




# Assessing risk and sustainability factors in spice supply chain management

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## Abstract

The inopportune organization of spice supply chains (SSCs) results in aided risks, resource wastages, and sustainability issues. Nevertheless, practitioners and academicians alike must investigate spice supply chain management (SSCM) in terms of long-term sustainability. This study draws on the available literature to compile a collection of characteristics and maintain sustainable spice supply chain management techniques which come up with associated risks and relevant obstacles. Existing studies claim that due to a lack of resources, the associated risks are the root of poor SSCM performance. As a result, the goal of this study is to identify the primary risk variables using qualitative data; nevertheless, the attributes must be converted into a scale that is comparable. The fuzzy Delphi method (FDM) was used to obtain valid and reliable attributes from qualitative data, while the fuzzy decision-making trial and evaluation laboratory (FDEMATEL) was used to address uncertainty and interrelationships simultaneously. FDM results suggest that there are eighteen critical risk variables and seven risks threatening effective SSCM. FDEMATEL results reveal qualitative data translated into crisp, comparable values in order to investigate causal linkages between variables and confirm the compatibility of the theoretical structure with industry realities. The findings show fluctuation in the Price (C8), diseases and pests (C20), human contamination (C23), spice adulteration (C24), and loss of food quality, and quantity (C36) are all important risks and sub-risks in these causative interrelationships. The primary risks involved in enhancing SCM include Financial Risk (A5), Ergonomic Risk (A8), and Operation and Management Risk (A10). The study recommends that industry professionals use future marketing tools to protect themselves from price changes which allow them to assess supply and demand circumstances and manage price risks over distance and time. Spices are the key contributors to earning a sizable amount of foreign currency through export in a developing country. It suggests to policymakers, regulatory organizations, and practitioners to develop regulations, raise farmer understanding about pest control, impose stiff penalties on vendors and businesses proven to be involved in spice adulteration, and develop a sustainable fertilizer distribution system. These corresponding action plans for improving the SSC sector and comparing it with agro-food and short-supply chains are investigated. This study contributes to theory by utilizing FDM and FDEMATEL methods for addressing the uncertainty and interrelationship among associated risks that hinder SCM from attaining sustainability.

**Keywords** Risk management · Supply chain · Sustainability · Spice supply Chain · Fuzzy delphi · DEMATEL

## 1 Introduction

Spices have an extensive background of use as a herbal remedy to prevent sickness and sustain the mental as well as physical health of humanitarians. Ayurveda is a traditional treatment of herbal medication and is also used to flavor, color, and preserve food (Gidwani et al. 2022). Dried or raw whole spices, powder forms, pastes, dehydrated material, and extractives are examples of spices which has specific properties due to a unique volatile oil or molecule that they

possess (Siruguri and Bhat 2015). Many enterprises begin to avoid reporting the spices' origin, especially when they are a combination of different sorts or sources, however, customers are becoming more conscious of food materials' quality in their diets. The reported rise in food adulteration occurrences in digital media has fueled calls for more stringent control over spice quality. The spice supply chain (SSC) has been plagued by economically motivated adulteration, such as the mixing of high and low-grade spices (Lixourgioti et al. 2022). As a result, detection of potential adulterants in the initial life stage, and other associated risks in spices are critical for supply chain stakeholders and consumers to achieve safe and sustainable livelihood. Though,

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at first glance, it looks like a simple food supply chain, the spice industry's control over spice quality, its durable shelf life, and safety monitoring make it more complex to manage (Aradwad et al. 2021).

The SSC has been managed in a three-phase procedure named, i) the collection of necessary inputs; ii) the production of spices in fields which involves the interaction of human labor, natural forces, and other inputs; and iii) the logistical distribution (Lezoche et al. 2020). The first and last phases of SSC can be controlled through administrative engagements, while the second phase of spice production raises superfluous challenges for the practitioners. Further to this, Nadezda et al. (2017) emphasized the importance of paying extra attention while considering natural events and climate risks in spice agriculture as output fluctuations owing to climate change are inherent. This can result in lower earnings and varying amounts of risks depending on the geographies where the spices are produced and stored. Also, Kamble et al. (2020) argued, that the spice agriculture sector has received more attention for accomplishing sustainability, with an emphasis on management practices in spice cultivation and improvements in social as well as environmental circumstances. The present literature states research restrictions that dearth of resilient food safety and quality control regulations, lack of organized industrialization, managerial inadequacy, and information inaccuracy are all key concerns that must be properly addressed in order to attain sustainability in SSC (Székács et al. 2018; Chauhan et al. 2020; Liu et al. 2021).

The goal of SSC management is to reduce the influence of the SC on the ecosystem, where the agricultural industry still holds 70% of employment (Kumar et al. 2021). SSC is characterized by stringent regulations and a number of middlemen, resulting in various inefficiencies and lower profit margins for the farmers. Firms are attempting to decrease carbon emissions, reduce transportation and food wastages, and utilize technologies to remain competitive (Goodarzian et al. 2022). SSC practitioners are collaborating with farmers to develop sustainable cultivations while simultaneously assisting their companies with digital transformation (Hobbs 2020). Managers must address the special concerns of SSC development, technology infrastructure, and logistics in the context of spices (Mangla et al. 2019; Raj et al. 2023a). Studies have indicated that detecting spice adulterants is of importance to regulatory bodies, food processors, and consumers in order to meet criteria for quality and safety (Gidwani et al. 2022). Furthermore, Székács et al. (2018) highlighted that human contamination is a major issue that has been linked to numerous pollutants found in spice goods and needs to be reduced.

Yazdani et al. (2019) claim that a large amount of effort is being paid to regulate and minimize hazardous effects on SSC. Furthermore, as far as the researchers are aware, the risk

assessment factors and their interdependency have not been adequately addressed. Recently, Harris et al. (2022) emphasized the need to enact policies that lower the impact of disaster risks on SSC performance and thereby improve its sustainability. This implies that analyzing climate hazards having a negative impact on supplied spice quantity could assist in prioritizing policy alternatives to prevent impacts on spice availability; one aspect of food security is to provide more relevant insights. Though the measure of risk has been widely attempted for food supply chains (Aggarwal and Srivastava 2016), the rising complexity and interdependence of SSC makes it difficult to foresee challenges, and it reveals managers' less preparedness towards uncertainty (Heckmann et al. 2015).

The SC uncertainties imply analyzing associated risks that have a negative impact on spice quantity. Further, the quality could assist in prioritizing policy alternatives to prevent impacts on spice availability; one aspect of food security is to provide insights that are more relevant but are still missing in literature focusing on SSC risks that they face in spice farming. The existing policies need to be re-designed to develop regulations, raise farmer's understanding of pest control, and impose penalties on vendors involved in spice adulteration. Also, it is required to develop a sustainable fertilizer distribution system that will directly benefit the SSC stakeholders. Though research for translating qualitative data into quantitative decisions for visual examination exists adequately (Tseng et al. 2022a), the decision-makers verbal preferences are required to investigate the causal links between them. This study contributes to existing state-of-art literature through a robust solution that helps to reach a consensus opinion from an expert panel for choosing the relevant judgments addressing uncertainty and interrelationship among associated risks which hinders SCM from attaining sustainability. In light of this, the goal of the research is to present a novel approach to investigating risk factors associated with SSCM and evaluating their combined impact. This research questions emphasis in the following ways.

*RQ1: How to identify and quantify the associated risk in the spice supply chain?*

*RQ2: Can the findings aid in risk mitigation by the industry managers?*

The points that follow are a few aspects that this work adds to the body of SSCM literature. To identify the risk factors that affect SSC, the research first uses FDM to conduct a literature review and expert interviews. In doing so, the study establishes a link between supply chain and risk management. Second, it categorizes the risk elements in accordance with SCM theories. Together, these two concepts enabled us to identify and classify facilitators in every situation. This offers valuable insights into the rationale for and methods for locating and valuing the

associated risk in SSCs. Third, fuzzy DEMATEL is employed in this study to rank the risk factors. The rest of the paper is structured as follows. Through a literature study of SSC, Section 2 tackles the risks, assessment features, and proposed approach. Section 3 examines the case history and details the procedures. The FDM results are reported in Section 4, followed by the study's discussion and findings as well as implications presented in Sections 5 and 6. Finally, Section 7 presents the limitations of the research along with further research directions.

## 2 Literature review

This section reviews literature addressing SSC risks, mitigation approaches, and sustainable measures that have been proposed to provide a better theoretical understanding.

### 2.1 Sustainability in SSC

The manufacturing industry emphasizes the processing of materials and their quality because it is vital for sustainable SSC management. A supply chain is a grouping of 3 or more entities, such as people or businesses, that are directly involved in the downstream and upstream flows of money, services, goods, and communication to the producer through the consumer. SSC is the cycle of procedures related to the purchasing, farming, production, and distribution of spices which may involve a number of sites around the world (Samad et al. 2021). Input suppliers, producers, intermediaries, processors, distributors, retailers/exporters, national/international markets, and lastly the consumers are all components of the SSC (Galvin-King et al. 2018). Due to their significant economic worth, spice, and their extracts are vulnerable to problems like fraudulent activities and contamination in many forms. Due to restricted quality and production in some geographic regions, SCM has lengthy and complex systems, making it extremely vulnerable to food fraud. Production, processing (cleanup, grading, separating, grinding, and pulverizing), packaging, long-term storage (for most of the spices), distribution, including retail and wholesale businesses, the auctioning process, intermediate, and export are all included in the supply chain of spices (Modupalli et al. 2021). As consumers are becoming more aware of food quality and safety issues as the globalization period progresses. Firms begin to implement "fraud control measures" in order to detect fraud possibilities or motives that may arise both within and externally. To ensure food safety, processing, and manufacturing must be closely monitored and coordinated efficiently. It's critical to keep the product clean and safe from contamination and adulteration. Adulteration can occur at any point during the mixing and packaging process, thus it must be closely monitored. The output is often enclosed

during this process in more contemporary processing plants. The cost of operating these requirements can be costly, but they are critical to SSC's long-term sustainability. SSC faces many risks from a growing global population, changing tastes with increased demand for spices, and climate change, making risk management (RM) more vital than ever. As a result, this research focused on creating an environment favorable to mitigate risks in SSC and also supporting the necessary drivers to attain an SSC system.

Produced and processed spices are distributed directly to customers by a number of businesses in the market (Sharangi and Acharya 2018). To ensure spices' long-term sustainability, processing and production must be closely monitored. A variety of fraud risks can occur, such as misrepresentation, adulteration, and substitution, can occur at any point along this supply chain (Galvin-King et al. 2018). This warrants the industries with an urgent need for quality assurance and control of spice components. Additionally, a rise in international business trends has made it easier for nations to import and export goods (IBEF (India Brand Equity Foundation) 2023). This makes it simple for endemic pests and contaminants to spread from one nation to another which demands quality and safety declaration along with a rise in consumer knowledge about food commodities (Modupalli et al. 2021). Moreover, Mangla et al. (2015) argued that a lack of skilled labor, information sharing, and IT infrastructures can also disrupt SC. Aside from these frauds, there are other risks to consider, such as weather/natural disasters, quality, market, logistic and infrastructure, technical, ergonomic, political, policy and institutional, financial operational, and management risk, which can affect the entire supply chain. Therefore, SSC is essential to impart in SSC because SSC is an eco-system in which the processed spices from raw spices are consumed on human demand for daily uses, and the sustainability in SSC is ensured through controlling or mitigating such risks.

### 2.2 Risk management in SSC

Risk is described as the likelihood of unexpected potential occurrence and the negative repercussions that occur throughout the SC. As a result, this research adheres to the Risk Management (RM) definition, which is defined as "the management of SSC-associated risk through collaboration or cooperation among supply chain participants in order to maintain profitability and continuity". The reasons for the development of risks are irrelevant in this classification: it could occur within a single company, within SSC, or its environment (Heckmann et al. 2015). There are two types of supply chain risk factors: endogenous risks and exogenous risks. The parties involved operate and oversee the supply chain. The shocks that are produced and exacerbated within the SC are referred to as endogenous hazards (Tsolaklis et al. 2021). There are five basic types of endogenous

risks in SSC: risks to quality, risks to technology, risks to ergonomics, risks to logistics and infrastructure, and risks to operation and management. Endogenous risks are unique, affecting supply chain members separately. It is possible that subsequent links won't be impacted and even benefit from the party in trouble. Contrarily, exogenous risks are shocks that originate from outside the SC and have an equal impact on all supply chain actors (Liu et al. 2023). These risks have an effect since they are correlated with supply chain concerns. Exogenous risks in SSC mostly fall under five categories: risks related to the environment/natural disasters, markets, politics, policies and institutions, and financial risks. When exogenous hazards arise, the government typically implements a safety net and provides subsidies. Unexpected risks that influence the environmentally cordial movement of materials, and even disrupt the proposed product flow from their site of origin to their consumption point, are threats to the SC (Mangla et al. 2015). The goal of RM is to lower the likelihood of dangers and lessen the severity of potential losses. One of the main strategies used by businesses to ensure their survival and get past uncertainties in order to achieve their objectives is RM, which takes into account the peripheral uncertainty of the business caused by political issues, the economic climate, natural phenomena, and technological advancements (Priscila et al. 2022).

All stakeholders must have an RM procedure in place to deal with risks that threaten logistics, information, relationships, and delays in the supply chain. It can be achieved via cooperation and the application of RM tools by all participants to ensure the delivery of a consistent product or service to customers (Priscila et al. 2022). Disruptions are expressions of SC threats, causing the development of methods to deal with them. SSC-RM practices, for the most part, aim to minimize susceptibility and try to reduce disruption effects. The existing research demands a complete SSC-RM framework that consists of identifying, analyzing, mitigating, and super-visioning associated risks. As a result, the purpose of SSC-RM operations is to reduce the impact of interruptions that disturb data and information flows inside the SSC (El Baz and Ruel 2021).

Achieving sustainability in SSC is becoming core for an organization considering the economical, societal, and environmental dimensions related to SSC-RM throughout the business process synchronization in order to ensure long-term viability, durability, and sustainability. SSC-RM has become an even more crucial topic in SSC where a large variety of associated risks such as seasonality, supply surges, extended supply lead-times, and perishability, not only cause disruption in SSC but also reduce the performance efficiency to attain sustainability in SSC. Moreover, unexpected events with significant consequences for spice growers continue to occur, implying that the nature of risk has altered

over time (Yazdani et al. 2019). Therefore, SSC performance cannot be measured without taking into account sustainable risk indicators, which is why SSC-RM is important when evaluating SSC sustainability performance (Abdel-Basset and Mohamed 2020).

### 2.3 Proposed method

Galvin-King et al. (2018) applied analysis, Mass spectrometry, Spectroscopy, Combination of detection methods to determine fraud detection in the spice industry and its customers. Yazdani et al. (2019) developed a multi-criteria decision-making methodology to reduce flood risks and their effects on farming regions. Kumar et al. (2021) integrated the ISM-ANP approach to determine barriers to adopting I4.0-CE. Aradwad et al. (2021) used the DEMATEL approach for reducing quality loss during spice processing.

In light of these concerns, we propose that the FDM and the FDEMATEL methodology be used in this research to analyze the risks in SSC. This research suggests using an FDM to reduce irrelevant risks, build a hierarchical connection, and highlight significant risks based on an expert evaluation to demonstrate the importance of related risks in SSC. Experts' linguistic choices are converted into numeric values based on human decisions using fuzzy set theory, which allows for significant uncertainty while maintaining qualitative qualities (Priyan et al. 2022). After that, the Delphi approach is used to absorb all expert assessments and eliminate unneeded variables (Tseng et al. 2022b). This combination strategy allows professionals to barter their judgment based on their experience and expertise while also simplifying difficulties by resolving the uncertainty associated based on the given information (Tseng et al. 2022a). Deveci et al. (2020) used the FDM to extract the features that are critical for approaching hydrogen-generating systems. When assessing the risks of the approached survey and the quality of survey analysis, Al-Rikabi and Montazer (2023) used this method to support the mitigation of uncertainty from evaluations. This method enables collective decision-making, which handles a large number of choices by achieving instant convergence in sentiment prediction and afterwards assisting decision-makers in reducing decision-making time.

In addition, fuzzy DEMATEL was used to identify the critical risks in SCM and to investigate the causative impacts and interconnectedness among the presented risks in this research. Wu et al. (2017) advocated for the qualities to transfer statistical computations to tackle complicated challenges. Gupta et al. (2020) looked at the distribution of attributes using a thorough methodology that can transcend complexity, classify variables into effect groups, and give visual analysis. As a result, the problem complexity is decreased, and the correlation between risks and sub-risks is validated, by combining the benefits of FDM for reducing unneeded attributes with the



virtues of FDEMATEL for analyzing the interdependencies among the attributes and the consistency among them.

## 2.4 Proposed risks

There is just a limited fraction of the study on the risks associated with SSC. Books, scientific journals, and management-oriented publications are the primary sources of information. These sources are especially relevant and influence the development of all research processes, particularly in the early stages of the SCM. This research examines the risks and sub-risks, magnitude, and level of risk presented to the spice supply chain. Table 1 lists the risks and sub-risks for the adoption of sustainable innovations, both general and unique to SSC, in order to provide an overview. This research highlights attributes that include 10 risks and 40 sub-risks. The risks are Weather/Natural Disasters Risk, Market Risk, Political Risks, Policy and Institutional Risks, Financial Risks (A5), Quality Risks (A6), Technical Risks (A7), Ergonomic risks (A8), Logistic and Infrastructure Risks (A9), and Operation and Management Risk (A10) as seen in Table 1.

Weather/Natural disasters such as hurricanes, thunderstorms, and floods have wreaked havoc on SC in recent decades, having a devastating impact on social communities and industrial sectors (Yazdani et al. 2019). Heckmann et al. 2015 conducted extensive research, and it is widely known that natural disasters are difficult to foresee because of climate change that affects agriculture production which has repercussions throughout the supply chain. Moreover, Flood has the greatest influence on agricultural growth, according to a significant number of current research in the larger literature, as it ruins massive hectares of crops and dwellings in a short period frame (Neupane and Kumar 2015; Coomes et al. 2016). However, Harris et al. (2022) argued that disruptions in the production and operation of essential productivity have significant detrimental effects on both the SC infrastructure and agricultural production.

Market risks are related to price volatility, market availability, seasonal variance, and the economic cycle. Moktadir et al. (2021) argued that supplier sourcing has benefited businesses by providing options in the event of a capacity restriction or a potentially harmful disruption but switching suppliers might come with hidden costs and managerial hurdles. The reliance on one or a few suppliers, and the shortage of suppliers, can halt the functioning of organizational supply chain-based operations (Mangla et al. 2015). However, Komarek et al. (2020) emphasized that climate hazards and their consequences on crops, fuel prices, and difficulties in information access are additional market risk sources.

Political risk (A3), as defined by Hartwell and Deviney (2021) is merely one side of a formalized environment of

the country. They claimed that the whole governance architecture of a foreign country more accurately represents the country's exterior unpredictability. Unlike this risk, overall governance encompasses a variety of formal institutional and environmental risks in a country's formal institutional environment, all of which influence managers' foreign entry mode decisions (GOI Annual Report (Government of India, Report) 2022). However, Yazdani et al. (2019) underlined the uncertainty that comes with socio-political instability within a country, as well as a lack of governance infrastructure that allows local suppliers or customers to take advantage of legal loopholes to act opportunistically toward foreign MNEs.

Policy and Institutional Risk (A4) refer to agricultural policy, regulations, accessibility, and support. Schattman et al. (2018) argued that most regulatory and legal changes are national or multinational in scope, therefore these less specific organizations have an edge in conveying such facts. Investment in private-sector agribusiness is limited due to the level of government rules. Moreover, Long et al. (2016) noted that persuading water boards and the ministry to collaborate is challenging, possibly due to the agriculture policy sector's rigidity in general. However, Komarek et al. (2020) reviewed those Informal institutions can also be sources of institutional risk, such as unpredictably changing activities of a rural producer, informal trade deals, and shifts in societal practices, all of which have an impact on spice cultivation.

Financial risk (A5) is one of the significant concerns in the agricultural industry, owing to the fact that the status of financing primary production is not improving. Moktadir et al. (2021) highlighted the risks connected with investment, cash flow, and the exchange rate, all of which have a substantial impact on a company's profit after taxes, vendor selection, market growth, and operations. Moreover, Smith and Siciliano (2015) argued landowners benefit from long-term subsidy beneficiaries, who are typically not farmers. Furthermore, Unpaid supplies, unpaid governmental duties, and debt collection are among the dangers included in this category of risk (Nadezda et al. 2017). However, Farmers believe insurance money has been squandered because droughts have happened in the past and no compensation has been paid for lost harvests (DASD 2018).

Quality risks (A6) refer to hazardous materials, deterioration over time, component availability, and shape and size variations. Meuwissen et al. (2001) emphasize the necessity of stringent hygiene regulations for farmers' production risk reduction. Moreover, Bengtsson-Palme (2017) suggested, that misuse of novel antibiotics and transgenic technologies poses a major threat to biodiversity and human health. Many studies have emphasized the lack of suitable fertilizers, plant protection chemicals, as well as adequate irrigation, processing, and storage facilities (Smith and Siciliano 2015; DASD 2018) many businesses started hunting for developing new

**Table 1** Risks and its sub-risks

Risk	Sub-risk	Description	References	
A1	Weather/ Natural Disasters Risk			
	C1	Land Fertility and Soil health	Plants and animals rely on agro-climatic conditions, hence agri goods are affected by natural advancements.	Ali and Gölgeci (2020), Yazdani et al. (2019)
	C2	climatic influence (e.g. Periodic deficit rainfall or excess rainfall)	Forecasting, early warnings, and preparedness to minimize the effects and dangers.	Coomes et al. (2016), Neupane and Kumar (2015)
	C3	extreme events (e.g. Extreme drought and cold, Hail storms)	Disruptions in the SSC generated by extreme events have an impact on the social and agriculture industry.	Harris et al. (2022), Ali and Gölgeci (2020)
	C4	accidental disasters( e.g. Flood, earthquake)	Disrupt agricultural production and all SC, which can lead to food security problems.	Heckmann et al. (2015), Ali and Gölgeci (2020)
A2	Market Risk			
	C5	Fluctuation in Demand,	Unmet demand balance, excess inventory, and demand uncertainty	Moktadir et al. (2021), Ali et al. (2023)
	C6	Fluctuation in Supply	depend on few vendors, varying lead time, due to flexibility, unexpected production interruption of supplies, financial difficulties, uncertain output quality period	Moktadir et al. (2021), Mangla et al. (2015)
	C7	Problems with strategic sourcing	single sourcing, sourcing flexibility, supplier choice, supply product tracking, and capacity	Moktadir et al. (2021), Mangla et al. (2018)
	C8	Fluctuation in the Price	commodity price uncertainty relies on international trade, liberalization	Komarek et al. (2020), Sun et al. (2021)
A3	Political Risk			
	C9	Political instability	Measures the risk of an unconstitutional means, such as mob violence or terrorism, destabilizing a country's government.	Slangen and Van Tulder (2009), Mangla et al. (2018), Sun et al. (2021)
	C10	Changes in the political environment	adverse changes in the system of government of a country or the policy issued by the system	Slangen and Van Tulder (2009), Sun et al. (2021)
A4	Policy and Institutional Risk			
	C11	Regulatory Issues	Regulation issues are difficult to interpret for SME companies with less analysis.	Schattman et al. (2018), Mangla et al. (2018)
	C12	market disruption	Informal suppliers, rural producer organizations, compliance with social norms, and unexpected changes.	Komarek et al. (2020), Sun et al. (2021)
	C13	political upheaval	rigid agricultural policy and Uncertainty about governance (e.g., corruption)	Long et al. (2016), Sun et al. (2021), Mangla et al. (2018)
	C14	unstable policies	unpredictable changes in policies, regulations, Monetary, fiscal, and tax policies.	Komarek et al. (2020), Sun et al. (2021), Paliwal et al. (2023)
A5	Financial Risk			
	C15	Inadequate financial support	Risk of unpaid supplies, unpaid state liabilities, and debt collection.	Nadezda et al. (2017), Kayikci et al. (2022)

Table 1 (continued)

Risk	Sub-risk	Description	References
A6 Quality Risk	C16	Access to finance and insurance	the scale of finance is not in line with the actual cost of production and lack of transparency DASD (2018), Prendeville et al. (2016)
	C17	Delays in receiving financial assistance	Subsidies and insurance subsidies will not reach the ultimate objective, the beneficiaries are landowners, who are not farmers Smith and Siciliano (2015), Prendeville et al. (2016)
	C18	Uncertainty about financial assistance	net cash flow, trouble in operation, credit crisis Moktadir et al. (2021), Mangla et al. (2018)
	C19	Interest and exchange rate policies	Exchange rate, price, and cost, supply chain partner financial strength, and financial handling/practice Moktadir et al. (2021), Sun et al. (2021)
	C20	Diseases and pests	Pesticide, fertilizer, and gene pollution endanger ecology and human health. Komarek et al. (2020), Smith and Siciliano (2015), Tokatli (2021)
	C21	Poor availability of Inputs	lack of proper pesticides and protection chemicals, irrigation, and on-farm processing and storage facilities DASD (2018), Hu et al. (2019)
	C22	Contamination caused by a lack of sanitation	Degradation of the environment may have an impact on output, the health of the employees, or down-market access. Meuwissen et al. (2001), Tokatli (2021), Hu et al. (2019)
	C23	Human contamination	Microbial not only contaminate during spice manufacturing, but they can also increase the human-to-human transmission route. Bengissson-Palme (2017), Tokatli (2021)
	C24	spice adulteration	Unintended chemicals may be contaminated by technology. Székács et al. (2018), Ndlovu et al. (2022)
	C25	Contaminants of pesticides	Agrochemical treatments of spice plants were used to protect them from weeds, fungi, and pests. Székács et al. (2018), Hu et al. (2019), Ndlovu et al. (2022)
	A7 Technical Risk	C26	Chemical contamination
C27		Production and processing processes are contaminated and degraded	loss of quality, contamination of fresh produce with deadly germs Aradwad et al. (2021), Gidwani et al. (2022), Kayikci et al. (2022)
C28		Technology Adaptability issues	communication, utilization, mining, learning, and lack of knowledge Kumar et al. (2021), Mangla et al. (2018)
C29		Internal IT infrastructure disruption	proper maintenance and upgrading of outdated systems Mangla et al. (2019), Raut et al. (2021), Kayikci et al. (2022)
A8 Ergonomic risks	C30	External IT infrastructure disruption	effectiveness of the SSC will be harmed if a machine, equipment, or facility fails. Mangla et al. (2015), Mangla et al. (2018)
	C31	Personal risks	Farm machinery injuries, family members' mortality or illnesses Komarek et al. (2020), Yarpuz-Bozdogan (2018)

Table 1 (continued)

Risk	Sub-risk	Description	References
A9 Logistic and Infrastructure Risk	C32 Family risk	loss of labor because of disease or accident etc.	e Saqib et al. (2016), Yarpuz-Bozdogan (2018)
	C33 transportation cost, communication, and energy	Forecasting, distribution, and product delivery delays and/or degraded quality	Han et al. (2021), Mangla et al. (2019), Mangla et al. (2018)
	C34 Undependable transport and cold SC challenges	lack of support for new technologies in packaging and the encouragement of packaging facilities	Mangla et al. (2019), Han et al. (2021)
	C35 Lack of modern infrastructure	Connectivity between the physical and digital world.	Lezoche et al. (2020), Kayikci et al. (2022)
A10 Operation and Management Risk	C36 Loss of Spice quality, and quantity	Temporary storage affects the quality of spices.	Chauhan et al. (2020), Kayikci et al. (2022)
	C37 lack of awareness	Awareness, training, and exposure visits on grading and quality standards can be provided.	DASD (2018), Mangla et al. (2018), Kayikci et al. (2022)
	C38 Scarcity of skilled labor	understanding and or knowledge of sustainable operations	Mangla et al. (2015), Mangla et al. (2018)
	C39 Information Sharing	Reliable information, external organizations, very costly and time-consuming.	Liu et al. (2021), Mangla et al. (2018), Han et al. (2021), Raj et al. (2023d)
C40 Lack of strategic goals	Not willing to alter product, process, or markets. Inadequate quality control	Mangla et al. (2015), Mangla et al. (2018), Han et al. (2021), Raj et al. (2023b)	



pests in order to increase profits (Komarek et al. 2020). Prior studies have addressed that chemical pollutants and pesticide residues that arise in spices, as a result of unintentional contamination, and other substances may be intentionally contaminated (spice adulteration) for financial reasons (Székács et al. 2018). Furthermore, several authors pointed out that spices lost their aromatic, flavorful, and other heat-sensitive qualities (Aradwad et al. 2021), when sun-dried on the ground which contaminates chemically and micro-biologically, rendering them unsafe for human consumption (Gidwani et al. 2022).

Technical risks (A7) arise due to process flaws, mechanical failures, or errors in dealing with handling, or technology adoption (Mangla et al. 2015; Raj et al. 2023c). Moreover, Mangla et al. (2019) noted that new technology innovations can also help to alleviate negative environmental effects. Implementing blockchain, big data, and sophisticated information technologies can improve the Spice supply chain's overall business sustainability. Furthermore, pointed out that the workforce lacks the technical skills which are needed to operate and understand technologically advanced equipment. There is no such digital platform or resources to provide training services for SSC adoption (Kumar et al. 2021).

The term "ergonomic risks" (A8) refers to the need to safeguard the personnel working in the SSC. Farmers may be less likely to suffer work-related accidents or be exposed to reduced pesticide levels. As a result, there may be a loss of labor for the corporation or the farmer's family (e Saqib et al. 2016). Some personal risks may be greater in developing countries than in developed ones, for example, because health insurance is sometimes more expensive in developing countries, labor laws, and workplace safety requirements are often more stringent and enforced in developed countries (Komarek et al. 2020).

Logistics risks (A9) include transportation, handling, warehousing, inventory carrying, distribution capacity, and processing in SSC. Mangla et al. (2019) highlighted products transported by trains have a substantial effect on delivery charges and time. To assist in the storage and shipping of perishable spice goods, transportation facilities such as refrigerated carriers are required. There is no infrastructure in place to support the established link between the physical and high-tech worlds. The traditional way is incompatible with a new method (Lezoche et al. 2020). Moreover, Chauhan et al. (2020) emphasized after post-harvesting, the storage facility has a direct effect on spice quality resulting in extended delivery time, and the quality of the spices suffers as a result.

Operation and Management risks (A10) refer to information-sharing gaps, participant coordination, and resource availability. Mangla et al. (2015) highlighted the lack of sustainable operation understanding and methodologies among the workforce which hinders organizational performance.

However, the majority of farmers sold single polished spices without any quality control (DASD 2018). Furthermore, Liu et al. (2021) argued that external groups are the best resource of information for farmers. Access to digital information is a barrier, which restricts the performance of high-value care. Therefore, without considering the SCM strategic perspective, it will not be able to execute the SSC business activities. Table 1 lists the suggested associated risks and their sub-risks.

### 3 Methodology

The adopted methodology includes the application of FDM and FDEMATEL to the SSC industry. Initially, the theoretical background is discussed and then the analysis is conducted along with the detailed application of the proposed research approach (Fig. 1).

#### 3.1 Case background

The SSC is becoming increasingly complex as globalization progresses. The Spice industry's associated risks have increased because of the rising number of intermediaries and the lack of modern infrastructure, which can create disruption throughout the SSC. Furthermore, government and corporate attempts at sustainable spice products are insufficient to overcome the distributed risk along the supply chain. However, SSC handles a variety of hazards in order to fulfill its goal of sustainable development.

As adulteration of spices, chemical pollution, pesticide residues, and other issues arose in the spice industry. In many situations, lack of infrastructure, sun drying of spices on the ground, unsuitable storage houses, and other factors contribute to the degradation of spice quality, flavor, and aroma. Due to overburdening businesses with spice demands, chemical residuals were not properly crosschecked, posing serious health and environmental risks. Furthermore, in the SSC system, insufficient technology and policies are insufficient which do not synchronize. The entire system is additionally hampered by a lack of technology and investment resources for effective spice handling from producer to end user, as well as the lack of a coordinated market with private participants, which affects promotion and profit. As a result, in order for the SSC system to be sustainable, it must overcome these dangers by assessing the risks that lead to reduced SSC performance; this study can assist practitioners in achieving a greater degree of sustainable development. Figure 2 shows the segment of the SSC process. This study brings together a group of 30 professionals from the everyday operations of the SSC, all of whom have substantial experience in the Indian spice industry which has been considered here as a "laboratory" to investigate the desired objectives.

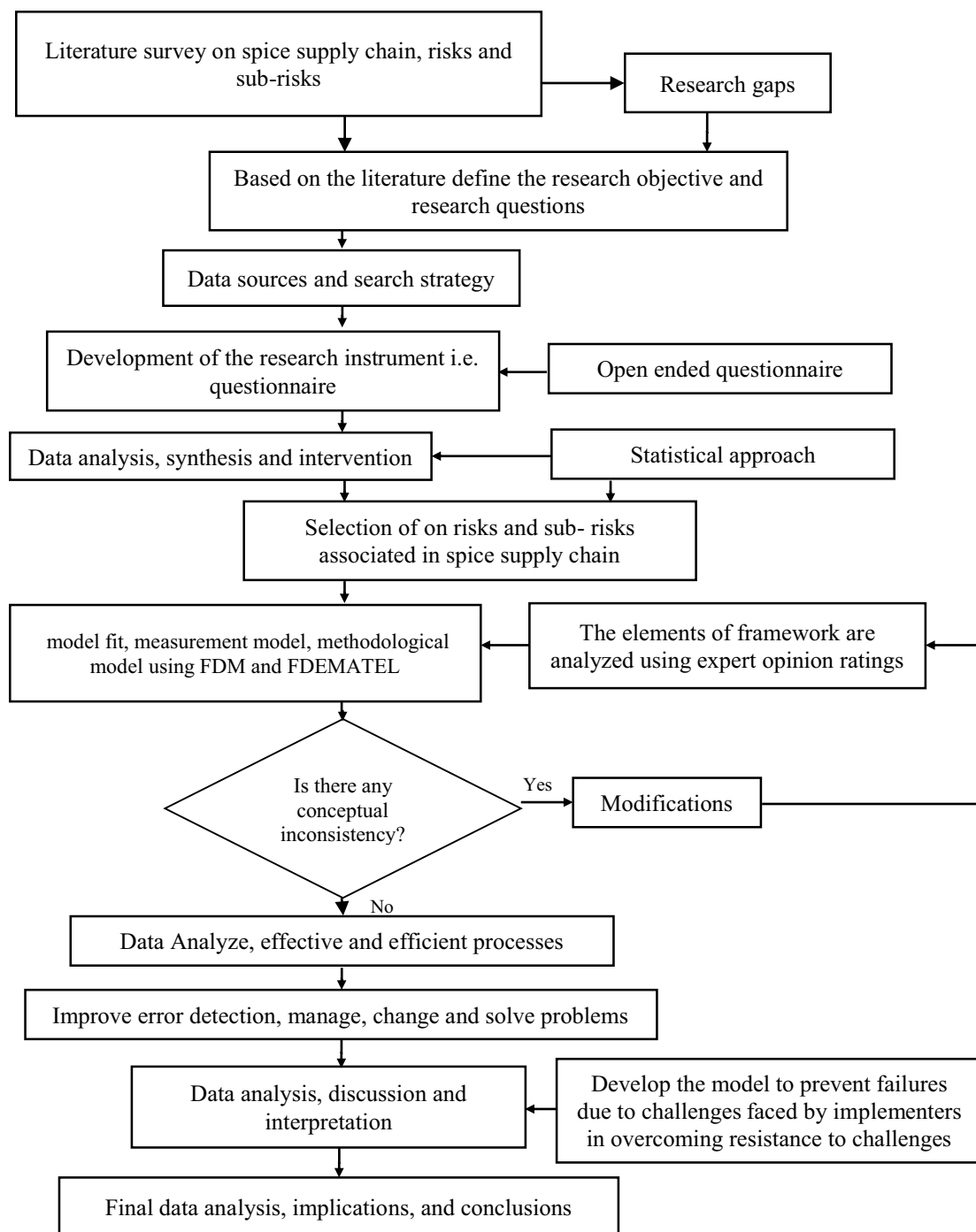


Fig. 1 Research design framework

### 3.2 Fuzzy Delphi method

To address the absence of expert references and improve the questionnaire, this study proposes combining fuzzy set theory as well as the Delphi method (Ishikawa et al. 1993). Using the experts' language references, the procedure is used to refine the indications (Münch et al. 2021). It has

benefits such as lowering the number of respondents and the time it takes for them to answer while ensuring that the expert's evaluation is properly assessed. With extra assistance, the fuzzy assessment is turned into exact values, and reduced survey time.

The analytical process starts with expert  $p$  scales value of indicator  $q$  as  $j = (a_{pq}; b_{pq}; c_{pq})$ ,  $p = 1, 2, 3, \dots, n$ ;

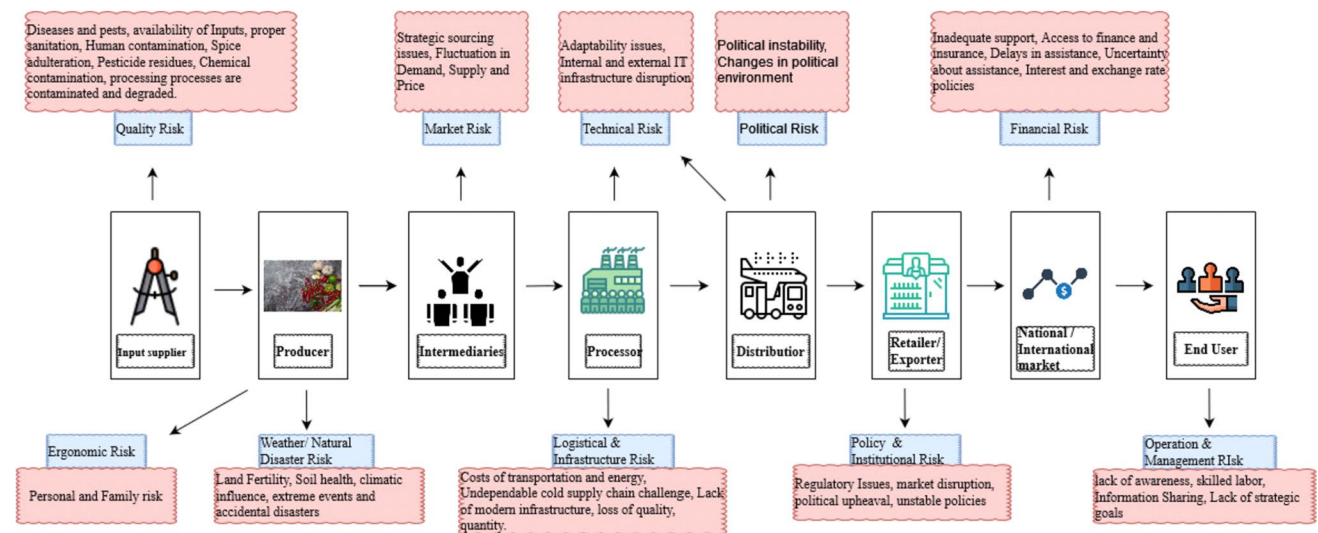


Fig. 2 The Segment of Supply Chain Process

$q = 1, 2, 3, \dots, m$ , as  $j_q$  is the weight of  $q$  presented as  $j_q = (a_q; b_q; c_q)$  with  $a_q = \min(a_{pq})$ ,  $b_q = (\prod_1^n b_{pq})^{1/n}$ , and  $c_q = \max(c_{pq})$ . Afterward, the linguistic references from experts are converted into triangular fuzzy numbers (TFNs) (in Table 2).

The convex combination value  $D_q$  is calculated utilizing a  $\gamma$  cut as:

$$u_q = c_q - \gamma(c_q - b_q), l_q = a_q - \gamma(b_q - a_q), q = 1, 2, 3, \dots, m \tag{1}$$

The  $\gamma$  value can be transformed from 0 to 1 regarding the negative or positive of experts' perceptions. The value is usually specified as 0.5 in the general scenario.

The  $D_q$  then is evaluated as:

$$D_q = \int (u_q, l_q) = \delta[u_q + (1 - \delta)l_q] \tag{2}$$

In which,  $\delta$  presents the positive balance on the expert's ultimate assessment.

The threshold to refine the valid indicators is computed by  $t = \sum_{p=1}^n (D_q/n)$ .

Once  $D_q \geq t$ , indicator  $q$  is accepted. If not, it is obligately eliminated.

Table 2 Transformation table of linguistic terms for FDM

Linguistic terms (performance/importance)	TFN
Very High	(0.75, 1.0, 1.0)
High	(0.5, 0.75, 1.0)
Normal	(0.25, 0.5, 0.75)
Low	(0, 0.25, 0.5)
Very Low	(0, 0, 0.25)

### 3.3 Fuzzy decision-making trial and evaluation laboratory (FDEMATEL)

The DEMATEL is designed to create causal inter-dependencies among indicators in complicated settings, while the fuzzy set theory is utilized to translate human verbal judgments under ambiguity into statistical data (Tseng et al. 2018; Farooque et al. 2019). The methodology adopts a defuzzification process to generate FTNs into crisp values. The fuzzy membership functions  $\tilde{q}_{ij}^k = (\tilde{q}_{1ij}^k, \tilde{q}_{2ij}^k, \tilde{q}_{3ij}^k)$  are applied to calculate the total weighted values. Accordingly, the right and left values are computed using the maximum and minimum fuzzy numbers. The crisp values are then acquired into a total direct relation matrix for diagram mapping to simplify analytical results. The inter-relationships structure comprises specific indicators that denote vital means in the construct. A set of indicators is presented as  $G = \{g1, g2, g3, \dots, gn\}$  to execute pairwise evaluation creating the mathematical connections.

This research accumulates the crisp values using linguistic scales from VL (very low) to VH (very high) (in Table 3). Provision there are  $k$  experts join in the evaluation process, the  $\tilde{q}_{ij}^k$  represent the fuzzy weight of the indicator  $i^{th}$  effects on the indicator  $j^{th}$  estimated by expert  $k^{th}$ .

Table 3 FDEMATEL TFNs linguistic scale

Scale	Linguistic terms	Corresponding TFNs
1	Very Low	(0.0, 0.1, 0.3)
2	Low	(0.1, 0.3, 0.5)
3	Normal	(0.3, 0.5, 0.7)
4	High	(0.5, 0.7, 0.9)
5	Very High	(0.7, 0.9, 1.0)

The fuzzy numbers are abbreviated as:

$$G = (g\tilde{q}_{1ij}^k, g\tilde{q}_{2ij}^k, g\tilde{q}_{3ij}^k) = \left[ \frac{(q_{1ij}^k - \min q_{1ij}^k)}{\Delta}, \frac{(q_{2ij}^k - \min q_{2ij}^k)}{\Delta}, \frac{(q_{3ij}^k - \min q_{3ij}^k)}{\Delta} \right] \tag{3}$$

where  $\Delta = \max q_{3ij}^k - \min q_{1ij}^k$

The right ( $rv$ ) and left ( $lv$ ) normalized values are generated as follows:

$$(lv_{ij}^n, rv_{ij}^n) = \left[ \frac{(gq_{2ij}^k)}{(1 + gq_{2ij}^k - gq_{1ij}^k)}, \frac{gq_{3ij}^k}{(1 + gq_{3ij}^k - gq_{2ij}^k)} \right] \tag{4}$$

The total normalized crisp values ( $cv$ ) is computed as:

$$cv_{ij}^k = \frac{(lv_{ij}^k(1 - lv_{ij}^k) + (rv_{ij}^k)^2)}{(1 - lv_{ij}^k + rv_{ij}^k)} \tag{5}$$

The synthetic values symbolization to accrue the individual insight from  $k$  respondents is afterward implemented by:

$$\tilde{q}_{ij}^k = \frac{(cv_{ij}^1 + cv_{ij}^2 + cv_{ij}^3 + \dots + cv_{ij}^k)}{k} \tag{6}$$

Consequently, the pairwise comparison is engaged to obtain a direct relation ( $IM$ )  $n \times n$  initial matrix, where  $\tilde{e}_{ij}^k$  regards to the effective level of indicator  $i$  on indicator  $j$ , moderated as  $IM = (\tilde{e}_{ij}^k)_{n \times n}$ .

The normalized direct relation matrix ( $V$ ) is developed as:

$$V = \tau \otimes IM$$

$$\tau = \frac{1}{\max_{1 \leq i \leq k} \sum_{j=1}^k \tilde{e}_{ij}^k} \tag{7}$$

The inter-relationships matrix ( $U$ ) is attained using:

$$U = V(I - V)^{-1} \tag{8}$$

where  $U$  is  $(u_{ij})_{n \times n}$   $i, j = 1, 2, \dots, n$

The values of the driving power ( $O$ ) and dependence power ( $P$ ) are summed from the rows and columns values inter-relationships matrix using:

$$O = (\sum_{i=1}^n u_{ij})_{n \times n} = (u_i)_{n \times 1} \tag{9}$$

$$P = (\sum_{j=1}^n u_{ij})_{n \times n} = (u)_{1 \times n} \tag{10}$$

The indicators are placed in an inter-relationships diagram obtained from the  $[(O + P), (O - P)]$ , which in turn are organized into horizontal and vertical vectors. The indicators are grouped into causal and affected groups based on the

positive or negative value of  $(O - P)$ . The  $(O + P)$  exhibits the indicators' importance, the larger  $(O + P)$  value indicator is, the more important it is. This study uses the average value of  $(O + P)$  to classify the top important causal indicators that need to be focused on.

### 3.4 Proposed analytical procedure

The role of this study is to assess experts' perceptions of the primary SSC risks using FDM and FDEMATEL. The procedure is carried out in three phases. The theoretical evaluation of and recommended Risks to SSC are gathered in the first phase from previous research and expert consultants. Interviews are undertaken to determine the expertise and dependability of the experts. To check the veracity, they are asked to answer YES or NO for every risk. FDM is used in the study's second phase to screen out unimportant traits and rank them accordingly as per their importance. Finally, FDEMATEL was employed in the third phase to assess inter-relationships between risks and sub-risks based on FDM findings. The following is the evaluation procedure:

- The likely characteristics of SSC Risks were gathered from the literature. Following that, the experts finalize the recommended attributes in a group discussion.
- In the first phase, FDM is used to optimize the important properties using Eqs. 1 and 2. The questionnaire is designed to allow specialists to perform a further assessment based on the proposed risks.
- In the second phase, FDM evaluation is carried out to improve measurement consistency and accuracy. The questionnaire is recreated based on the results of the first phase in order to obtain an expert assessment for the best-performing validation. To obtain the final list of SSC Risks, the FDM technique is repeated, and the most critical Risks are assessed to provide exact implications for improving SSC performance.
- Ultimately, in the third round, The FDEMATEL questionnaire was created based on the results of FDM, and interviews were conducted. Equations 3–8 were used in the defuzzification procedure. Equations 9 and 10 were used to determine the  $(O + P)$  and  $(O - P)$  values in the end. The values were then utilized to create a graphic demonstrating the SSC sub-risks' cause-effect interrelationships.

## 4 Empirical analysis

The findings of the data collection and analysis mentioned in the previous part are summarized in this section.

**Table 4** FDM Results

A1	0.333333	DENY	C17	0.516075	ACCEPT
A2	0.520283	ACCEPT	C18	0.535067	ACCEPT
A3	0.333333	DENY	C19	0.333333	DENY
A4	0.333333	DENY	C20	0.468957	ACCEPT
A5	0.555685	ACCEPT	C21	0.450585	ACCEPT
A6	0.540035	ACCEPT	C22	0.333333	DENY
A7	0.517009	ACCEPT	C23	0.522494	ACCEPT
A8	0.50774	ACCEPT	C24	0.687104	ACCEPT
A9	0.530607	ACCEPT	C25	0.525866	ACCEPT
A10	0.510151	ACCEPT	C26	0.333333	DENY
C1	0.333333	DENY	C27	0.333333	DENY
C2	0.333333	DENY	C28	0.530219	ACCEPT
C3	0.333333	DENY	C29	0.333333	DENY
C4	0.333333	DENY	C30	0.333333	DENY
C5	0.333333	DENY	C31	0.531615	ACCEPT
C6	0.333333	DENY	C32	0.333333	DENY
C7	0.333333	DENY	C33	0.563855	ACCEPT
C8	0.523836	ACCEPT	C34	0.546961	ACCEPT
C9	0.333333	DENY	C35	0.333333	DENY
C10	0.333333	DENY	C36	0.532317	ACCEPT
C11	0.333333	DENY	C37	0.538984	ACCEPT
C12	0.500897	ACCEPT	C38	0.548053	ACCEPT
C13	0.333333	DENY	C39	0.510151	ACCEPT
C14	0.333333	DENY	C40	0.333333	DENY
C15	0.562325	ACCEPT	Threshold	0.432204	
C16	0.333333	DENY			

**4.1 FDM results**

This research proposed 40 sub-risks based on the associated 10 risks, see Table 1. Table 4 shows a summary of phases 1 and 2 of the FDM, as well as its weight and threshold, which exclude risks and sub-risks. In phase 1, the experts evaluated the initial batch of SSC risk variables, presented in Table 1, based on their experience and assessment. The linguistic phrases were translated into comparable TFNs after evaluation, as illustrated in Table 2. FDM was used to refine the significant risks, as shown in Table 4 with threshold = 0.432204.

**Table 5** Initial direct relation matrix for risks

	A2	A5	A6	A7	A8	A9	A10	SUM
A2	0.822	0.523	0.474	0.338	0.1464	0.3791	0.4794	3.161
A5	0.412	0.834	0.507	0.415	0.4055	0.4506	0.4595	3.483
A6	0.460	0.549	0.744	0.385	0.057	0.5408	0.2767	3.013
A7	0.458	0.264	0.514	0.798	0.1895	0.5077	0.4596	3.190
A8	0.139	0.226	0.470	0.554	0.875	0.0352	0.5127	2.813
A9	0.471	0.221	0.474	0.433	0.0126	0.8698	0.4861	2.968
A10	0.480	0.443	0.474	0.505	0.5235	0.5673	0.7423	3.735
							MAX	3.735

A threshold must be selected after choosing an acceptable approach and defuzzing the screening item values. The threshold value is 0.432204, however, it varies depending on the researcher's assessment in different studies (Abdi et al. 2022). If the defuzzification crisp value of the combined expert opinions is above the threshold, the factor is considered to be confirmed or accepted. If the crisp value is below the threshold, the component is disregarded or deleted (Razavi Hajiagha et al. 2022). As stated in Table 4, a total number of 25 risks and sub-risks were acknowledged as legitimate.

**4.2 Fuzzy DEMATEL results**

On linguistic scales ranging from "very low" to "very high," DEMATEL the refined set of features and criteria used for input into phase 3 for expert judgments to find out the interdependencies among the various risks are available, as shown in Tables 5, 6 and 7. The real-world information is converted into TFN as illustrated in Table 3. Using Eqs. 6–8, the TFNs are normalized into crisp values that retain incomputable and irreconcilable features. To convert ambiguous connotations to definite crisp values, the described techniques are required. After obtaining crisp values, they are entered into an interconnection matrix and grouped according to Eqs. 7 and 8. DEMATEL is used to investigate interdependencies, dependent power, and driving power using a cause-and-effect approach.

There are seven risks to the interrelation matrix: Market Risk (A2), Financial Risk (A5), Quality Risk (A6), Technical Risk (A7), Ergonomic Risk (A8), Logistics and Infrastructure Risk (A9), and Operation and Management Risk (A10) are the different types of risks (A10). As indicated in Fig. 3, this matrix is translated into causal interdependencies. The total value of the columns is P, while the total value of the rows is O. The risks are classed as cause groups if the (O – P) value is positive; risks are classified as effect groups. The dataset is then mapped on ((O + P), (O – P)) to produce a cause and effect diagram. The diagram of cause and effect has been plotted in Fig. 3. The cause group includes (A5), (A8), and (A10), while the effect group includes (A2), (A6), (A7), and (A9). The



**Table 6** Total Interdependencies Matrix of risks

	A2	A5	A6	A7	A8	A9	A10	D
A2	1.025	0.881	0.989	0.873	0.478	0.94	0.919	6.100
A5	0.970	1.032	1.081	0.977	0.609	1.03	0.989	6.686
A6	0.875	0.844	1.017	0.840	0.412	0.94	0.809	5.740
A7	0.915	0.787	0.998	1.010	0.482	0.975	0.909	6.077
A8	0.695	0.677	0.873	0.849	0.665	0.697	0.825	5.281
A9	0.872	0.727	0.927	0.846	0.389	1.034	0.864	5.657
A10	1.048	0.965	1.135	1.065	0.679	1.124	1.131	7.147
R	6.401	5.912	7.019	6.459	3.715	6.736	6.445	0.871

three key variables that influence SCM are Financial Risk (A5), Ergonomic Risk (A8), and Operation and Management Risk (A10).

Similarly, as shown in Tables 8 and 9, the crisp values and total interdependence matrix for the criterion are derived. The cause-and-effect interdependencies among sub-risks are depicted in Fig. 4. The results of the cause and effect diagram demonstrate that C8, C15, C17, C20, C23, C24, C33, and C36 are cause sub-risks, whereas C18, C21, C25, C28, C31, C34, C37, C38, and C39 are effect sub-risks. The most important causes in the cause category are fluctuation in the Price (C8), diseases and pests (C20), human contamination (C23), spice adulteration (C24), and loss of food quality, and quantity (36).

## 5 Discussion and findings

This research adds to the body of knowledge by identifying the risks that cause decreased SCM performance. The findings revealed that addressing financial risk (A5), ergonomic risk (A8), and operation and management risk (A10) are significant causal risks, that present practical uncertainties throughout SCM.

When it comes to implementing SSC principles in their organization, many companies face cost constraints and limitations. SSC, on the other hand, is still inefficient in terms of resource mobilization and investment for the implementation of sustainable practices. Despite the assistance of some of the industry's biggest regulatory agencies in achieving a

sustainable measure in SSC, the results are not adequate. The existing budgetary resource allocation strategy for SCM is less sustainable. The SCM system must be adequately funded as a requirement. It is critical to allocate funds to the design and construction of technical and management infrastructure, cold chain transit facilities, and cold storage zones (Moktadir et al. 2018). As a result, enterprises should adopt several strategies for controlling SSC financial risks, such as the construction of fiscal resources and capacities, as well as the formulation of contingency.

The findings reveal that ergonomic risk (A8) is a significant factor in poor SCM performance. In the context of SSC, the majority of assembly activities include ergonomic risks such as repetitive movements, awkward positions, and loads, all of which contribute to chronic mental and physical health problems. Personal threats are created by a poor production line design, which can lead to economic losses for businesses owing to job absences, healthcare treatments, labor recovery, manual defects, a decline in quality, and even labor loss. Ergonomic risk is a big issue in many industries, hence it warrants special consideration. Optimizing preventative steps against accidents, enhancing work health and safety performance, decreasing errors creating organizational advantages, and improving the company's corporate social responsibility are all attainable with such systematic management (Ozturkoglu et al. 2019). Potential environmental consequences should be considered for sustainable risk management linked to ergonomics such as workplace health, working conditions, and economic cycles. In this regard, as preventative measures for ergonomic risk, it is critical for a strategic plan and the adoption of long-term sustainable measures in SSC.

In the context of SSC, operational risk (A10) is described as the risk of financial loss as a result of insufficient or failing internal processes, operations, and workforce systems. Case firms lack the equipment required for the successful implementation of effective SSC processes, and hence face a variety of risks and uncertainties linked to tech, equitable expertise, applicability, and upgradation. As a result, in order to implement a successful SCM strategy, businesses must create and enhance sustainability in their respective industries (Moktadir

**Table 7** Driving and Dependence Power of risks

	D	R	D+R	D-R
A2	6.100	6.401	12.501	(0.301)
A5	6.686	5.912	12.598	0.774
A6	5.740	7.019	12.758	(1.279)
A7	6.077	6.459	12.536	(0.382)
A8	5.281	3.715	8.996	1.566
A9	5.657	6.736	12.394	(1.079)
A10	7.147	6.445	13.592	0.701

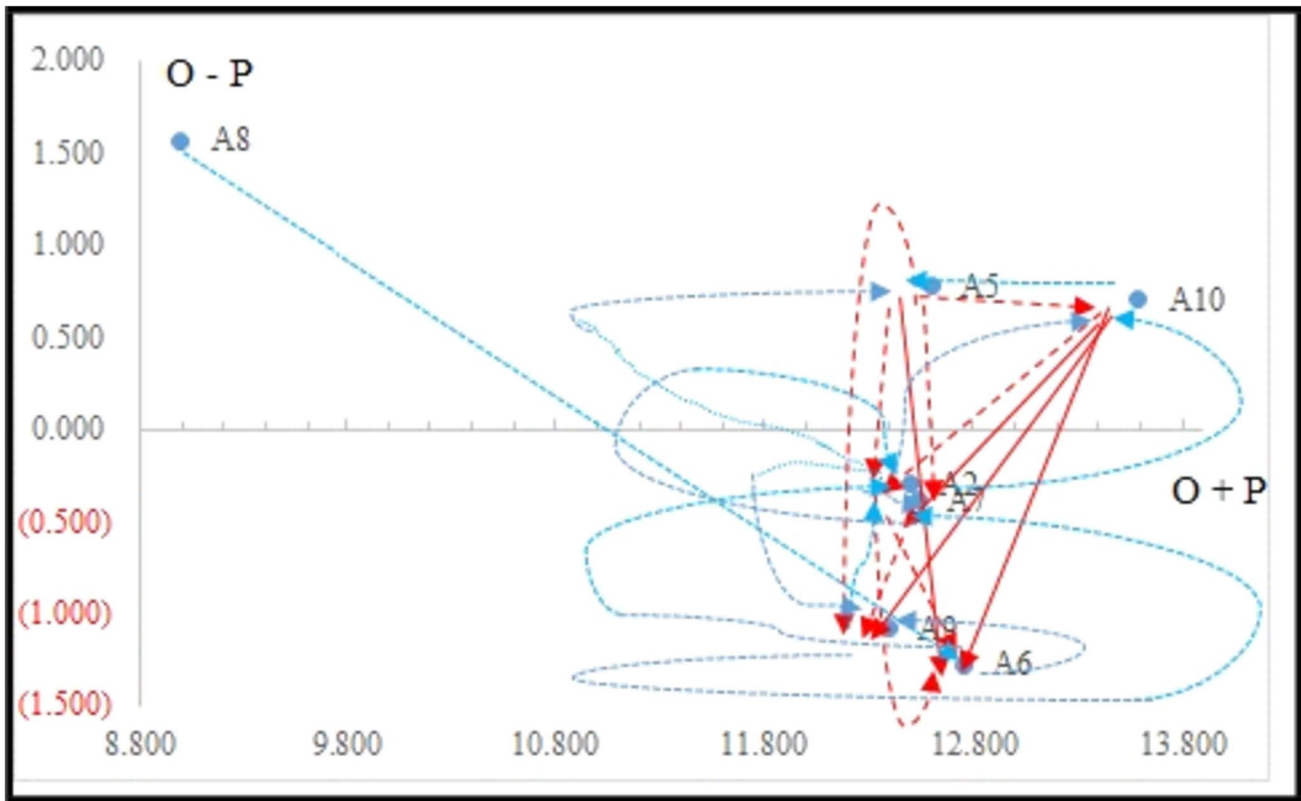


Fig. 3 Causal interrelationships diagram among the risks

et al. 2018). Throughout managing and controlling operational disruptions in SSC, it is critical to establish effective and precise sustainable operations, manufacturing, labeling,

packaging, and other areas (Zaid et al. 2018). Furthermore, businesses are confronted with risks connected to workforce sustainability knowledge and expertise, as well as challenges

Table 8 Total Interdependencies Matrix of sub-risks

	C8	C15	C17	C18	C20	C21	C23	C24	C25	C28	C31	C33	C34	C36	C37	C38	C39	D
C8	0.386	0.360	0.373	0.389	0.386	0.414	0.398	0.395	0.425	0.446	0.397	0.359	0.458	0.439	0.446	0.460	0.470	7.001
C15	0.328	0.335	0.325	0.355	0.346	0.381	0.352	0.360	0.367	0.377	0.365	0.320	0.403	0.371	0.362	0.386	0.409	6.142
C17	0.306	0.271	0.327	0.320	0.323	0.322	0.315	0.313	0.336	0.378	0.351	0.283	0.400	0.366	0.378	0.354	0.383	5.727
C18	0.310	0.277	0.286	0.348	0.323	0.362	0.317	0.317	0.352	0.382	0.360	0.306	0.388	0.369	0.365	0.369	0.387	5.819
C20	0.367	0.337	0.329	0.368	0.388	0.397	0.383	0.388	0.408	0.433	0.402	0.354	0.439	0.423	0.419	0.433	0.454	6.722
C21	0.299	0.314	0.300	0.315	0.334	0.383	0.353	0.341	0.376	0.410	0.385	0.298	0.382	0.404	0.379	0.390	0.418	6.079
C23	0.355	0.318	0.349	0.372	0.384	0.399	0.409	0.376	0.430	0.454	0.407	0.334	0.463	0.447	0.422	0.452	0.462	6.834
C24	0.382	0.367	0.380	0.404	0.402	0.432	0.381	0.414	0.445	0.463	0.403	0.364	0.466	0.463	0.447	0.469	0.471	7.153
C25	0.315	0.305	0.332	0.334	0.365	0.384	0.346	0.374	0.414	0.432	0.398	0.322	0.400	0.424	0.415	0.428	0.437	6.424
C28	0.351	0.340	0.367	0.379	0.349	0.382	0.400	0.352	0.422	0.456	0.420	0.348	0.462	0.427	0.435	0.439	0.458	6.787
C31	0.287	0.294	0.321	0.322	0.309	0.337	0.342	0.309	0.368	0.375	0.372	0.282	0.384	0.371	0.342	0.374	0.383	5.773
C33	0.332	0.308	0.315	0.346	0.309	0.334	0.322	0.322	0.345	0.384	0.335	0.332	0.411	0.394	0.350	0.399	0.370	5.905
C34	0.376	0.341	0.356	0.393	0.367	0.395	0.409	0.360	0.400	0.458	0.393	0.354	0.501	0.451	0.443	0.457	0.466	6.919
C36	0.396	0.346	0.357	0.380	0.411	0.444	0.432	0.420	0.456	0.485	0.447	0.391	0.496	0.483	0.468	0.485	0.493	7.388
C37	0.257	0.248	0.287	0.272	0.289	0.340	0.326	0.295	0.350	0.384	0.355	0.294	0.393	0.378	0.374	0.365	0.371	5.578
C38	0.239	0.248	0.241	0.273	0.252	0.314	0.310	0.297	0.341	0.362	0.321	0.257	0.349	0.339	0.331	0.364	0.349	5.187
C39	0.307	0.295	0.289	0.346	0.324	0.387	0.376	0.349	0.401	0.411	0.394	0.304	0.431	0.399	0.407	0.421	0.434	6.277
R	5.592	5.302	5.535	5.918	5.860	6.407	6.171	5.982	6.637	7.091	6.507	5.502	7.225	6.948	6.781	7.046	7.212	0.373

**Table 9** Driving and Dependence Power of sub-risks

	D	R	D+R	D-R		D	R	D+R	D-R
<b>C8</b>	7.001	5.592	12.593	1.409	<b>C25</b>	6.424	6.637	13.061	(0.213)
<b>C15</b>	6.142	5.302	11.444	0.839	<b>C28</b>	6.787	7.091	13.878	(0.304)
<b>C17</b>	5.727	5.535	11.262	0.192	<b>C31</b>	5.773	6.507	12.280	(0.734)
<b>C18</b>	5.819	5.918	11.736	(0.099)	<b>C33</b>	5.905	5.502	11.408	0.403
<b>C20</b>	6.722	5.860	12.582	0.863	<b>C34</b>	6.919	7.225	14.145	(0.306)
<b>C21</b>	6.079	6.407	12.486	(0.327)	<b>C36</b>	7.388	6.948	14.336	0.441
<b>C23</b>	6.834	6.171	13.005	0.662	<b>C37</b>	5.578	6.781	12.359	(1.203)
<b>C24</b>	7.153	5.982	13.134	1.171	<b>C38</b>	5.187	7.046	12.233	(1.859)
<b>C25</b>	6.424	6.637	13.061	(0.213)	<b>C39</b>	6.277	7.212	13.489	(0.935)

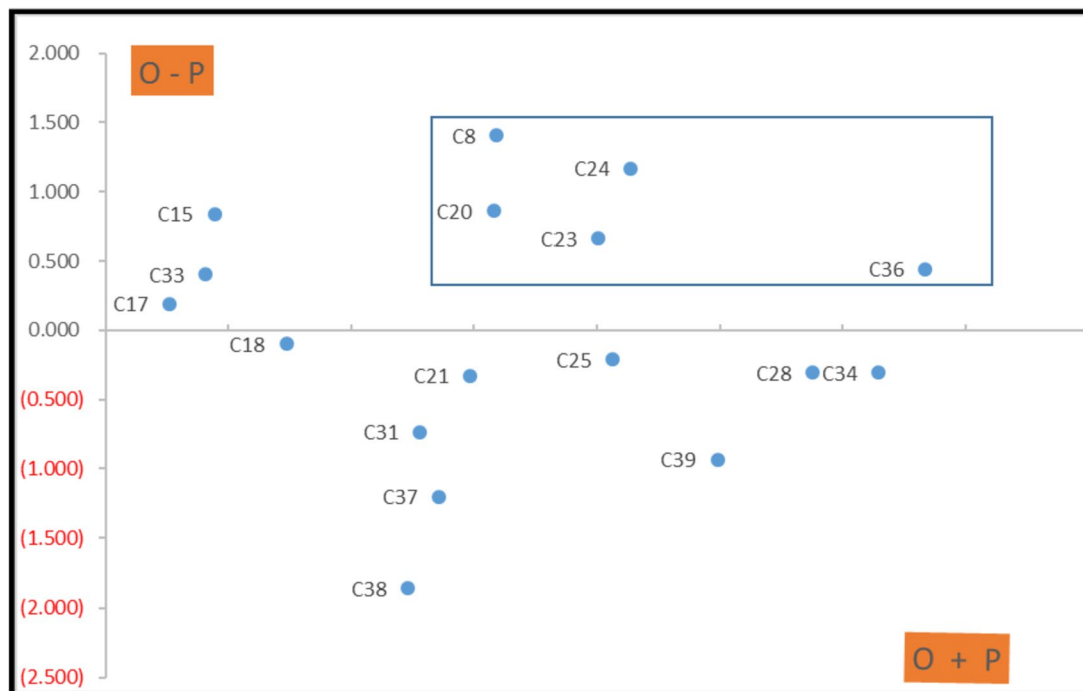
in implementing effective SSC processes. As a result, effective training programs for staff to improve their competency in adopting SSC procedures are required. Hence, an interdisciplinary strategy is required to improve significantly linked challenges. To meet development needs, the precise implementation of SCM in connection to other integrated features must receive enough attention.

## 6 Implications of the research

This research is being done to determine the risks that are negatively impacting the SSC. We sought to determine the crucial risk and its sub-risks, as well as the most effective combination of existing mitigation techniques. Fluctuation in the Price (C8), diseases and pests (C20), human contamination (C23), spice adulteration (C24), and loss of

food quality, and quantity (C36), among other significant causal sub-risks, present practical uncertainties throughout the SCM. The corresponding action plans for improving the sector are investigated. The following is a description of the managerial and practical implications of risk identification and strategy evaluation:

1. *Fluctuation in the Price (C8)* is one of the key roles of the commodities market, which ensures the protection of both producers and consumers by hedging sharp price changes. Agricultural production, unlike other industries, is heavily reliant on the swings of the weather (Komarek et al. 2020). As a result, agricultural commodities face dramatic price fluctuations both domestically and internationally due to uncontrolled natural phenomena. Futures trading is a price discovery and risk management tool that benefits all sectors of the economy,



**Fig. 4** Causal effect diagram among the sub-risks

including farmers and consumers. It is recommended that industry professionals use future marketing tools to protect themselves from price changes (Sun et al. 2021). The futures market allows us to assess supply and demand circumstances and manage price risks over distance and time. It also offers advice to farmers and agricultural commodity purchasers. Spices are the key contributors to earning a sizable amount of foreign currency through export in a developing country.

2. *Diseases and pests* (C20) are major issues that cause SCM systems to fail. Excessive use of mineral agrochemicals, as well as their improper handling, poses a major health risk. These health issues are a source of concern for human well-being, and they have an impact on agricultural production due to lower labor productivity (Smith and Siciliano 2015). It's difficult to quantify these human health issues, but defining the risk is the first step toward calculating its value. It is suggested that policymakers and practitioners develop regulations, raise farmers' understanding of proper pest control, and develop sustainable fertilizer distribution systems (Tokatli 2021). With more awareness among producers greater will be productivity, and adopting these measures easily overcomes associated risks.
3. *Reducing the risk of human contamination* (C23). Each stage of the SSC must prioritize sickness issues, waste, safety, contamination prevention, and reduction at all segments of the SSC. As a result, it is proposed that practitioners and regulatory agencies establish strict food and feed legislation. The best preventive measure is to provide effective pre- and post-harvest techniques, which may include physical, chemical, and biological strategies for a workout (Bengtsson-Palme 2017). Spices must be cleaned from physical contaminants and dried to secure storage moisture levels shortly after harvest. It is unacceptable for even a small amount of tainted spices to enter the food supply chain (Tokatli 2021). To avoid such problems, spices must be carefully handled and maintained in the best possible circumstances, as per scientific management methods.
4. *Spice adulteration* (C24) for economic reasons can now be seen in a wide range of spices. Adulteration is not confined to a specific region of the world, and it affects a wide range of products and raw resources; spices are currently dangerous because of the way they are sold and exchanged. Spice adulteration is a fast-paced deception that includes chemical, synthetic organic, and tree compounds (Székács et al. 2018). To effectively tackle spice adulteration, businesses should employ a variety of analytical procedures based on a variety of technologies. These methods should help detect adulterants and establish quantifiable concentrations for the substances of concern in a variety of matrixes, such as spices and

related plant materials (Ndlovu et al. 2022). Furthermore, regulatory organizations should enact strong rules and impose strong penalties on vendors and businesses proven to be involved in spice adulteration.

5. *Loss of food quality and quantity* (C36) is a major concern, which hinders attaining sustainability in SSC. It not only reduces the performance of the SC but also reduces the profit ratio for each SSC segment. Mostly food wastage in the supply chain is related to logistics handling, product processing, and consumption. It is recommended that practitioners adopt proper packaging and store spices at appropriate temperatures so that they do not lose their natural, scent, and aroma (Kaykci et al. 2022). As the spice has natural properties such as aroma and medicinal, it is suggested that spice processing firms adopt modern infrastructure to reduce the chances of contamination while drying as well as provide proper training and knowledge to workers for the handling of spices (Chauhan et al. 2020). In conclusion, the SCM system is ineffective due to a number of hurdles that require appropriate and viable solutions in the context of local circumstances.

## 7 Conclusions, limitations, and future scope

In recent decades, SCM has been acknowledged as a key issue; yet, associated risks still exist, preventing the ecosystem from attaining sustainable performance. As a result, the purpose of this study is to look into experts' perspectives on the issues in order to identify the primary hazards that lead to ineffective SCM. Weather/ Natural Disasters Risk, Market Risk, Political Risk, Policy and Institutional Risk, Financial Risk, Quality Risk, Technical Risk, Ergonomic Risk, Logistic and Infrastructure Risk, and Operation and Management Risk are found more critical among the proposed 40 sub-risks. To convert quantitative data from respondents into quantitative data and Delphi technique is used to eliminate non-essential traits and rank them in order of relevance. As a result, this study examines experts' linguistic choices in order to produce credible and reliable results for practical ramifications. Further, this study used the DEMATEL approach to discover the causal interdependencies among the risks and sub-risks in order to develop a hierarchical framework based on the revised FDM results. The findings help managers by assessing SCM performance and identifying causal interrelationships between those characteristics and sub-risks. The SCM model clarifies the important roles of Financial Risk (A5), Ergonomic Risk (A8), and Operation and Management Risk (A10), as well as the major features that can assist decision-makers in improving performance and efficiency. The fluctuation in the Price(C8), diseases

and pests (C20), human contamination (C23), spice adulteration (C24), and loss of food quality, and quantity (36) are revealed to be the foci of practice for practitioners to guide plans of action which can be used to improve the criteria for practitioners so that they can take corrective action and enhance sustainability development. These linked risks play a crucial role in jeopardizing the SCM system's long-term viability, necessitating practitioners' special attention to sustainability goals.

This research adds to the SCM literature by understanding the risks that lead to unsustainable SCM and providing important theoretical and managerial consequences. The strategic plan is centered on these risks and presents a better tool for achieving the SCM system's long-term development. Nonetheless, there are some restrictions. First, the current risks were chosen from previous research, making the presented framework insufficient. Future research should emphasize its extension. Second, the FDM and FDEMATEL were used to evaluate the qualities in this study; however, the approach still has flaws. However, expert confirmation is used to prove the technique's reliability. To improve clarity affecting the outcome, it is advised that a required technical validation evaluation be developed and the sample size be increased for future investigations. Third, although this study focused solely on the SCM in India, generalization is also a constraint. To add to the literature, researchers should look into other geographies or compare the academic and practitioner sectors. Further, the identified risk factors and their implications are expected to be compared with fresh, agro-food, and other short-supply chains.

**Data availability** Not Applicable.

## Declarations

**Conflict of interest** The authors have no competing interests to declare that are relevant to the content of this article.

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