

Risk identification and structuring in Brazilian food supply chains: an ISM and MICMAC-based multicriteria approach

Eveliny Dias de Medeiros^{a*} , Rosania Monteiro Coutinho^a , João Paulo Maximiano Almeida^a ,
Marina Bouzon^a 

^aUniversidade Federal de Santa Catarina, Florianópolis, SC, Brasil

*evelinydias@gmail.com

Abstract

Paper aims: This study aims to identify the main risks affecting food supply chains (FSCs) in Brazil, analyze their interrelationships, and propose mitigation strategies.

Originality: This research presents a structured approach to modeling the interdependencies among FSC risks, offering original insights with practical applications for risk managers in the Brazilian food sector.

Research method: The methodology consists of three phases: (1) an Exploratory Literature Review (ELR) to identify and categorize FSC risks; (2) a survey with industry experts to collect qualitative data on the interrelationships among the identified risks; and (3) the application of Interpretive Structural Modeling (ISM) and the Matrix of Cross-Impact Multiplications Applied to Classification (MICMAC) analysis to explore the relationships among risks and propose mitigation strategies.

Main findings: Ten key risks were identified and ranked. Natural risks and macro-level risks emerged as the most influential, while demand, supply, and operational risks were found to be more dependent on these factors. The ISM model illustrated the interconnections among the risks, and the MICMAC analysis classified them according to their driving and dependence power.

Implications for theory and practice: The findings support the development of targeted mitigation strategies, strengthening risk resilience and decision-making within FSCs. Additionally, the study contributes to academic discourse by integrating structural analysis into food supply chain risk management.

Keywords

Food system. Disruptions. ISM. MICMAC.

How to cite this article: Medeiros, E. D., Coutinho, R. M., Almeida, J. P. M., & Bouzon, M. (2025). Risk identification and structuring in Brazilian food supply chains: an ISM and MICMAC-based multicriteria approach. *Production*, 35, e20250049. <https://doi.org/10.1590/0103-6513.20250049>

Received: Apr. 30, 2025; Accepted: Sept. 22, 2025.

Financial Support

This research was carried out with institutional support through graduate scholarships provided by the Public Call FAPESC No. 06/2023 – Postgraduate Development Program (PDPG) – Strategic Partnerships in the States III, in partnership with CAPES Call No. 38/2022, Government of the State of Santa Catarina. No specific external funding was received for the development of this study.

Conflict of Interest

The authors have no conflict of interest to declare.

Ethical Statement

This study involved the use of an anonymous questionnaire. No personally identifiable information was collected, and participants' confidentiality was fully preserved. All participants provided their informed consent before participation. Given the nature of the study and the absence of sensitive data collection, approval from an ethics committee was not required according to the applicable institutional and national guidelines.

Editor(s)

Adriana Leiras



1. Introduction

Food Supply Chains (FSCs) represent a complex system of interconnected events that begins with agricultural production and extends through all subsequent stages—processing, commercialization, distribution, and final consumption—in a flow often referred to as “from farm to fork” (Nakai, 2018). The fundamental importance of these chains in ensuring sustainable, accessible, safe, and sufficient food supplies makes their efficient operation imperative, especially in a business environment marked by increasing volatility and dynamism (Zhao et al., 2020).

The growing complexity of global FSCs, driven by rising demand, the adoption of digital business models, and globalization, underscores the need for innovative approaches to manage these chains (Gruzauskas et al., 2023). However, this same complexity exposes FSCs to a wide range of vulnerabilities and risks, highlighting the need for effective management to enhance performance and resilience (Zhao et al., 2020). Challenges such as geographic dispersion, transportation, and packaging can lead to waste and shortages, necessitating precise logistical coordination (Teerasoponpong & Sopadang, 2022).

Large-scale disruptive events, such as climate change, economic crises, and pandemics, can expose the structural fragilities of extensive and complex supply chains. The COVID-19 pandemic demonstrated the severe impact such disruptions can have on international food distribution (Lund et al., 2020). Despite ongoing advances in both industry and academia, the frequency and severity of these disruptions remain significant (Ahmad & Qahmash, 2021), reinforcing the need for robust risk management.

Effective supply chain management is a cornerstone of organizational performance, particularly in vulnerable and dynamic environments (Hendricks & Singhal, 2009; Altay & Ramirez, 2010). Although risk management has been widely discussed across various sectors, its specific application to food supply chains has not yet received sufficient attention in the literature (Nyamah et al., 2017). Therefore, a focused approach to risk management in FSCs is needed—at local, national, and international levels—emphasizing the development and maintenance of multiple distribution channels to increase resilience (Gruzauskas et al., 2023).

The complexity of supply networks is further intensified by greater uncertainty in supply and demand, changing consumer preferences for higher-quality products, stricter food safety standards, shorter shelf lives, and inherent dependence on climatic conditions, all of which contribute to heightened risk (Leat & Revoredo-Giha, 2013; Zhao et al., 2020). At the same time, growing environmental concerns, cost reduction efforts, and the social impacts of business operations have elevated sustainable supply chains to a strategic priority (Bassett et al., 2021). In this context, risk in FSCs is defined as the probability of failures, operational obstacles, and economic losses resulting from uncertainties across all stages of the chain (Septiani et al., 2016), encompassing climatic, biological, logistical, market, regulatory, and managerial factors (Zhao et al., 2020, 2022).

Given this scenario, studying risk mitigation in Brazilian food supply chains is particularly relevant, as their operations can serve as both sources of vulnerability and resilience (Ivanov et al., 2014). FSCs exhibit specific vulnerabilities such as unpredictable demand, seasonality, and high perishability, which require special attention, since any delays can result in significant losses (Lund et al., 2020).

To analyze the complex web of interdependencies among these risks, this study employs Interpretive Structural Modeling (ISM), a well-established methodology that identifies and hierarchically structures relationships among multiple system elements. ISM is particularly effective in decision-making contexts involving qualitative judgments (Attri et al., 2013) and is widely used in supply chain risk analysis due to its ability to reveal causal and hierarchical links between interdependent variables (e.g., Luthra et al., 2011; Haleem et al., 2012).

While other techniques, such as DEMATEL, also explore causal relationships, ISM was selected for its explicit hierarchical structuring and intuitive visualization of dependencies, which align closely with this study's objectives. Although DEMATEL effectively maps cause-and-effect relationships in complex systems, it does not provide the hierarchical organization essential for structuring risks by levels of influence and dependence. Therefore, ISM was chosen based on the fit between its capabilities and the analytical requirements of the research problem.

Despite its applicability, there is a noticeable lack of studies employing ISM in food supply chains, especially in the Brazilian context. Few investigations have deeply explored the risks involved and their interrelationships. This study aims to fill that gap by contributing both theoretically—by expanding the literature on FSC risks in Brazil—and practically—by identifying the main risks and analyzing their interdependencies using the ISM approach.

The relevance of this topic is further supported by studies published in the *Production* journal, which reflect ongoing interest in food supply chains in Brazil. Previous research has addressed logistical challenges, such as bottlenecks in the lettuce supply chain and strategies for managing multiple distribution channels (Carvalho et al., 2014; Silva et al., 2015). More recently, contributions to the journal have revealed a growing concern with sustainability, risk management, and supply chain transformations. For instance, Camargo (2023) proposed a hybrid method to economically evaluate CO₂ emissions in the Argentine productive chain,

addressing environmental impacts of supply networks. Montes Causil & Morais (2023) developed a multicriteria negotiation model for selecting sustainable suppliers in agribusiness, reflecting the sector's complexity and need for resilience, while Senna et al. (2023) identified critical KPIs for risk assessment in healthcare supply chains, highlighting vulnerabilities and robustness in essential sectors. Kersten et al. (2024) examined traceability in agri-food supply chains from a Circular Economy perspective, linking digitalization to sustainability challenges. Kobayashi et al. (2025) analyzed multilayered barriers to agile methodologies, while Kawasaki & Mascia (2025) explored challenges in operational experience feedback—both reinforcing the journal's emphasis on methodological rigor and contextualized analysis.

By applying Interpretive Structural Modeling (ISM) to Brazilian food supply chains, this study advances that dialogue, offering a structured approach to map interrelations among risks and strategies in a context marked by climatic extremes, logistical bottlenecks, and social asymmetries. In doing so, it not only broadens the methodological approaches already featured in *Production*, but also contributes an original, Brazil-specific perspective that resonates with the journal's ongoing efforts to strengthen research on supply chain resilience and sustainability.

By adopting an integrated approach, this research seeks not only to advance the theoretical understanding of risks in FSCs but also to provide practical insights for more effective management in the Brazilian context. Accordingly, the study is guided by two central research questions: “What are the main risks faced by food supply chains in Brazil?” and “What are the most effective mitigation strategies for these risks, according to experts in the field?”

The first question aims to map and identify the most critical threats, while the second seeks to derive validated, experience-based knowledge to support the construction of more resilient supply chains.

Beyond this introduction, the article is structured into four additional sections. The second section discusses the theoretical foundations of the study. The third describes the methodological procedures. The fourth presents the results, followed by the discussion in the fifth section. Finally, the last section offers the conclusions.

2. Literature review

Recent literature discusses several risks in food supply chains. Ali et al. (2023a) explore the relationship between knowledge management, risk management culture (RMC), and resilience. Meanwhile, Ali & Govindan (2023) analyze the impact of Industry 4.0 technologies on operational risks, such as supply and demand imbalances, financial challenges, and transportation issues. Jacobi et al. (2019) assess the resilience of food systems, highlighting production-related risks and the need for innovative policies. Fan et al. (2021) address the coincidence of multiple risks, such as climate crises, food insecurity, and political instability. Collectively, these studies emphasize the complexity of the challenges and the urgency for effective strategies to ensure sustainable and resilient food systems.

2.1. Main risks identified in food supply chains

Based on the Exploratory Literature Review (ELR), it was possible to identify and synthesize ten main risks in food supply chains, as presented in Table 1.

3. Method

The application of Interpretive Structural Modeling (ISM) using the SmartISM software aims to establish interrelationships among elements within a specific domain, ensuring the reachability of variables and the digraph structure in the final model (Ahmad & Qahmash, 2021). Multi-Criteria Decision-Making (MCDM) methods offer advantages when analyzing both quantitative and qualitative factors, resulting in effective solutions to decision-making problems (Singh et al., 2021; Carpitella et al., 2022).

In the context of ISM, Diabat et al. (2012) categorized risks into five groups and discussed mitigation strategies. Ramos et al. (2021) applied ISM to analyze risks in the agri-food supply chain in Peru. Zhao et al. (2020) used a multi-method approach to assess risks in Agri-Food Supply Chains (AFSC), employing TISM and MICMAC (Matrix of Cross-Impact Multiplications Applied to Classification) to identify and interrelate risk factors. Hachicha & Elmsalmi (2014) integrated structural modeling tools to quantify and classify risks according to their influence and dependency.

Table 1. Risk categories in food supply chains.

Code	Risk	Concept	Reference
R1	Macro-level Risk	Encompasses threats that affect not just a single organization but the entire system, influenced by large-scale factors such as macroeconomic, geopolitical, environmental, and social issues. Examples include political instability, terrorist attacks, government regulations, labor strikes, shortage of skilled labor, trade shocks, and lack of information sharing among partners.	(Ali et al., 2023a, 2023b; Ali & Govindan, 2023; Altay & Ramirez, 2010; Diabat et al., 2012; Fan et al., 2021; Jacobi et al., 2019; Leat & Revoredo-Giha, 2013; Nyamah et al., 2017; Zhao et al., 2020)
R2	Demand Management Risk	Refers to threats that may compromise the chain's ability to meet market demands. Examples include declining demand, communication failures with customers, changes in food safety requirements, forecasting errors, surplus or shortage of supply, information asymmetry, and price volatility in the market.	(Ali et al., 2023a, 2023b; Ali & Govindan, 2023; Altay & Ramirez, 2010; Diabat et al., 2012; Fan et al., 2021; Jacobi et al., 2019; Leat & Revoredo-Giha, 2013; Nyamah et al., 2017; Zhao et al., 2020)
R3	Supply Management Risk	Refers to threats that may hinder the efficient procurement of essential inputs and products for food production and distribution. Examples include supplier bankruptcy, poor product quality, inconsistency in quantity and quality, and fluctuations in input costs.	(Ali et al., 2023a, 2023b; Altay & Ramirez, 2010; Diabat et al., 2012; Nyamah et al., 2017; Zhao et al., 2020)
R4	Product Management Risk	Refers to threats that may impair the efficiency and effectiveness of product management throughout the production, distribution, and commercialization process. Examples include overstocking, variability in production quantity and quality, labeling issues, changes in consumer preferences, and fluctuations in production costs.	(Ali et al., 2023a, 2023b; Altay & Ramirez, 2010; Diabat et al., 2012; Jacobi et al., 2019; Leat & Revoredo-Giha, 2013; Nyamah et al., 2017; Zhao et al., 2020)
R5	Technology and Information Management Risks	Relate to threats associated with the use of information technologies and effective data management in the supply chain. These include storage and distribution problems, IT system failures, cybersecurity issues, connectivity disruptions, lack of data standardization, regulatory compliance, data quality, lack of real-time information, insufficient training, and irregular collaboration among supply chain partners.	(Ali et al., 2023a; Altay & Ramirez, 2010; Diabat et al., 2012; Zhao et al., 2020)
R6	Political and Regulatory Risks	These risks pertain to uncertainties and changes in governmental policies and regulations that can negatively affect organizational operations and competitiveness, such as changes in tax, trade, regulatory policies, and quality and safety standards.	(Altay & Ramirez, 2010; Jacobi et al., 2019; Leat & Revoredo-Giha, 2013; Nyamah et al., 2017; Zhao et al., 2020)
R7	Financial and Corporate Management Risks	These risks involve threats to the financial and operational stability of organizations, including economic uncertainty, regulatory changes, high costs, operational failures, and managerial decisions related to resource allocation and market competitiveness.	(Ali & Govindan, 2023; Altay & Ramirez, 2010; Leat & Revoredo-Giha, 2013; Nyamah et al., 2017; Zhao et al., 2020)
R8	Logistical and Infrastructural Risks	These risks affect the efficiency and reliability of logistics operations and infrastructure stability. They include changes in transportation, rising energy costs, unreliable transport, lack of infrastructure, fuel price volatility, delivery delays, cargo theft, packaging issues, and lack of coordination in transportation.	(Nyahmah et al., 2017; Zhao et al., 2020)
R9	Managerial and Operational Risks	These risks negatively affect management and operations along the supply chain. They include poor asset allocation decisions, misuse of inputs, equipment breakdowns, inability to adapt to change, forecasting errors, lack of investment in agri-food product promotion, and lack of legal security in contracts or agreements with partners.	(Zhao et al., 2020)
R10	Natural Risks	These risks impact production, transportation, and storage, including earthquakes, hurricanes, floods, and fires. Extreme weather conditions, pandemics, landslides, resource contamination, pests, crop diseases, and resource scarcity also affect the supply chain.	(Ali et al., 2023a; Ali & Govindan, 2023; Altay & Ramirez, 2010; Diabat et al., 2012; Fan et al., 2021; Jacobi et al., 2019; Leat & Revoredo-Giha, 2013; Nyamah et al., 2017)

Source: Authors (2025).

The research procedure for this study was conducted in three distinct phases: (i) Exploratory Literature Review (ELR), (ii) Expert consultation, and (iii) Application of ISM, as illustrated in Figure 1.

Regarding the Exploratory Literature Review (ELR), this research aimed to identify the main risks in food supply chains through an exploratory search in the Scopus database. Keywords from Group 1 and Group 2 were combined using the Boolean operator 'AND' between the groups and 'OR' within each group, as presented in Table 2. The search was conducted within article titles.

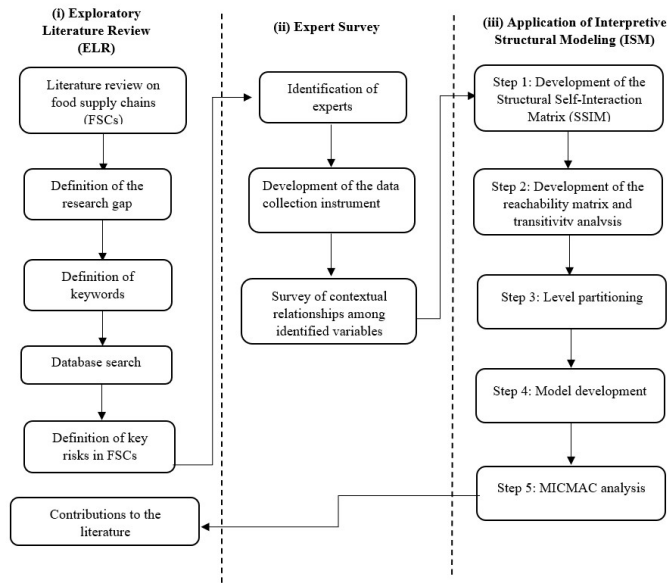


Figure 1. Methodological Procedures.
Source: Authors (2025).

Table 2. Keywords.

Group 1	Group 2
"Risk*" or "food supply chain risk" or "food industry hazards" or "risks in food networks" or "agricultural system risks" or "hazards in the food sector" or "food security challenges" or "hazards in food supply" or "threats to food systems" or "vulnerabilities in food chains" or "risks in agricultural networks" or "supply chain risk management"	"Food Chain" or "Food Distribution Network" or "Food Logistics" or "Food Production Chain" or "Food Value Chain" or "Food System" or "Food Network" or "Food Supply Chain" or "Food Manufacturing and Distribution" or "Agri-Food Supply Chain" or "Farm-to-Fork Chain" or "Food Procurement Chain" or "Food Industry"

Source: Authors (2025).

Regarding the experts responsible for analyzing the contextual relationships among the risks identified in food supply chains, a total of 10 respondents were consulted, including both academics and professionals from the food industry, as detailed in Table 3.

Table 3. Experts description.

Experts	Professional profile	Area of activity	Years of experience in the field
1	Professor and researcher	Production Engineering	15
2	Food Industry Professional	Supply chain, Source design, and strategy	20
3	Food Industry Professional	Customer Experience	6
4	Food Industry Professional	Environmental sustainability, occupational safety, and quality	24
5	Professor and researcher	Production Engineering	25
6	Food Industry Professional	Logistics	5
7	Professor and researcher	Logistics and Supply Chain Management	16
8	Professor and researcher	Product engineering	8
9	Professor and researcher	Product Development for the food sector, logistics and related areas.	12
10	Food Industry Professional	Oyster Farming	30

Source: Authors (2025).

In order to collect the data needed to carry out this study, a survey instrument was drawn up (see Supplementary Material – Questionnaire), which was sent to the experts using an electronic form. The choice of experts was based on their experience and knowledge of the topic covered in this article.

ISM represents a consolidated methodology for identifying relationships between specific items that define a problem or question (Hoang et al., 2023). Through a systematic and efficient process, it makes use of transitive inference to significantly reduce the number of relational queries required, achieving a reduction of 50% to 80% (Hossain et al., 2022; Kumar et al., 2015). This approach makes the hierarchy of complex systems and the logical relationship between internal factors more intuitive, making it easier to understand the interaction between the various elements in a system (Hoang et al., 2023).

To map and understand the relationships and interdependencies between the risks identified from the ELR and the operationalization of the ISM, several steps were followed:

The first step was the Development of the Structural Self-Interaction Matrix (SSIM): The SSIM was developed to represent the relationships between pairs of risks. These relationships were classified by the Decision Makers (DMs) into four categories: V: risk *i* influences *j*; A: risk *j* influences *i*; X: there is mutual influence; O: there is no relationship between *i* and *j*. These classifications were assigned on the basis of pairwise comparisons and contextual relationships. The total number of comparisons is given by nC_2 , where *n* is the number of variables analyzed (Ahmad & Qahmash, 2021).

The second step involved the Development of the Accessibility Matrix and Transitivity Analysis: Based on the SSIM, a binary accessibility matrix was constructed, converting the symbols into 0 and 1 values, as shown in Table 4. The transitivity check was applied to ensure logic between the pairs of variables, as required by the ISM model.

Table 4. Conversion of evaluations to a binary scale.

VAXO symbology	Correspondence (i, j)	Correspondence (j, i)
V	1	0
A	0	1
X	1	1
O	0	0

Source: Ahmad & Qahmash (2021).

The third step was partitioning the levels. This step is essential for defining the hierarchy between the variables. The sets of accessibility (influenced variables), antecedents (influencing variables), and their intersection are determined. Variables with the same accessibility and intersection sets receive the highest classification, are removed, and the process is repeated until all the variables have been classified. The partitioning of the risk variables into levels of importance within the modeled system has occurred, enabling the development of the model's digraph, which is a graphic representation of the causal relationships of the variables studied (Silva et al., 2024).

The fourth step was the MICMAC analysis: In this study, the MICMAC analysis was conducted to classify risks in food supply chains in Brazil, taking into account both Driving Power and Dependency Power. This tool allows risks to be categorized into four distinct groups: autonomous variables, binding variables, dependent variables, and independent variables. The integrated application of ISM and MICMAC resulted in the construction of a graphic model of the relationships between risks, offering a systemic view of their structure and interdependence.

This representation makes it possible to identify the most influential risks, guiding effective strategies for risk management in food supply chains in Brazil. The following stages of the study present the results and discussions derived from the application of these methods.

4. Results and discussions

The following section presents and discusses the results obtained through the ISM methodology. The process was structured into four stages, beginning with the development of the Structural Self-Interaction Matrix (SSIM), followed by the construction and analysis of the accessibility matrix, the partitioning of risk levels, and finally the formulation of the hierarchical model. These steps enabled the identification of the relationships and interdependencies among key risk factors affecting Brazil's food supply chains, providing a clear understanding of which risks exert the greatest influence on the system and which are most vulnerable.

4.1. Stage 1: development of the Structural Self-Interaction Matrix (SSIM)

The Structural Self-Interaction Matrix (SSIM) was constructed taking into account the conceptual relationships identified by the research participants, using symbology:

- V indicates that risk 'i' influences risk 'j', but there is no interdependence between them.
- A indicates that risk 'j' influences risk 'i', also without interdependence between the two.
- X represents a mutual relationship of influence between risks 'i' and 'j'.
- O shows that there is no relationship between risks 'i' and 'j'.

Table 5 shows the SSIM used to build the model, with the aggregate responses of the respondents. In this case, only one interaction was rated "O", specifically between risks R5 (technology and information management risks) and R6 (political and regulatory risks), indicating that there is no influence between them.

Table 5. SSIM of the model.

Variables	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
R1 Macro-level Risk		V	V	V	V	V	V	V	V	A
R2 Demand Management Risk			X	X	A	A	X	X	X	A
R3 Supply Management Risk				V	X	A	X	X	X	A
R4 Product Management Risk					A	A	X	X	X	A
R5 Technology and Information Management Risks						O	V	V	V	A
R6 Political and Regulatory Risks							V	V	V	A
R7 Financial and Corporate Management Risks								X	X	A
R8 Logistical and Infrastructural Risks									X	A
R9 Managerial and Operational Risks										A
R10 Natural Risks										

Source: Authors (2025).

4.2. Stage 2: development of the accessibility matrix and transitivity analysis

Table 6 shows the Accessibility Matrix of the model under development on a binary scale.

Table 6. Initial accessibility matrix for the model.

Variables	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	Driving power
R1 Macro-level Risk	1	1	1	1	1	1	1	1	1	0	9
R2 Demand Management Risk	0	1	1	1	0	0	1	1	1	0	6
R3 Supply Management Risk	0	1	1	1	1	0	1	1	1	0	7
R4 Product Management Risk	0	1	0	1	0	0	1	1	1	0	5
R5 Technology and Information Management Risks	0	1	1	1	1	0	1	1	1	0	7
R6 Political and Regulatory Risks	0	1	1	1	0	1	1	1	1	0	7
R7 Financial and Corporate Management Risks	0	1	1	1	0	0	1	1	1	0	6
R8 Logistical and Infrastructural Risks	0	1	1	1	0	0	1	1	1	0	6
R9 Managerial and Operational Risks	0	1	1	1	0	0	1	1	1	0	6
R10 Natural Risks	1	1	1	1	1	1	1	1	1	1	10
Dependence power	2	10	9	10	4	3	10	10	10	1	

Source: Ahmad Et Qahmash (2021).

The final matrix (Table 7) shows the connections between the 10 types of risks analyzed, classifying them according to their driving power and dependence. According to Yu et al. (2022), risks with high driving power are those that cause significant changes in the system. Risks with high dependency power are more vulnerable to external influences and must be closely monitored to prevent them from causing systemic instability.

Table 7. Final model accessibility matrix.

Variables	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	Driving power
R1 Macro-level Risk	1	1	1	1	1	1	1	1	1	0	9
R2 Demand Management Risk	0	1	1	1	1*	0	1	1	1	0	7
R3 Supply Management Risk	0	1	1	1	1	0	1	1	1	0	7
R4 Product Management Risk	0	1	1*	1	1*	0	1	1	1	0	7
R5 Technology and Information Management Risks	0	1	1	1	1	0	1	1	1	0	7
R6 Political and Regulatory Risks	0	1	1	1	1*	1	1	1	1	0	8
R7 Financial and Corporate Management Risks	0	1	1	1	1*	0	1	1	1	0	7
R8 Logistical and Infrastructural Risks	0	1	1	1	1*	0	1	1	1	0	7
R9 Managerial and Operational Risks	0	1	1	1	1*	0	1	1	1	0	7
R10 Natural Risks	1	1	1	1	1	1	1	1	1	1	10
Dependence power	2	10	10	10	10	3	10	10	10	1	

Source: Ahmad & Qahmash (2021).

The most influential risks are R10 (natural risks), with the greatest driving power (10), impacting all the other variables and potentially generating systemic effects, and R1 (macro-level risk), which largely influences the other risks, especially in the context of economic crises and global changes. With intermediate driving power (7), demand management risk (R2), supply management risk (R3), product management risk (R4), technology and information management risks (R5), financial and corporate management risks (R7), logistical and infrastructural risks (R8) and managerial and operational risks (R9) affect and are affected by other risks, demonstrating high interdependence. R6 (political and regulatory risks), with a driving power of 8, gained relevance in the final matrix, highlighting the importance of regulatory policies. The most vulnerable risks, with high dependency power (10), include demand management risk (R2), supply management risk (R3), product management risk (R4), technology and information management risks (R5), financial and corporate management risks (R7), logistical and infrastructural risks (R8) and managerial and operational risks (R9), which depend on other factors to manifest themselves and can be directly impacted by more influential risks. R6 (political and regulatory risks), with dependency power 3, has lower vulnerability, while R10 (natural risks), with dependency power 1, is the least influenced by the system, as its occurrence is independent of other variables.

4.3. Step 3: partitioning the levels

Table 8 shows the hierarchy of risks based on their accessibility, antecedents, and intersection, determining their levels within the model. R10 (natural risks) is at the highest level (4), as it only influences itself. R1 (macro-level risk) occupies level 3, influencing all risks except R10 (natural risks). R6 (political and regulatory risks) is at level 2, impacting itself and being influenced by R1 (macro-level risk) and R10 (natural risks). Demand management risk (R2), supply management risk (R3), product management risk (R4), technology and information management risks (R5), financial and corporate management risks (R7), logistical and infrastructural risks (R8) and R9 (managerial and operational risks) are at the lowest level (1), as they are highly interdependent, being simultaneously influenced by several risks and influencing others in the same group. This structure reveals that

Table 8. Partitioning of the listed risks.

Risks (Mi)	Accessibility Set R(Mi)	Antecedent Set A(Ni)	Intersection set R(Mi) ∩ A(Ni)	Levels
R1	1	1,10	1,	3
R2	2, 3, 4, 5, 7, 8, 9	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	2, 3, 4, 5, 7, 8, 9	1
R3	2, 3, 4, 5, 7, 8, 9	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	2, 3, 4, 5, 7, 8, 9	1
R4	2, 3, 4, 5, 7, 8, 9	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	2, 3, 4, 5, 7, 8, 9	1
R5	2, 3, 4, 5, 7, 8, 9	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	2, 3, 4, 5, 7, 8, 9	1
R6	6,	1, 6, 10	6,	2
R7	2, 3, 4, 5, 7, 8, 9	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	2, 3, 4, 5, 7, 8, 9	1
R8	2, 3, 4, 5, 7, 8, 9	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	2, 3, 4, 5, 7, 8, 9	1
R9	2, 3, 4, 5, 7, 8, 9	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	2, 3, 4, 5, 7, 8, 9	1
R10	10,	10,	10,	4

Source: Ahmad & Qahmash (2021).

R10 (natural risks) and R1 (macro-level risk) are the main drivers of impacts on the system, while the other risks are more vulnerable to external influences and require robust mitigation strategies.

4.4. Stage 4: model development

The ISM Model was designed by grouping the risks in Brazil's food supply chains, as detailed in Table 7. Next, the graphical representation of the structural model was constructed, in which the variables and their relationships are presented at the levels defined, as shown in Figure 2.

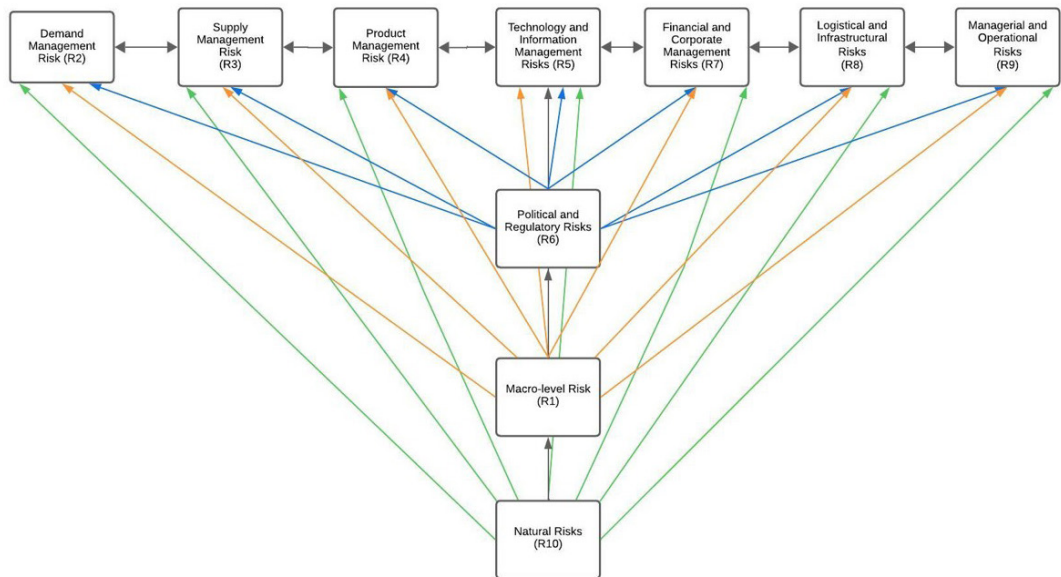


Figure 2: Representation of the proposed ISM model.

Source: Authors (2025).

According to the model obtained, the hierarchical structure indicates that the most influential risks are located at the bottom of the digraph, as they represent the aggregation of the various risk categories affecting the FSC. In this study, variable R10 (Natural risks) occupies the base of the model, reflecting the accumulated influence of the other risks throughout the structure. Variables demand management risk (R2), supply management risk (R3), product management risk (R4), technology and information management risks (R5), financial and corporate management risks (R7), logistical and infrastructural risks (R8) and R9 (managerial and operational risks) are positioned at the top level of the digraph, being the factors that have the greatest impact on the intermediate risks R6 (Political and regulatory risks) and R1 (Macro-level risks).

The model suggests that R6 (Political and regulatory risks) and R1 (Macro-level risks) act as connecting variables, as they receive direct influences from various risks and consolidate their interdependencies. These variables, in turn, converge on R10 (Natural risks), indicating that natural risks are strongly conditioned by the interaction between political, operational, technological, and infrastructural factors.

4.5. Step 5: MICMAC analysis

The MICMAC (Figure 3) analysis identified that demand management risk (R2), supply management risk (R3), product management risk (R4), technology and information management risks (R5), financial and corporate management risks (R7), logistical and infrastructural risks (R8) and R9 (managerial and operational risks), located in Quadrant III, have high steering power and high dependency power, which means that they influence other risks and are also strongly impacted. In Quadrant IV - Independent Variables, there are risks R1 (Macro-level risk), R6 (Political and regulatory risks), and R10 (Natural risks). These risks have high steering power and low dependency power, i.e., they are primary factors influencing the supply chain. This indicates that economic, political, and environmental changes can trigger or aggravate other risks within the chain.

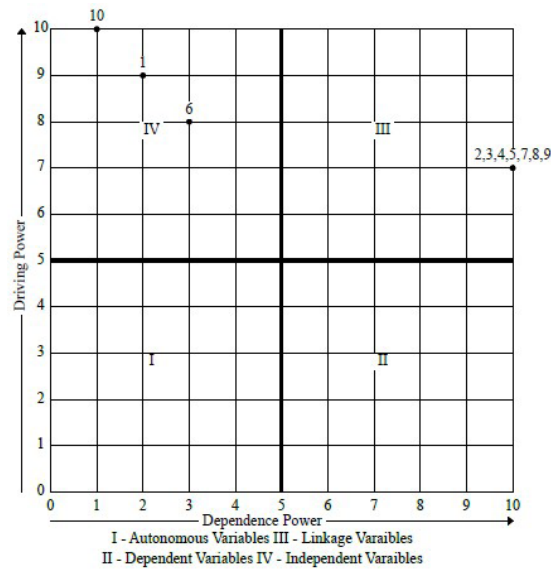


Figure 3. MICMAC analysis of the model. Source: Ahmad & Qahmash (2021).

In general, the analysis suggests that natural risks (R10) have the greatest driving power, being one of the main triggers of other risks in the FSCs, which was also presented in the studies by Ramos et al. (2021). Political and regulatory risks (R6) and macro-level risks (R1) also have a major influence, demonstrating that external and structural factors are crucial to the chain's functioning. On the other hand, the most dependent risks demand management risk (R2), supply management risk (R3), product management risk (R4), technology and information management risks (R5), financial and corporate management risks (R7), logistical and infrastructural risks (R8) and R9 (managerial and operational risks) suffer the impacts of these primary factors, which indicates that mitigation strategies should prioritize reducing the effects caused by independent risks to strengthen the resilience of the food supply chain.

4.6. Step 6: proposal to mitigate the identified risks

The mitigation strategies were not exclusively based on the literature but were formulated with input from the experts who participated in the modeling process. After analyzing the ISM hierarchy and the MICMAC influence–dependence map, the experts identified the most critical risks and proposed practical strategies for their mitigation. These proposals were subsequently reviewed and refined by the authors, based on the convergence of responses and supported by relevant literature.

Thus, the strategies reflect both the structural findings of the model and practical insights from industry professionals. The contributions were obtained through a questionnaire administered to the experts (see Supplementary Material – Questionnaire), and the analysis of their responses allowed the strategies to be synthesized, as presented in Table 9.

The strategies suggested by respondents to mitigate risks in FSCs in Brazil are in line with the literature. For macro-level risks, strategic partnerships, operational balance and the use of data stand out, as pointed out by (Kuizinaite et al., 2023). In the case of demand risks, the use of forecasting technologies, customer loyalty and internal integration are in line with (Nyamah et al., 2017; Jacobi et al., 2019).

In supply management, supplier diversification, robust contracts, and audits are strategies advocated by (Diabat et al., 2012; Zhao et al., 2020). For product and technology risks, the focus on quality, innovation, and information security confirms the findings of (Ali et al., 2023a; Diabat et al., 2012). As for regulatory risks, monitoring and early action are practices already recommended by Jacobi et al. (2019). In the financial area, cash control and investment diversification are in line with Zhao et al. (2022). Finally, preventive actions and rapid response to natural risks reflect what they propose (Jacobi et al., 2019; Zhao et al., 2022).

Table 9. Strategies suggested by respondents.

Risk category	Suggested strategies
Macro-level Risk	- Monitoring government and social trends. - Early warning system for instabilities. - Strategic partnerships for regulatory insights. - Mechanisms for forecasting trends. - Professionals trained to disseminate knowledge. - Development of resilience criteria: - Long-term partnerships; - Balance between lead time, capacity, and stock; - Investment in data collection and processing. - Forming a solid network of chain members.
Demand Management Risk	- Continuing education and exchange between sectors. - Increased quality and customer loyalty. - Constant communication with clients. - Collaborative planning with clients. - Advanced demand forecasting technologies. - Efficient feedback system. - Market monitoring and consumer trends. - Making the product essential to the customer. - Developing sales partners. - Portfolio management to avoid complexity. - Information standardization (systems, communication). - Calculation of minimum stock and turnover with alerts. - Approval policy for new clients/suppliers. - Supplier control. - Multiple suppliers per input. - Efficient S&OP. - Supplier diversification. - Strong contractual agreements. - Regular audits and quality assurance. - Research into innovation and identification of alternative raw materials. - Contingency plans for supply failures. - Strategic partnerships with a focus on reliability. - Proportionality in purchases. - Contracts with clear sanctions. - Logistics team focused on vehicle occupancy and route management. - Small product mix. - Communication with the consumer market. - Actions from the SAC. - Quality control. - Integrated quality control systems. - Active market research. - Production planning and control (PCP). - Professionals trained to analyze the production process. - Stock occupancy indicators. - Regular movement and balance follow-ups. - Crop planning with producers. - Research into storage and conservation. - Certifications and good production practices. - Reuse of underused packaging or raw materials. - Data security. - Qualified and motivated staff. - Efficient support in the face of instability. - IT continuity plan. - Ongoing IT training. - Knowledge management. - Alignment between technology and decision-making.
Supply Management Risk	
Product Management Risk	
Technology and Information Management Risks	

Source: Authors (2025).

Table 9. Continued...

Risk category	Suggested strategies
Political and Regulatory Risks	- Monitoring trends and speeding up adjustments. - Regulatory impact assessment. - Participation in lobby groups and associations. - Monitoring legislative projects. - Prevention of government changes. - Active action at a macro level. - Guarantee of compliance at the manufacturing and technological level. - Management of the fleet and/or contractors with strict procedures. - Reducing the structure and number of suppliers. - Diversity of service providers. - Investment in quality of service and efficient partnerships. - Definition of standards to minimize errors. - Continuous analysis of transport routes. - Strategic logistics partnerships. - Technologies for controlling loads and updating planning. - A complete study of the logistics process.
Financial and Corporate Management Risks	
Logistical and Infrastructural Risks	- Definition of whether logistics will be a competitive differentiator (e.g., own or outsourced fleet). - Control of suppliers and analysis of financial health. - Committed management and agile decisions. - Efficient control of standards to reduce waste. - Analysis of financial risks (exchange rates, interest rates). - Investment diversification. - Tools compatible with the market and financial capacity. - Trained professionals to avoid unnecessary costs. - Currency lock strategy. - Preventive maintenance of machinery and equipment. - Improving the quality of the workforce. - Management is committed to the mission and objectives. - Well-defined processes. - Dynamic strategic planning. - Investment in innovation. - Indicators and monitoring metrics. - Professionally trained in process analysis. - Focus on operational efficiency and continuous improvement. - Alignment of operational management with business strategy. - Agility to adapt and change. - Preventive maintenance (roofs, bodies, trunks). - Well-defined security plan. - Reaction to unavoidable events (e.g., RS flood). - Early warning and response systems. - Environmental risk assessment. - Plan for preventing abnormalities. - Insurance against mishaps.
Managerial and Operational Risks	
Natural Risks	- Consider tactical (production and distribution) and strategic (minimizing impact with agents of change) actions.

Source: Authors (2025).

5. Conclusion

This study aimed to identify the main risks affecting Brazilian food supply chains, analyze their interrelationships, and propose mitigation strategies using Interpretive Structural Modeling (ISM) and MICMAC analysis. The results obtained made it possible to identify the most influential and dependent risks, as well as to understand the structure of interrelationships between them.

The most influential were macro-level risks and natural risks, which are considered critical because of their high impact on other risks. On the other hand, risks such as demand, supply management, and

operational risks were highly dependent, highlighting the need for coordinated and integrated strategies to mitigate them.

The ISM application made it possible not only to rank the risks, but also to map their interdependencies, offering a systemic and strategic view of the chain. The MICMAC analysis complemented the model by categorizing risks according to their driving power and dependency, making it easier to define priorities for organizational management.

In the theoretical field, the study investigates risks in FSCs in Brazil and the use of ISM. In the practical field, it offers guidance for managers, based on mitigation strategies drawn up on the basis of the perceptions of specialists, contributing to increasing the resilience, predictability, and response capacity of organizations in the face of disruptive events.

However, some limitations must be acknowledged. The qualitative approach and the small number of participants may limit the generalizability of the results. In addition, the impact of certain risks may vary according to the type of food (fresh or processed), the size of the company, and the geographical scope of its operations (local, national, or international).

It is therefore recommended that future studies be carried out that expand the sample, incorporate quantitative methods, and carry out case studies in different segments and regions. Comparisons with international research could also enrich our understanding of the challenges faced by FSCs and validate the applicability of the proposed model.

The findings offer practical guidance for managers and policymakers by identifying which risks—especially macro-level and natural risks—exert the greatest systemic influence. This prioritization enables more effective targeting of mitigation efforts, contributing to the strengthening of the food supply chain (FSC) resilience. To enhance the empirical robustness of these findings, future studies are encouraged to adopt quantitative validation techniques such as Structural Equation Modeling (SEM), Analytic Network Process (ANP), or Fuzzy Cognitive Maps (FCM). These approaches can help verify causal relationships, assess the consistency of expert judgments, and quantify interdependencies among risk factors.

Data availability

Research data is available in the body of the article.

References

- Ahmad, N., & Qahmash, A. (2021). SmartISM: implementation and assessment of interpretive structural modeling. *Sustainability*, 13(16), 8801. <http://doi.org/10.3390/su13168801>.
- Ali, I., Golgeci, I., & Arslan, A. (2023a). Achieving resilience through knowledge management practices and risk management culture in agri-food supply chains. *Supply Chain Management*, 28(2), 284-299. <http://doi.org/10.1108/SCM-02-2021-0059>.
- Ali, I., Sadiddin, A., & Cattaneo, A. (2023b). Risk and resilience in agri-food supply chain SMEs in the pandemic era: a cross-country study. *International Journal of Logistics Research and Applications*, 26(11), 1602-1620. <http://doi.org/10.1080/13675567.2022.2102159>.
- Ali, I., & Govindan, K. (2023). Extenuating operational risks through digital transformation of agri-food supply chains. *Production Planning and Control*, 34(12), 1165-1177. <http://doi.org/10.1080/09537287.2021.1988177>.
- Altay, N., & Ramirez, A. (2010). Impact of disasters on firms in different sectors: implications for supply chains. *The Journal of Supply Chain Management*, 46(4), 59-80. <http://doi.org/10.1111/j.1745-493X.2010.03206.x>.
- Attri, R., Dev, N., & Sharma, V. (2013). Interpretive structural modelling (ISM) approach: an overview. *RESEARCH Journal of Management Sciences*, 2(2), 117-127.
- Bassett, H. R., Lau, J., Giordano, C., Suri, S. K., Advani, S., & Sharan, S. (2021). Preliminary lessons from COVID-19 disruptions of small-scale fishery supply chains. *World Development*, 143, 105473. <http://doi.org/10.1016/j.worlddev.2021.105473>. PMID:36567900.
- Camargo, F. G. (2023). A hybrid novel method to economically evaluate the carbon dioxide emissions in the productive chain of Argentina. *Production*, 33, e20220053. <http://doi.org/10.1590/0103-6513.20220053>.
- Carpitella, S., Mzougui, I., & Izquierdo, J. (2022). Multi-criteria risk classification to enhance complex supply networks. *Opsearch*, 59(3), 769-785. <http://doi.org/10.1007/s12597-021-00568-8>.
- Carvalho, K. L. D., Costa, R. P. D., & Souza, R. D. C. (2014). Strategic management of relationships in lettuce supply chain. *Production*, 24, 271-282. <http://doi.org/10.1590/S0103-65132013005000031>.
- Diabat, A., Govindan, K., & Panicker, V. V. (2012). Supply chain risk management and its mitigation in the food industry. *International Journal of Production Research*, 50(11), 3039-3050. <http://doi.org/10.1080/00207543.2011.588619>.
- Fan, S., Cho, E. E., Meng, T., & Rue, C. (2021). How to prevent and cope with coincidence of risks to the global food system. *Annual Review of Environment and Resources*, 46(1), 601-623. <http://doi.org/10.1146/annurev-environ-012220-020844>.

- Gruzauskas, V., Burinskiene, A., & Krisciunas, A. (2023). Application of information-sharing for resilient and sustainable food delivery in last-mile logistics. *Mathematics*, 11(2), 1-21. <http://doi.org/10.3390/math11020303>.
- Hachicha, W., & Elmsalmi, M. (2014). An integrated approach based on structural modeling for risk prioritization in supply network management. *Journal of Risk Research*, 17(10), 1301-1324. <http://doi.org/10.1080/13669877.2013.841734>.
- Haleem, A., Sushil, S., Qadri, M. A., & Kumar, S. (2012). Analysis of critical success factors of world-class manufacturing practices: an application of interpretative structural modelling and interpretative ranking process. *Production Planning and Control*, 23(10-11), 722-734. <http://doi.org/10.1080/09537287.2011.642134>.
- Hendricks, K. B., & Singhal, V. R. (2009). An empirical analysis of the effect of supply chain disruptions on long-run stock price performance and equity risk of the firm. *Production and Operations Management*, 14(1), 35-52. <http://doi.org/10.1111/j.1937-5956.2005.tb00008.x>.
- Hoang, T. T., Bell, J. E., & Goldsby, T. J. (2023). Making supply chain traceability strategic: insights from the food industry. *International Journal of Physical Distribution & Logistics Management*, 53(9), 913-945. <http://doi.org/10.1108/IJPDLM-03-2022-0064>.
- Hossain, M. K., Thakur, V., & Mangla, S. K. (2022). Modeling the emergency health-care supply chains: responding to the COVID-19 pandemic. *Journal of Business and Industrial Marketing*, 37(8), 1623-1639. <http://doi.org/10.1108/JBIM-07-2020-0315>.
- Ivanov, D., Sokolov, B., & Dolgui, A. (2014). The Ripple effect in supply chains: trade-off 'efficiency-flexibility-resilience' in disruption management. *International Journal of Production Research*, 52(7), 2154-2172. <http://doi.org/10.1080/00207543.2013.858836>.
- Jacobi, J., Mukhovi, S., Llanque, A., Toledo, D., Speranza, C. I., Käser, F., Augstburger, H., Delgado, J. M. F., Kiteme, B. P., & Rist, S. (2019). Actor-specific risk perceptions and strategies for resilience building in different food systems in Kenya and Bolivia. *Regional Environmental Change*, 19(3), 879-892. <http://doi.org/10.1007/s10113-018-1448-x>.
- Kawasaki, B. C., & Mascia, F. L. (2025). Discussing the challenges of Operational Experience Feedback processes from the perspective of Psychodynamics of Work. *Production*, 35, e20240049. <http://doi.org/10.1590/0103-6513.20240049>.
- Kersten, C. C., Kerber, J. M. C., Silva, J. D. S., Bouzon, M., & Campos, L. M. S. (2024). Traceability in the agri-food supply chain: A new perspective under the Circular Economy approach. *Production*, 34, e20240009. <http://doi.org/10.1590/0103-6513.20240009>.
- Kobayashi, K. K., Cantamessa, M., & Carvalho, M. M. (2025). Unveiling multilayered barriers to agile methodologies: An exploratory study on relationships among barriers. *Production*, 35, e20240096. <http://doi.org/10.1590/0103-6513.20240096>.
- Kuizinaite, J., Morkunas, M., & Volkov, A. (2023). Assessment of the most appropriate measures for mitigation of risks in the agri-food supply chain. *Sustainability*, 15(12), 9378. <http://doi.org/10.3390/su15129378>.
- Kumar, S., Gorane, S., & Kant, R. (2015). Modelling the supplier selection process enablers using ISM and fuzzy MICMAC approach. *Journal of Business and Industrial Marketing*, 30(5), 536-551. <http://doi.org/10.1108/JBIM-01-2013-0012>.
- Leat, P., & Revoredo-Giha, C. (2013). Risk and resilience in agri-food supply chains: the case of the ASDA PorkLink supply chain in Scotland. *Supply Chain Management*, 18(2), 219-231. <http://doi.org/10.1108/13598541311318845>.
- Lund, S., Manyika, J., Woetzel, J., Barriball, E., Krishnan, M., Alick, K., Birshan, M., George, K., Smit, S., Swan, D., & Hutzler, K. (2020). *Risk, resilience, and rebalancing in global value chains*. New York: McKinsey Global Institute.
- Luthra, S., Kumar, V., Kumar, S., & Haleem, A. (2011). Barriers to implementing green supply chain management in the automobile industry using interpretive structural modeling technique: an Indian perspective. *Journal OF Industrial Engineering and Management*, 4(2), 231-257. <http://doi.org/10.3926/jiem.2011.v4n2.p231-257>.
- Montes Causil, O. M., & Morais, D. C. (2023). Multicriteria negotiation model for selecting sustainable suppliers' problem in the agribusiness. *Production*, 33, e20220090. <http://doi.org/10.1590/0103-6513.20220090>.
- Nakai, J. (2018). Food and Agriculture Organization of the United Nations and the sustainable development goals: natural resources management officer, FAO. From the millennium development goals to the sustainable development goals. *Sustainable Development*, 22, 3-11.
- Nyamah, E. Y., Jiang, Y., Feng, Y., & Enchill, E. (2017). Agri-food supply chain performance: an empirical impact of risk. *Management Decision*, 55(5), 872-891. <http://doi.org/10.1108/MD-01-2016-0049>.
- Ramos, E., Pettit, T. J., Habib, M., & Chavez, M. (2021). A model ISM-MICMAC for managing risk in the agri-food supply chain: an investigation from the Andean region of Peru. *International Journal of Value Chain Management*, 12(1), 62-85. <http://doi.org/10.1504/IJVC.2021.112845>.
- Septiani, W., Marimin, M., Herdiyeni, Y., & Haditjaroko, L. (2016). Method and approach mapping for agri-food supply chain risk management: a literature review. *International Journal of Supply Chain Management*, 5(2), 51-64.
- Senna, P., Reis, A., Guimarães, J. D., Marujo, L. G., Santos, A. C. S. G., & Severo, E. A. (2023). Healthcare supply chain risk assessment KPIs: an empirical study using PLS-SEM. *Production*, 33, e20220107. <http://doi.org/10.1590/0103-6513.20220107>.
- Silva, V. L. D. S., Souza, R. D. C., Silva, A. A. P. D., & Saes, M. S. M. (2015). Strategy management of multi-channel distribution: a study in the Brazilian food industry. *Production*, 26, 115-128. <http://doi.org/10.1590/0103-6513.039112>.
- Silva, J. S., Oliveira, A. M., Oliveira, J. V., & Bouzon, M. (2024). Barriers to digital transformation in fruit and vegetable supply chains: a multicriteria analysis using ISM and MICMAC. *Opsearch*, 62(1), 460-482. <http://doi.org/10.1007/s12597-024-00809-6>.
- Singh, A., Gupta, A., & Mehra, A. (2021). Best criteria selection based PROMETHEE II method. *Opsearch*, 58(1), 160-180. <http://doi.org/10.1007/s12597-020-00464-7>.
- Teerasoponpong, S., & Sopadang, A. (2022). Decision support system for adaptive sourcing and inventory management in small- and medium-sized enterprises. *Robotics and Computer-integrated Manufacturing*, 73, 102226. <http://doi.org/10.1016/j.rcim.2021.102226>.
- Yu, V. F., Chiang, F.-Y., Le, T. H. A., & Lin, S.-W. (2022). Using the ISM method to analyze the relationships between various contractor prequalification criteria. *Applied Sciences*, 12(8), 3726. <http://doi.org/10.3390/app12083726>.

- Zhao, G., Liu, S., Lopez, C., Chen, H., Lu, H., Mangla, S. K., & Elgueta, S. (2020). Risk analysis of the agri-food supply chain: a multi-method approach. *International Journal of Production Research*, 58(16), 4851-4876. <http://doi.org/10.1080/00207543.2020.1725684>.
- Zhao, G., Olan, F., Liu, S., Hormazabal, J. H., Lopez, C., Zubairu, N., Zhang, J., & Chen, X. (2022). Links between risk source identification and resilience capability building in agri-food supply chains: a comprehensive analysis. *IEEE Transactions on Engineering Management*, 71, 13362-13379. <http://doi.org/10.1109/TEM.2022.3221361>.

Author Contributions

Eveliny Dias de Medeiros: Conceptualization, Funding acquisition, Supervision, Writing – original draft, Writing – review & editing

Rosania Monteiro Coutinho: Writing – original draft, Methodology

João Paulo Maximiano Almeida: Methodology

Marina Bouzon: Writing – review & editing, Methodology

Supplementary Material

Supplementary material accompanies this paper.

Legenda S1. Questionnaire.

This material is available as part of the online article from <https://doi.org/10.1590/0103-6513.20250049>