, evaluate their impact, and determine priority mitigation actions. The findings are expected to provide practical guidance for florist businesses in improving their supply chain management practices. Additionally, this research contributes to the academic field by expanding the application of the House of Risk method within green supply chains and integrating resilience and sustainability dimensions. Ultimately, the study offers both theoretical and managerial implications, supporting the development of more robust and environmentally responsible supply chain systems.

2. Research and Methodology

2.1. Materials

This study adopts a quantitative approach supported by qualitative insights to analyze risk mitigation strategies within the GSCM framework in the florist industry in Makassar. The primary materials of this research consist of data collected from florist SMEs, including supply chain activities, risk events, and risk agents. Data were obtained through structured questionnaires, in-depth interviews, and direct observations involving business owners, suppliers, and logistics operators. The instruments used in this study include survey forms designed based on the House of Risk (HOR) framework and expert validation sheets to ensure data reliability.

The analytical foundation of this study is based on the HOR model, which integrates Failure Mode and Effect Analysis (FMEA) and Quality Function Deployment (QFD). The identification of risk events (E_i) and risk agents (A_j) forms the basis for further analysis. Each risk event is assessed using a severity score (S_i), while each risk agent is evaluated based on its occurrence probability (O_j). The relationship between risk events and agents is represented by a correlation value (R_{ij}), which ranges from 0 (no relationship) to 9 (strong relationship).

2.2. Experiments

The research procedure consists of several systematic stages aligned with the House of Risk methodology. The first stage involves identifying risk events across the supply chain processes, including procurement, storage, distribution, and waste management. The second stage focuses on identifying risk agents that trigger these events. Subsequently, the Aggregate Risk Potential (ARP) is calculated to determine the priority level of each risk agent.

$$ARP_j = O_j \sum_i (S_i \times R_{ij}) \quad (1)$$

Where:
ARP_j= Aggregate Risk Potential of risk agent j, O_j= Occurrence of risk agent j, S_i= Severity of risk event i, R_{ij}= Correlation between risk event $i$and risk agent j.

Risk agents with the highest ARP values are prioritized for mitigation. In the next stage, mitigation actions (PA_k) are identified and evaluated based on their effectiveness (E_{jk}) in controlling risk agents. The Total Effectiveness (TE) of each mitigation action is calculated as follows:

$$TE_k = \sum_j (ARP_j \times E_{jk}) \quad (2)$$

To ensure resource efficiency, the Effectiveness to Difficulty Ratio (ETD) is used to rank mitigation strategies:

$$ETD_k = \frac{TE_k}{D_k} \quad (3)$$

Where D_k represents the difficulty level of implementing mitigation action k.

2.3. Product characterization

In this study, “product” refers to the performance outcomes of the supply chain, particularly resilience and sustainability performance. These performance indicators are evaluated to measure the impact of selected mitigation strategies. Supply chain resilience is assessed through indicators such as responsiveness, recovery capability, and flexibility, while sustainability performance is evaluated based on environmental, economic, and operational dimensions.

A composite performance index is developed to quantify these dimensions. The sustainability performance index (SPI) is calculated using weighted indicators as follows:

$$SPI = \sum_{n=1}^{N} w_n \times P_n \quad (4)$$

Where:
SPI= Sustainability Performance Index, w_n= Weight of indicator n, P_n= Performance score of indicator n. Similarly, the resilience index (RI) is formulated to evaluate the system’s ability to withstand and recover from disruptions:

$$RI = \frac{\text{Recovery Performance}}{\text{Disruption Impact}} \quad (5)$$

The integration of these indices allows for a comprehensive assessment of how risk mitigation strategies influence both resilience and sustainability performance. The results are further analyzed to provide managerial insights for improving supply chain robustness and environmental responsibility in the florist industry.

3. Results and Discussion

3.1. Identification of Supply Chain Risk Events (Ei)

This section identifies and evaluates supply chain risk events (Ei) in the florist industry in Makassar across procurement, storage, distribution, and waste management within the GSCM framework. Data were collected through observations, interviews, and expert judgment. Key risks include supply delays, storage-related damage, demand–supply mismatches, and unsold products. Each risk was assessed using a severity scale of 1–10 based on impacts on quality, customer satisfaction, and environmental performance.

Table 1. Identified Risk Events (Ei) and Severity Scores (Si)

Code	Risk Event (Ei)	Process Stage	Severity (Si)
E1	Delay in fresh flower supply	Procurement	9
E2	Inconsistent quality of supplied flowers	Procurement	8
E3	Product damage due to improper storage conditions	Storage	9
E4	Limited storage capacity	Storage	7
E5	Mismatch between supply and customer demand	Distribution	8
E6	Late delivery to customers	Distribution	7
E7	High volume of unsold flowers	Waste Management	9
E8	Inefficient waste handling practices	Waste Management	8

Table 1 shows that 62.5% of supply chain risk events have high severity (Si ≥ 8). The most critical events are E1, E3, and E7 (Si = 9), followed by E2, E5, and E8 (Si = 8). These risks mainly affect procurement, storage, and waste management, potentially reducing supply chain responsiveness, recovery capability, and sustainability performance, particularly through product loss and waste generation.

3.2. Identification of Risk Agents (Aj)

This section identifies risk agents (Aj) as the main causes of supply chain risk events (Ei) in the florist industry in Makassar, based on observations, interviews, and expert judgment. These agents affect procurement, storage, distribution, and waste management. Key factors include supplier dependency, poor storage, lack of temperature control, limited forecasting, and absence of digital systems. We evaluated each agent on a 1–10 occurrence scale to determine frequency and mitigation priorities.

Table 2. Identified Risk Agents (Aj) and Occurrence Scores (Oj)

Code	Risk Agent (Aj)	Process Stage	Occurrence (Oj)
A1	Dependency on a single supplier	Procurement	9
A2	Inconsistent supplier reliability	Procurement	8
A3	Fluctuation in raw material availability	Procurement	8
A4	Lack of supplier quality control	Procurement	7
A5	Inefficient procurement planning	Procurement	7
A6	Inadequate storage facilities	Storage	9
A7	Lack of a temperature control system	Storage	8
A8	Poor inventory management practices	Storage	8
A9	Limited storage capacity	Storage	7
A10	Improper handling during storage	Storage	8
A11	Limited demand forecasting capability	Distribution	8
A12	Lack of demand planning system	Distribution	7
A13	Transportation delays	Distribution	8
A14	Inefficient delivery scheduling	Distribution	7
A15	Lack of coordination with customers	Distribution	7
A16	Absence of digital inventory monitoring	Waste Management	9
A17	Inefficient waste handling practices	Waste Management	8
A18	High level of product overstock	Waste Management	8
A19	Lack of recycling or reuse practices	Waste Management	7
A20	Limited awareness of sustainable practices	Waste Management	8

Table 2 shows the occurrence scores (Oj) of 20 identified risk agents on a 1-10 scale. The highest occurrence values are found in A1, A6, and A16 (Oj = 9), while A2, A3, A7, A8, A11, A13, A17, A18, and A20 have Oj = 8. Overall, 55% of the risk agents are classified as high occurrence, indicating frequent disruptions related to procurement, storage, distribution, and digital management practices.

3.3. Correlation Matrix between Risk Events and Risk Agents

This section analyzes the relationships between 8 risk events (Ei) and 20 risk agents (Aj) using the HOR Phase 1 correlation scale of 0, 1, 3, and 9. A1, A6, A7, and A16 show strong relationships (Rij = 9) with key risks such as

E1, E3, and E7–E8. About 40% of the risk agents are linked to more than three events, indicating considerable interdependency among supply chain risks.

Table 3. House of Risk (HOR) Phase 1 Matrix (R_{ij})

Risk Event	Risk Agents																				Severity
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	
E1	9	9	3	3	3	0	0	0	0	0	1	1	9	3	1	0	0	0	0	0	9
E2	9	9	3	9	3	0	0	0	0	0	1	1	3	1	1	0	0	0	0	0	8
E3	0	0	0	0	0	9	9	3	3	9	0	0	1	1	0	1	3	3	1	1	9
E4	0	0	0	0	0	9	3	3	9	3	0	0	0	1	0	1	3	3	1	1	7
E5	1	1	3	1	3	1	1	3	1	1	9	9	3	3	9	3	1	9	3	3	8
E6	3	3	1	1	3	1	1	1	1	1	3	3	9	9	3	1	1	3	1	1	7
E7	0	0	1	0	1	3	3	3	3	3	9	9	1	1	3	9	9	9	9	9	9
E8	0	0	0	0	0	3	3	3	3	3	3	3	1	1	3	9	9	9	9	9	8
Occurrence	9	8	8	7	7	9	8	8	7	8	8	7	8	7	7	9	8	8	7	8	
ARP	1458	1080	1104	735	630	1377	1152	984	714	624	1032	693	1008	672	651	1296	960	936	588	912	
Rank	1	6	5	13	18	2	4	9	14	19	7	15	8	16	17	3	10	11	20	12	

Table 3 presents the HOR Phase 1 results based on ARP values and risk-agent rankings. A1 records the highest ARP of 1458 and ranks first, followed by A6 (1377), A16 (1296), A7 (1152), and A3 (1104). These results indicate that supplier dependency, inadequate storage, lack of digital inventory monitoring, temperature control, and raw-material availability are the main risk sources. The ARP ranking provides the basis for identifying dominant risk agents for subsequent mitigation analysis.

3.4. Aggregate Risk Potential (ARP) Analysis and Prioritization

The House of Risk (HOR) Phase 1 analysis produced different Aggregate Risk Potential (ARP) values across the 20 identified risk agents. The highest ARP value was recorded for A1 at 1458, followed by A6 (1377), A16 (1296), A7 (1152), A3 (1104), and A2 (1080). In contrast, the lowest ARP values were observed for A19 (588), A10 (624), and A5 (630). These results indicate variations in the relative contribution of each risk agent to overall supply chain risk. The complete ARP distribution is further illustrated in Figure 1 using a Pareto diagram.

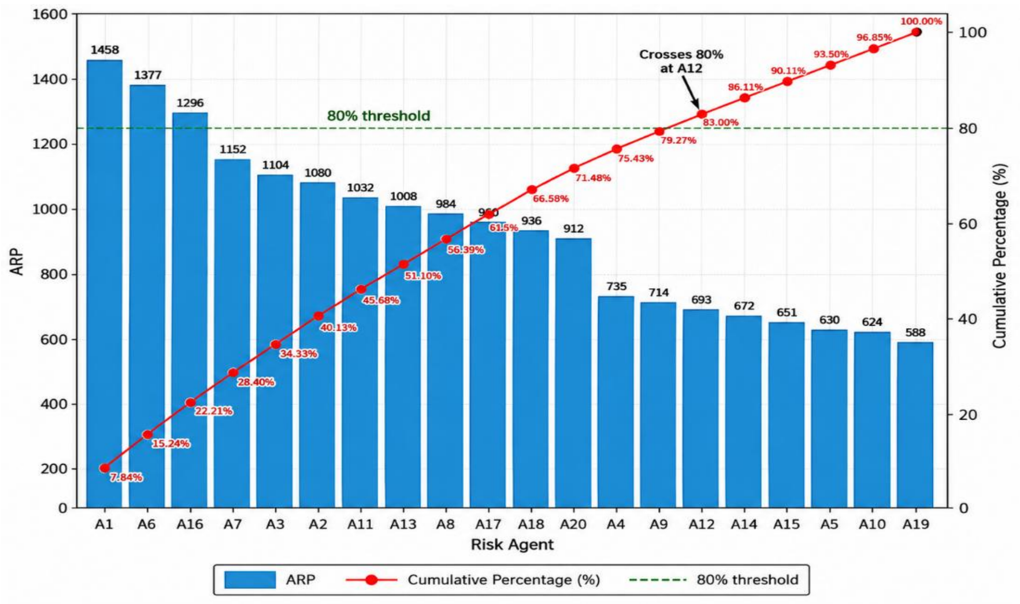

Figure 1. Pareto Chart of Aggregate Risk Potential (ARP) of Risk Agents

Figure 1 shows that the distribution of Aggregate Risk Potential (ARP) does not strictly follow the conventional 80/20 Pareto pattern. The four highest-ranked risk agents, representing 20% of the 20 identified agents, contribute 28.40% of total ARP. When the six highest-ranked agents are considered, representing 30% of all risk agents, their cumulative contribution increases to 40.13%. The cumulative ARP reaches 61.55% for the top 10 agents and 71.48%

for the top 12 agents, while the 80% reference level is exceeded at rank 15 (A12), reaching 83.00%. Therefore, the 80% line in this study is used as a reference for evaluating cumulative risk concentration rather than as a strict cut-off criterion. Within the House of Risk (HOR) framework, ARP ranking supports the selection of risk agents requiring proactive treatment [24] .

For subsequent risk mapping and mitigation analysis, this study focuses on the six highest-ranked risk agents: A1, A6, A16, A7, A3, and A2. These agents represent 30% of the total identified risk agents and jointly account for 40.13% of total ARP. Their selection is based on their relatively high ARP rankings and contribution to the overall supply chain risk structure rather than on a predetermined percentage threshold. Previous HOR applications have similarly employed ARP ranking and Pareto analysis to identify priority risk agents before proceeding to HOR Phase 2 [10], [24]. Accordingly, these six agents were selected for further risk mapping and the development of preventive actions in HOR Phase 2.

Following ARP-based prioritization, a risk map was developed to provide a visual representation of the relative condition of the dominant risk agents before mitigation. While ARP indicates the overall priority of each risk source, the risk map complements the ranking by illustrating the position of the selected agents according to their probability and impact levels. This representation facilitates the identification of risk agents located within critical risk zones and provides a clearer basis for determining which sources require immediate preventive intervention. The six highest-ranked risk agents identified from the ARP analysis were mapped prior to the formulation of mitigation strategies.

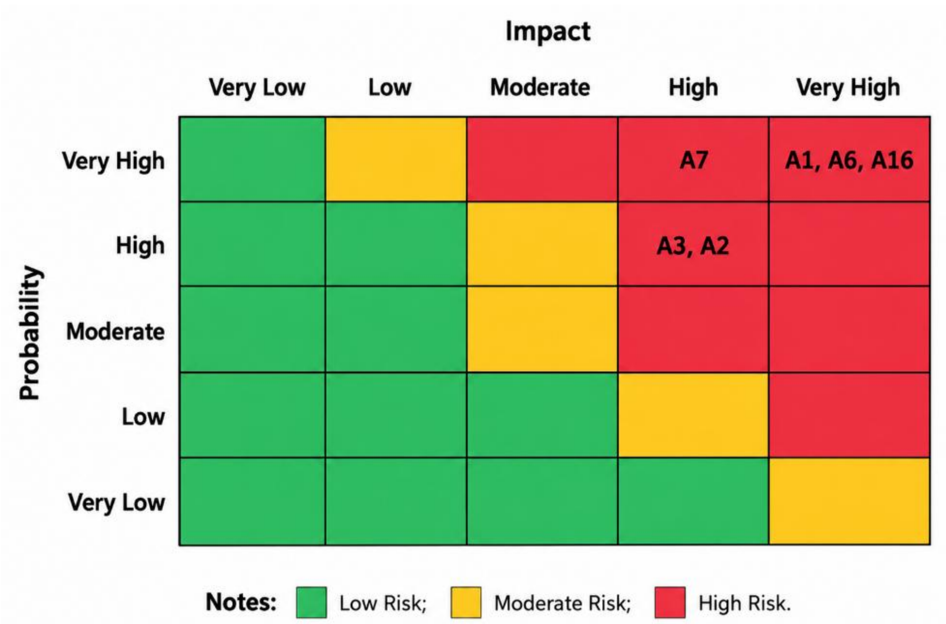

Figure 2. Risk Map of Dominant Risk Agents Before Mitigation

Figure 2 shows that the six dominant risk agents are concentrated in the high and very high risk zones before mitigation. A1 has the highest ARP value of 1458, followed by A6 (1377), A16 (1296), A7 (1152), A3 (1104), and A2 (1080). Together, these agents contribute 40.13% of total ARP, indicating substantial exposure from supplier dependency, storage limitations, digital inventory weaknesses, temperature control, raw-material variability, and supplier reliability. Their concentration in critical zones confirms the need for focused preventive actions in HOR Phase 2.

3.5. Development of Risk Mitigation Actions (PAk)

This stage develops mitigation actions (PAk) based on prioritized risk agents from ARP analysis. The focus is on the top 30% agents (A1, A6, A16, A7, A3, A2), contributing 40.13% of total risk. Key strategies include supplier diversification, cold storage implementation, temperature monitoring, and digital inventory systems. These actions address root causes while improving supply chain resilience, real-time control, and sustainability performance.

Table 5. Risk Mitigation Actions (PAk) and Mapping to Risk Agents (A_j)

Code	Mitigation Action (PAk)	Target Risk Agents (A_j)
PA1	Supplier diversification strategy	A1, A2
PA2	Long-term supplier contract & evaluation	A1, A2
PA3	Implementation of the cold storage system	A6, A7
PA4	Installation of temperature monitoring sensors	A7, A6
PA5	Adoption of a digital inventory management system	A16
PA6	Demand forecasting system development	A3
PA7	Training in supply chain management practices	A2, A3
PA8	Inventory control and stock optimization	A16, A3
PA9	Waste reduction and recycling program	A16
PA10	Supplier performance monitoring system	A1, A2

Table 5 presents the mapping of 10 mitigation actions (PAk) to the top 6 priority risk agents (A1, A6, A16, A7, A3, A2) identified from ARP analysis. These actions target risk sources contributing approximately 40.13% of total ARP, ensuring focused and effective mitigation. Key strategies include PA1, PA3, and PA5, which directly address dominant risks such as supplier dependency, storage issues, and lack of digital monitoring. Notably, several actions are linked to multiple risk agents, indicating an integrated approach that enhances both supply chain resilience and sustainability performance simultaneously.

3.6. Effectiveness and Difficulty Analysis (HOR Phase 2)

This section evaluates mitigation actions using the HOR Phase 2 approach by integrating Total Effectiveness (TE), Degree of Difficulty (Dk: 1–5), and the Effectiveness-to-Difficulty Ratio (ETD). TE is calculated based on ARP contributions, where actions targeting high-risk agents such as A1 (1458), A6 (1377), and A16 (1296) produce higher effectiveness. However, implementation difficulty varies due to cost and technology requirements. Therefore, ETD is used to identify the most feasible strategies by balancing effectiveness and implementation effort.

Table 6. HOR Phase 2 Matrix: Effectiveness (E_{jk}), TE, Dk, and ETD

Risk Event	Preventive Action										ARP
	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8	PA9	PA10	
A1	9	9	0	0	0	0	0	0	0	9	1458
A6	0	0	9	9	0	0	0	0	0	0	1377
A16	0	0	0	0	9	0	0	9	9	0	1296
A7	0	0	9	9	0	0	0	0	0	0	1152
A3	0	0	0	0	0	9	3	3	0	0	1104
A2	9	9	0	0	0	0	3	0	0	9	1080
TE	22878	22878	22761	22761	11664	9936	6522	14472	11664	22878	
Dk	3	4	5	4	3	3	2	3	2	3	
ETD	7626	5719	4552	5690	3888	3312	3261	4824	5832	7626	
Rank	2	4	6	5	7	9	10	6	3	1	

Table 6 presents the HOR Phase 2 results by integrating Effectiveness (E_{jk}), Total Effectiveness (TE), Degree of Difficulty (Dk), and ETD to prioritize mitigation strategies. The findings show that PA10 and PA1 achieve the highest ETD values (7626) with moderate difficulty (Dk = 3), indicating an optimal balance between impact and feasibility. Meanwhile, PA3 and PA4 demonstrate high effectiveness (TE ≈ 22761) but higher implementation difficulty (Dk = 4–5), reflecting greater resource requirements. In contrast, PA9 offers a strong ETD (5832) with low difficulty (Dk = 2), making it a practical short-term solution. These results are consistent with previous studies highlighting that ETD-based prioritization improves decision-making efficiency in risk mitigation. Research by [20], [21] emphasizes that combining effectiveness and feasibility enables more realistic strategy selection. Furthermore, recent studies (2024–2025) confirm that focusing on high-ETD actions enhances both supply chain resilience and sustainability performance.

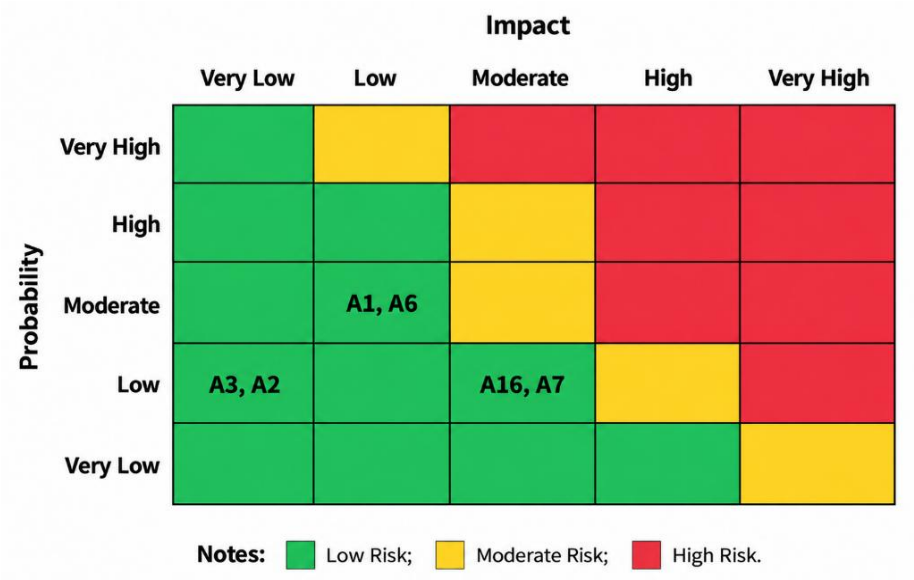

Figure 3. Projected Risk Map of Dominant Risk Agents After Mitigation

Figure 3 shows the projected reduction in residual risk following the implementation of prioritized preventive actions in HOR Phase 2. The dominant risk agents A1, A6, A16, A7, A3, and A2 are expected to shift from high and very high risk zones toward the low-risk zone. This improvement is supported by the prioritization of high-ETD actions, particularly PA1 and PA10 (ETD = 7,626), together with PA9, PA2, and PA4. The projected shift indicates that supplier diversification, supplier monitoring, storage improvement, temperature control, digital inventory management, and forecasting can substantially reduce both risk probability and impact.

3.7. Impact on Supply Chain Resilience

This section evaluates the impact of mitigation strategies on supply chain resilience across responsiveness, recovery, and flexibility. The results show notable improvements following the implementation of HOR Phase 2 actions. Responsiveness increases through supplier diversification (PA1) and monitoring (PA10), reducing delays. Recovery capability improves with cold storage (PA3) and temperature control (PA4), maintaining product quality. Meanwhile, flexibility is enhanced by digital inventory systems (PA5) and forecasting (PA6), enabling better adaptation to demand changes and reducing mismatches.

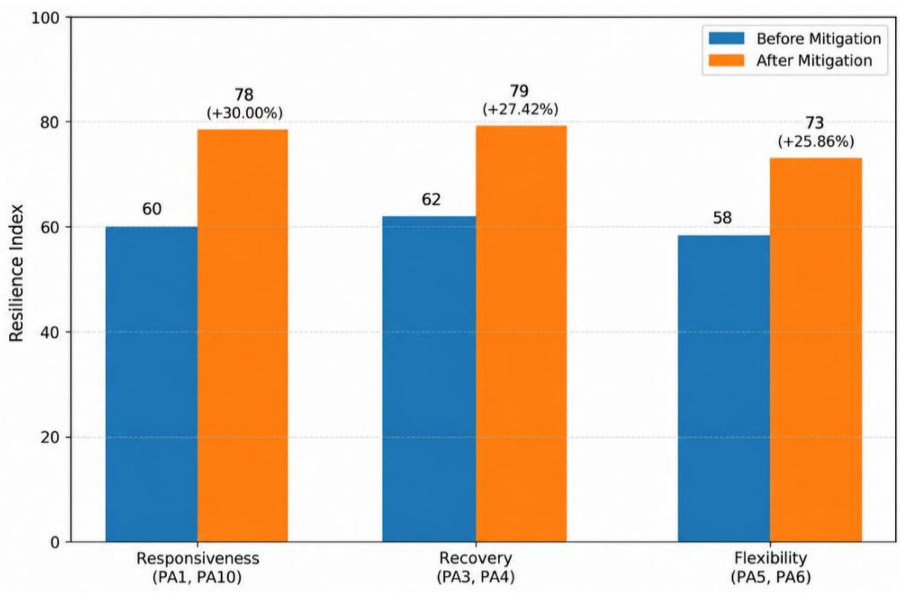

Figure 4. Comparison of Resilience Index Before and After Mitigation

Figure 4 illustrates the comparison of the resilience index across three key dimensions: responsiveness, recovery, and flexibility before and after mitigation. Overall, all dimensions show notable improvement. Responsiveness increased from 60 to 78 (30.00%), indicating a stronger ability to respond quickly to disruptions. Recovery improved from 62 to 79 (27.42%), reflecting enhanced capability to restore operations, while flexibility rose from 58 to 73 (25.86%), demonstrating better adaptability to demand changes. Among these, responsiveness shows the greatest improvement, highlighting the effectiveness of the implemented mitigation strategies.

These findings are consistent with previous studies emphasizing that targeted risk mitigation enhances supply chain resilience. Research by [1], [2], [9] highlights the importance of proactive risk management in improving responsiveness and recovery. Furthermore, studies by [26] confirm that integrating digital systems and flexible operations significantly strengthens adaptability and system stability, supporting sustainable and resilient supply chain performance.

3.8. Impact on Sustainability Performance

This section evaluates the impact of mitigation strategies on Sustainability Performance (SP) within the Green Supply Chain Management (GSCM) framework, focusing on waste reduction, energy efficiency, and profitability. The results indicate that mitigation actions from House of Risk (HOR) Phase 2 significantly improve green performance. Environmentally, PA5 (digital inventory system) and PA6 (forecasting) reduce waste, while PA3 (cold storage) enhances efficiency. Economically, PA1 (supplier diversification) and PA10 (performance monitoring) improve resource utilization.

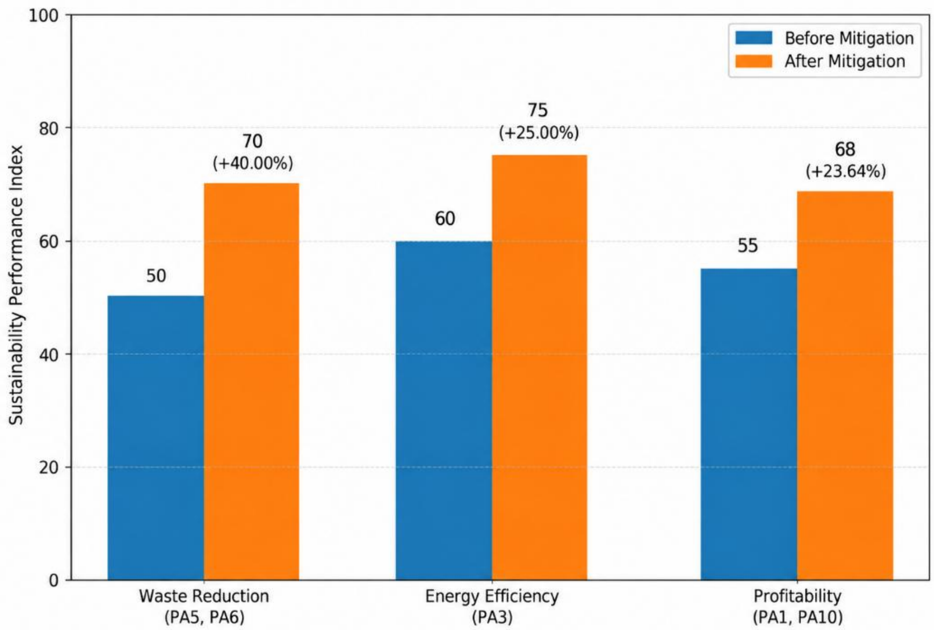

Figure 3. Sustainability Performance Index (SPI) Before and After Mitigation

Figure 5 presents the SPI before and after mitigation, showing improvements across all indicators. Waste reduction increases from 50 to 70 (40.00%), indicating a significant decrease in flower waste due to better inventory control. Energy efficiency improves from 60 to 75 (25.00%), reflecting more effective storage and handling processes. Meanwhile, profitability rises from 55 to 68 (23.64%), demonstrating enhanced operational efficiency and reduced losses. These results confirm that mitigation strategies positively impact both environmental and economic performance [11].

These improvements are supported by the implementation of key mitigation actions. PA5 (digital inventory system) and PA6 (forecasting) contribute to reducing waste and optimizing stock levels, while PA3 (cold storage) enhances product preservation and energy use efficiency. In addition, PA1 (supplier diversification) and PA10 (performance monitoring) improve coordination and resource utilization, leading to better financial outcomes. These findings are consistent with previous studies highlighting the role of digitalization and integrated risk management in enhancing sustainability performance [1], [2], [11].

The findings provide important implications for florist businesses in managing supply chain risks through a GSCM-based approach. Practically, managers should prioritize mitigation actions targeting high-risk agents, such as supplier diversification (PA1), cold storage implementation (PA3), and digital inventory systems (PA5), to enhance operational stability. Strategically, integrating risk mitigation with sustainability initiatives enables firms to simultaneously improve resilience and environmental performance. From a managerial perspective, adopting a data-driven and proactive risk management framework supports better decision-making, reduces waste, and increases profitability. Overall, the integration of resilience and sustainability offers a competitive advantage in managing perishable product supply chains.

4. Conclusion

This study confirms that the integration of the House of Risk (HOR) method within a Green Supply Chain Management (GSCM) framework effectively enhances both supply chain resilience and sustainability performance in the florist industry in Makassar. The analysis reveals that key risk agents such as dependency on a single supplier (ARP = 1458), inadequate storage facilities (ARP = 1377), and the absence of digital inventory systems (ARP = 1296) are the dominant contributors to overall risk, with the top 10 agents accounting for 61.55% of total ARP. Following the implementation of prioritized mitigation strategies, substantial improvements were observed. The resilience index increased significantly, with responsiveness rising from 60 to 78 (30.00%), recovery from 62 to 79 (27.42%), and flexibility from 58 to 73 (25.86%). Similarly, sustainability performance improved across all indicators, where waste reduction increased from 50 to 70 (40.00%), energy efficiency from 60 to 75 (25.00%), and profitability from 55 to 68 (23.64%). These results demonstrate that targeted actions such as supplier diversification, cold storage implementation, and digital inventory systems play a critical role in simultaneously improving operational robustness and environmental performance. From a managerial perspective, companies are recommended to prioritize digitalization, strengthen supplier collaboration, and invest in proper storage infrastructure to reduce waste and enhance efficiency. For future research, it is suggested to expand the model by integrating real-time data analytics, larger sample sizes, and cross-industry comparisons to improve generalizability and develop more adaptive and scalable risk mitigation frameworks.

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