Received: 2 December 2022 | Revised: 28 March 2023 | Accepted: 12 April 2023

DOI: 10.1002/bse.3435

RESEARCH ARTICLE

Business Strategy and the Environment WILEY

A systematic assessment of multi-dimensional risk factors for sustainable development in food grain supply chains: A business strategic prospective analysis

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Abstract

The food grain supply chain (FGSC) is composed of several links, stretching from the point of production to the point of consumption. A broken connection might produce a food catastrophe. The structural imbalance of India's FGSC is an obstacle to achieving sustainability; this has to be addressed if the country is to preserve national food security. This present study aims to develop a systematic assessment of the risks and the priority of risk-mitigating solutions in attaining sustainability in the Indian FGSC. Multiple groups of individuals and businesses involved in the FGSC have been surveyed and interviewed, with their responses analyzed. A total of 31 risk factors and 11 risk-reduction strategies are identified. Further, the identified risk factors are classified into five-dimensional sustainability criteria (environmental, economic, institutional, technical, and social) by using exploratory factor analysis (EFA). Then, a fuzzy analytical hierarchy process (FAHP), combined with the fuzzy technique for order performance by similarity to ideal solution (FTOPSIS) method, is adopted to find the most critical risk factors and choose the best course of strategies for risk mitigation. The study finds that inability to incorporate advanced technology imposes the highest risk to sustainability followed by natural disasters. Ensuring end-to-end computerization using advanced technology like agri 4.0 is the need of the hour in intercepting the range of FGSC risks. The results may help policymakers create a comprehensive risk mitigation plan and taxonomy to increase supply chain resilience.

KEYWORDS

business strategy, food grain supply chain, risk assessment, risk-reduction strategy, sustainable development

Abbreviations: AFSC, agri food supply chain; ASC, agri supply chain; CMB, common method bias; EFA, exploratory factor analysis; ER, environmental risk; FAHP, fuzzy analytical hierarchy process; FCI, Food Corporation of India; FGSC, food grain supply chain; FIFO, first-in-first-out; FMEA, failure mode effect analysis; FR, economic risk; FTOPSIS, fuzzy technique for order performance by similarity to ideal solution; IoT, internet of things; IPM, integrated pest management; IR, institutional risk; ISM, interpretive structural modeling; KMO, Kaiser–Meyer–Olkin; MCDM, multi-criteria decision-making; MICMAC, cross-impact matrix multiplication applied to a classification; MSA, measure of sampling adequacy; PDS, public distribution system; PRISMA, preferred reporting items for systematic reviews and meta-analyses; RFID, radio frequency identification; RI, random index; RQs, research questions; SA, sensitivity analysis; SC, supply chain; SCRM, supply chain risk management; SR, social risk; TFNs, triangular fuzzy numbers; TISM, total interpretive structural modeling; TR, technical risk.

1 | INTRODUCTION

Risk refers to the occurrence of detrimental consequences as a result of an action or occurrence, whereas a risk factor is a characteristic or exposure that raises the probability of harm or damage (Sadgrove, 2016). Risk management in the context of supply chains is a relatively new area of study. Globalization, an unstable economy, climate change, and complex interconnections among supply chain participants, such as suppliers, manufacturers, and service providers, have rendered supply networks vulnerable to a variety of risks.

The fair, sustainable, and rational use of the natural resources that underpin the worldwide food supply, such as clean water, soil, labor, oil, and other agricultural inputs, is of concern in the 21st century since failure to preserve the environment presages civil strife and starvation. Furthermore, the demand for food has grown dramatically due to a decline in land usage for food crop production and an increase in climate change and urbanization. By 2050, the total global population is projected to increase to 9.8 billion people, and about 70% of additional food supplies will be needed to feed them (Kumar & Kalita, 2017). Over the last few decades, several countries have focused on improving farming production, land use, and population management as part of their strategies to satisfy the growing need for food. It is a critical challenge for humankind to meet the food demand of a rapidly rising worldwide population.

Food security is one of the primary concerns in developing nations like India, despite the significant technological advancements that have been made in the agricultural sector. For instance, a major reason why there is not enough food to go around is because of food waste. Dealing with uncertainty is a major obstacle in risk management (Gurtu & Johny, 2021; Rathore et al., 2020). Several studies have been made by researchers on risk assessment in various industries. For instance, Raihan et al. (2022) have identified the risk and vulnerabilities involved in the soft drink industry supply chain. This study found that natural disasters and infrastructural unavailability hinder the performance of the supply chain in Bangladesh. Gokarn and Kuthambalayan (2017) pointed out the risk associated with poor packaging and concluded that it can damage the grain stock during transportation in the agri-food supply chain. Other studies have revealed critical risks in the Indian agri-food supply chain due to inadequate capacity, poor planning, improper conditions in warehouses, poor quality control, and so forth (Kumar et al., 2020; Ling & Wahab, 2020; Mithun Ali et al., 2019). Hence, understanding the sources of risk and the interactions between them is essential for developing a successful risk mitigation strategy.

In this context, a five-dimensional sustainability model offers a thorough framework for evaluating risks across five interconnected dimensions; these are environmental, economic, social, institutional, and technology. The industry can take responsible and well-informed actions to encourage sustainable development in the supply chain by using a five-dimensional risk analysis that takes into account all of these risk factors (Moktadir et al., 2021). However, very few studies have focused on the empirical aspects of prioritizing and managing the risks in agri-food supply chains in India (Kumar, Mangla, et al., 2021; Mithun Ali et al., 2019; Sharma et al., 2020). Only one study has focused exclusively on the induced risks in Indian food grain supply chain (FGSC) (Rathore et al., 2021). There has been no study that focuses on evaluating the risk factors from the five-dimensional sustainability criteria and also prioritizes the risk mitigative strategies. Hence, the present study aims to analyze different risk factors that might affect the sustainability of FGSC and provide practical insights into how practitioners might reduce risks by addressing the following research questions (RQs).

> **RQ1.** What are the most significant risk factors in Indian FGSC under the five-dimensional sustainability strategy?

> **RQ2.** What are the most significant risk mitigative strategies in attaining sustainability in Indian FGSC?

> **RQ3.** How can the findings of this study assist decision-makers in making informed decisions to improve the sustainability of the agriculture supply chain?

The fact that there is a significant amount of subjectivity involved in risk analysis is the primary barrier that must be overcome. This research has incorporated integrated fuzzy analytical hierarchy process (FAHP) and fuzzy technique for order performance by similarity to ideal solution (FTOPSIS) to deal with ambiguity while analyzing the data set. A complicated issue may be broken down into multiple smaller problems by organizing them into hierarchical levels, with each level representing a different set of criteria or qualities that are relevant to the problem being tackled using analytical hierarchy process (AHP). FTOPSIS uses the weightings determined by FAHP to evaluate the alternatives and uses proximity to the ideal solution as a basis for ranking alternatives, providing a more intuitive and straightforward approach to decision-making. Academics and professionals have previously made substantial use of integrated FAHP and FTOPSIS, primarily in engineering applications (Pathan et al., 2022).

From practical and intellectual viewpoints, this study makes the following contributions. We have sought empirical validation of the risk factors and risk mitigative strategies impacting the different phases of Indian FGSC from experts using a questionnaire survey. To the best of our knowledge, this is the first study to use five-dimensional sustainability criteria to analyze and evaluate risk factors in the FGSC. By taking a multi-dimensional sustainability-based approach, this study provides a more holistic and in-depth understanding of the risks in the FGSC. The findings of this study will be valuable for decision-makers in the FGSC to enhance the sustainability and resilience of the sector.

The remainder of the paper is as follows. Section 2 highlights existing relevant literature. Section 3 depicts the data collection and research methodology. Results are shown in Section 4. Section 6 discusses the new findings and compares these with existing recorded outcomes. Section 7 highlights the research implications. Finally, Section 7 illustrates the conclusion and limitations of the study and also gives direction for future research.

2 | LITERATURE REVIEW

An exploratory literature analysis is conducted to identify and analyze the risks associated with the Indian FGSC. This task is divided into two steps. The first step involves a comprehensive search of the available literature to understand the risks associated with the FGSC. This search is performed using a variety of databases including Science Direct, Scopus, Emerald, and Google Scholar. Keywords related to FGSC risk assessment—supply chain risk management (SCRM), agricultural sustainability, and agricultural risk—are used in the search. The search results in 257 articles to be reviewed for relevance. The articles are screened based on the following criteria:

- They offer a comprehensive understanding of agri-food supply chain risks.
- They emphasize the need for risk assessment in the FGSC in India.
- They provide detail on SCRM for agricultural sustainability.

The exclusion criteria include articles that are not relevant to the research question or do not meet the inclusion criteria. The process of inclusion and exclusion is performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher, 2009). After the screening process, 75 references are considered relevant and are included in the final analysis. These references provide a comprehensive overview of the various risks associated with the FGSC and offer insights into SCRM practices that can be used to mitigate these risks. In the second step, the relevant references are analyzed to gain a better understanding of the associated risks. This analysis is performed using a combination of qualitative and quantitative methods.

2.1 | Risk factors and sustainability challenges in Indian FGSC

One of FGSC's defining features is its inherent uncertainty. The Indian FGSC is characterized by challenges such as farmers' predominance, scattered supply chains, lack of scale economies, poor value addition, and inadequate infrastructure (Kamble et al., 2020; Kumar, Mangla, et al., 2021). There are few significant contributions to the field of risk assessment that highlight these problems. Risks may arise in several FGSC phases prior to ultimate food consumption, including production, warehousing, processing, and transportation (Ling & Wahab, 2020; Rathore et al., 2020). For example, Dani and Deep (2010) highlight that contamination is the most significant food safety risk that may occur during manufacturing and processing and can lead to local or worldwide public health emergencies. Miranda and Schaffner (2019) emphasize the risk of viruses in food supply chains. Kamble et al. (2020) highlight significant problems in an agri-food supply chain including a lack of industrialization, poor management, inaccurate information, and ineffective supply chain networks. The suggested solutions to these difficulties should incorporate food production and social, environmental, and economic issues to achieve agricultural sustainability. Jiang et al. (2022) recommend the use of organic manure instead of chemical fertilizer and also mention that excessive subsidies can be fatal to the long-term sustainability of the AFSC. Chaudhuri et al. (2016) identify the risk factors and a strategy for mitigating those risks to improve food processing supply chains. Manning and Soon (2016) propose a risk resilience model to improve the food supply chain's responsiveness as well as its stability and sustainability; they also focus on crucial risk factors like seasonality, supply spikes, and perishability qualities of agri-food items that may lead to significant value loss. Das et al. (2021) analyze the causal factors that hamper the distribution process of food grains. Researchers also highlight the need for policy reformation and technological incorporation in the Public Distribution System (PDS) supply chain for sustainable development. Furthermore, previous literature emphasizes the risks associated with the long-term effects of climate change. This area has attracted huge attention owing to worries about sustainable consequences on agriculture, supply of water, social equity, and economic and geopolitical stability (Chauhan et al., 2020; Kumar & Kumar Singh, 2021).

Additionally, numerous quantitative and qualitative research techniques are used for supply chain risk assessment. For example, Bai et al. (2018) establish a fuzzy comprehensive assessment model and failure mode effect analysis (FMEA) to estimate quality risks in food supply chains. Zhao et al. (2020) adopt TISM and MICMAC methods to identify the significant agri-food supply chain risks in different countries such as Spain, France, Italy, and Argentina. They conclude that political and weather-related difficulties are the most significant risks to achieving sustainability in ASC. Diabat et al. (2012) develop an ISM model on different risks in food supply chain and suggest implications for risk mitigation. Balaji and Arshinder (2016) use the TISM method to create a structural model of 16 contributing factors for food waste and the risk associated with it. Rathore et al. (2017) adopt grey AHP and TOPSIS to develop a risk quantification framework in the Indian FGSC. The study concludes that the most pressing challenges faced by the Indian FGSC are those related to technical risk, food grain quality, correct handling at different locations, safe storage, and regular maintenance.

Although agri-food systems are experiencing gradual changes, integrated food supply chains are a noticeable commercial phenomenon in India. Still, the Indian FGSC lacks optimism as a sustainable supply chain is faced with difficulties (Mangla et al., 2018). Hence, for conclusive risk analysis and management, it is important to create a taxonomy that includes a systematic and complete collection of risks. Table 1 presents a summary of important research articles on agri-food supply chain risk, including the methodology used, its strengths, and areas for potential future research and development. The identified risk factors that hinder the sustainability of the Indian FGSC are listed in Table 2.

TABLE 1 Literature on SCRM in agri-food supply chain.

Author	Research design	Research strength	Research gaps and future direction of research
(Dani & Deep, 2010)	Theoretical perspective and case study approach	The study aims to recognize and comprehend many strategies, contributing variables, and pertinent laws for risk management in the food industry. It then offers a conceptual framework for risk reduction from a reactive perspective.	No empirical study is made. Several risk factors are not considered as the study focuses on only suggesting reactive risk reduction strategies.
(Leat & Revoredo-Giha, 2013)	Theoretical perspective and case study approach	The report explores one of Scotland's main pork supply chains in an effort to pinpoint the significant risks and difficulties associated with creating a robust agri-food supply chain. The study mainly focuses on production risk, market risk, and institutional risk.	Focus is on the cooperation between stakeholders for reducing risks. The results have broad applicability to various agri-food supply chains.
(Rathore et al., 2017)	A thorough risk index is developed using grey AHP and grey TOPSIS	Analyzes the impact of risk factors in AFSC. The study mainly focuses on supply risk, storage and transportation risk, social risk, and demand risk	The study only considers 16 risk factors and does not prioritize the risk mitigative strategies
(Nyamah, Jiang, & Enchill, 2017)	Pearson correlation and an ordinary least square regression model are used to evaluate how significant risk factors have influenced Ghana's AFSC performance	Examines the major risk factors and their associated thresholds that have an impact on Ghana's AFSC.	No framework was proposed for prioritizing risk mitigative strategies.
(Behzadi et al., 2018)	Reviewed research articles	This study reviews research articles based on quantitative decision models for agricultural supply chain risk management. The study highlights key missing areas in quantitative AFSC studies related to risk mitigation.	Study priority is especially important from an industrial standpoint; there is a dearth of research on risk assessment articles that combine qualitative and quantitative approaches.
(Yazdani et al., 2019)	A multi-criteria approach is proposed to estimate agricultural flooding risks. A Spanish case study ranks agricultural initiatives that aim to reduce flood risks and crop damage to test the suggested approach.	This paper investigates and identifies the factors that influence flood risk and how they affect an agricultural supply chain's sustainability in light of a circular economy approach.	No framework was proposed for prioritizing risk mitigative strategies. The authors only consider an emergency situation to analyze the risk and how it affects crop yield.
(Sharma et al., 2020)	Fuzzy linguistic quantifier order weighted aggregation is used to evaluate risks in micro, small, medium, and multi-national companies	This research investigates COVID-19 disruption-related AFSC risks and focuses on 10 dimensions of major risk criteria.	No framework was proposed for prioritizing risk mitigative strategies. The study has also shown a future direction of research with other MCDM techniques for better decision-making and mentions that a bigger dataset is necessary.
(Zhao et al., 2020)	Using TISM, the linkages between identified risks are constructed. Using fuzzy MICMAC analysis, the suggested risks are divided into several groups.	This research uses a multi-method approach to analyze different AFSC risks, including theme analysis. Thematic examination of empirical data from experienced AFSC practitioners reveals eight risk categories and 16 risk variables.	No preventive measures are suggested to reduce the risks discussed and only qualitative research techniques are used.
(Ali & Gölgeci, 2021)	A mixed-methods approach is utilized, and data from SMEs in an Australian AFSC, both qualitative and quantitative, is used.	The study reveals four important climatic risks; the quantitative research supports the idea that businesses that actively participate in consortia and build up their social capital are better prepared to adapt to climate risks than other SMEs.	The study only focuses on mitigating climate risks, highlighting risk reduction through social consortia. Also concludes that there can be some geographical and sampling constraints.

TABLE 1 (Continued)

Author	Research design	Research strength	Research gaps and future direction of research
(Rathore et al., 2021)	This research aims at analyzing the risks associated with the Indian foodgrain supply chain and suggests a taxonomy of risk reduction to help with decision-making.	The paper uses a fuzzy VIKOR method to evaluate the risk at the Food Corporation of India (FCI) and finds that technological impact is very significant.	This study is limited to 14 risk factors. The study ignores cost factor; no framework was proposed for prioritizing risk mitigative strategies.
(Kumar & Kumar Singh, 2021)	The study aims to investigate the effects of COVID-19 on agri-food supply chains and potential methods for enhancing supply chain resilience.	The best-worst method (BWM) is used to calculate the significance rating for COVID-19's effects on the agri-food supply chain. The solutions for enhancing AFSC's resilience via the use of quality function deployment (QFD) are further linked to these effects	The research evaluates COVID-19 risks based on a few customers and business people, emphasizing the need for additional study for a proper decision-making framework with inputs from more experts. Research may be expanded to examine the risk in emergency situations like COVID-19's influence on operational sustainability.

TABLE 2 Identified risks in Indian FGSC.

Risk factors	Which stage of supply chain is affected by the risk factors	How it influences the sustainability of FGSC in India	Relevant literature
Lack of storage capacity	Storage and distribution	Inadequate storage capacity forces grain to be stored in the open atmosphere; this causes wastage.	(Bhardwaj & Sharma, 2020; Das et al., 2021; Pattanaik & Tripathi, 2016)
Improper storage conditions	Storage, distribution, and consumption	Lack of regular maintenance damages storage facilities; this in turn damages grains that are stored.	(Das et al., 2021; Mogale et al., 2020; Rathore et al., 2020)
Non-utilization of existing storage capacity	Storage, distribution, and consumption	Due to a lack of status awareness, many storage systems remain underused. The organization loses money maintaining it.	(Kumar & Kumar Singh, 2021; Weerabahu et al., 2021)
Improper inventory management	Storage, distribution, and consumption	Not following first-in-first-out (FIFO) principle can damage old stock while new stock will be sold out.	(Ali et al., 2022; Sharma et al., 2022; Sufiyan et al., 2019)
Shift in consumer preference	Distribution and consumption	Post-pandemic, individuals want healthful, nutrient-rich food. This change in customer preference may hurt small-scale farmers, who lack the capital for efficient grain management/farming.	(Cariappa et al., 2022; Moktadir et al., 2021)
Inability to control field losses	Production	Yield losses caused by pests, pathogens, and weeds are major challenges to crop production. This affects the quality of grains.	(Das et al., 2021; Gunasekera et al., 2017; Raut et al., 2018)
Poor quality control	Storage, distribution, and consumption	A quality control check is necessary as it differentiates low-quality from good-quality grains.	(Gardas et al., 2018; Nandi & Swamikannu, 2019; Raut et al., 2018)
Improper tracking and traceability system	Production, storage, distribution, and consumption	Rare use of advanced technology like blockchain, IoT, and RFID hinders the sustainability of FGSC	(Ali et al., 2022; Mangla et al., 2022; Sharma et al., 2022)

(Continues)

TABLE 2 (Continued)

Risk factors	Which stage of supply chain is affected by the risk factors	How it influences the sustainability of FGSC in India	Relevant literature
Poor packaging system	Storage, distribution, and consumption	Packaging helps in protecting grains from external damage. Improper packaging causes leakage and causes huge losses. This leads to early perishability of food grains	(Gokarn & Kuthambalayan, 2017; Rathore et al., 2022; Shende et al., 2022)
Poor handling of grains	Storage and distribution	Manual handling of gunny bags and other old grain handling techniques results in operational losses in supply chain.	(Rathore et al., 2022; Verma et al., 2018; Weerabahu et al., 2021)
Imbalance of supply and demand of food grains	Distribution and consumption	An imbalance of supply and demand leads to price fluctuations	(Behzadi et al., 2018; Nyamah, Jiang, Feng, & Enchill, 2017; Zhao et al., 2020)
Unbalanced demand in labor	Production	As production is seasonal, labor is not required throughout the year. Hiring permanent labor may generate losses due to lack of work during off season.	(Rathore et al., 2020; Verma et al., 2018)
Political instability	Production, storage, distribution, and consumption	Political instability leads to limited economic freedom in terms of food, health, education, etc.	(Das et al., 2021; Warsame et al., 2022)
Carrying cost of buffer stocks	Storage and distribution	Carrying the cost of buffer stock beyond a required level is expensive during high-production years	(Das et al., 2021; Mogale et al., 2020)
Low integration among the national food grain markets	Distribution and consumption	There is no proper directive for the physical market at national level; this hinders the opportunity of getting better prices for farmers	(Ahmed et al., 2022; Singha Mahapatra & Mahanty, 2020)
Lack of a long-term approach for mitigating supply chain risks	Production, storage, distribution, and consumption	The absence of a long-term risk mitigation plan suggests the organization is not focusing on objectives. Time and money are wasted.	Author's contribution
Improper information transfer between stakeholders	Production, storage, distribution, and consumption	Incorrect information affects all FGSC stages. The supply chain efficiency increases with timely information.	(Reshad et al., 2023; Sahu et al., 2022; Yazdani et al., 2021)
Lack of government supportive policies	Production, storage, distribution, and consumption	Lack of proper government policies regarding health, environment, and transportation generates a huge loss to the entire supply chain.	(Das et al., 2023; Reshad et al., 2023)
Lack of commitment of top management	Production, storage, distribution, and consumption	Top management should be very clear in making policies and should be committed; if not, the whole administration will deviate from the required goals.	(Mehmood et al., 2021; Somlai, 2022; Yadav et al., 2020)
Non- availability of procurement and distribution centers	Production, storage, and distribution	Ineffective procurement and distribution networks hinder the smooth supply of grain movement to demand locations.	(Rathore et al., 2020; Yadav et al., 2020)
Labor strike	Production, storage, and distribution	Labor strikes due to various reasons can hamper the flow and efficiency of FGSC.	(Mithun Ali et al., 2019; Rathore et al., 2020)

TABLE 2 (Continued)

Risk factors	Which stage of supply chain is affected by the risk factors	How it influences the sustainability of FGSC in India	Relevant literature
Timely availability of vehicles	Storage and distribution	The movement of grains is hampered due to the unavailability of vehicles; this causes exposure to different types of threats for the entire value chain.	(Mogale et al., 2016; Mogale et al., 2020; Rathore et al., 2020)
Lack of an internal auditing program	Storage and distribution	An internal auditing program is very important as it identifies internal frauds and helps to eliminate them completely.	(Meena et al., 2019; Rathore et al., 2020)
Natural disasters	Production, storage, distribution, and consumption	Natural disasters like floods, storms, and earthquakes are rare but cause a huge loss in every stage of FGSC.	(Mithun Ali et al., 2019; Song et al., 2017)
Insect infestation	Production, storage, distribution, and consumption	Improper or lack of management leads to food grain wastage.	(Das et al., 2023; Verma et al., 2018)
Use of excess chemical fertilizers	Production and consumption	Excess use of chemical fertilizer can damage health and also make land unfertile in the long term.	(Chen et al., 2021; Zhang et al., 2011)
Unexpected climate changes	Production, storage, distribution, and consumption	An unsuitable climate can significantly reduce food grain production. In the post-harvesting phase, climatic change effects the movement of food grains.	(Chen et al., 2021; Das et al., 2021; Rathore et al., 2020)
Safety issues related to workers	Production, storage, distribution, and consumption	Lifting heavy gunny bags causes musculoskeletal damage to the human body; any kind of contamination in the food grains causes serious health issues for the entire country.	(Bera et al., 2021; Gupta et al., 2021; Nath et al., 2021)
Theft and pilfering of food grains	Storage and distribution	Theft and pilfering mostly happen during transportation. It results in a huge loss of products and sometimes causes a threat to lives.	(Das et al., 2021; Mogale et al., 2020)
Exploitation by intermediaries	Production, storage, distribution, and consumption	Corruption at different stages of FGSC in India ultimately hampers the sustainability of the SC and imposes a serious threat to food security.	(Das et al., 2021; Kumari & Kumari, 2015; Verma et al., 2018)
Unavailability of agriculture inputs	Production, storage, distribution, and consumption	The unavailability of agricultural resources like sufficient water, seeds, and fertilizers sometimes causes delays for farmers.	(Rathore et al., 2020; Verma et al., 2018)
Unavailability of personal protective equipment	Production, storage, and distribution	During Covid-19, the unavailability of PPE leads to disruption of the supply chain.	(Kumar, Azad, et al., 2021; Singh et al., 2020)

2.2 | Risk management

In the context of the business world, the fast revolutions and technical developments that have recently taken place have led to an increase in the scope of risk. The SCRM identifies, assesses, mitigates, monitors, and controls supply chain risks. Risk management is a systematic method that enables businesses to have a better understanding of what a risk is, who is at risk, what regulators are currently in place to tackle those risks, and what processes need to be introduced to decide whether or not these regulations are acceptable (Moktadir et al., 2021). SCRM helps businesses to function more effectively, cut costs, and improve customer service. The primary goal of risk management is to reduce supply chain vulnerability (Chu et al., 2020). The four fundamental stages of risk management are as follows.

First, identify risks that might foster a common understanding of the supply chain's ambiguity. The goals of risk identification are to identify important risks and to differentiate between different types of future uncertainties so that these goals may be achieved as effectively as possible. Hence, the identification of significant risk factors must adopt a strategy that is comprehensive to detect all of the potential threats and vulnerabilities that exist in the SC. An initial analysis of the existing threats has to be carried out before any further steps can be taken in the direction of risk management. If the risks are identified from the beginning of the process, then the likelihood of risk may be reduced by taking the right precautions and making risk management easier (Moktadir et al., 2021). Spotting potential dangers requires using a variety of techniques, including risk mapping and risk assessment checklists.

The second stage involves a thorough assessment of potential risks. Supply chain risk assessment begins by determining how the organization uses its unique understanding of the market and industry to characterize and categorize the risk. Since different forecasters have different ideas about what constitutes a risk and how downstream and upstream links behave, this method may be considered independently (Fan & Stevenson, 2018; Norrman & Wieland, 2020).

The third phase involves putting risk management activities into practice. This stage includes prevention and mitigation strategies to deal with pre-determined threats. The potential risk and the company's budgetary policy influence decisions on a risk mitigation approach (Fan & Stevenson, 2018; Zimon & Madzík, 2019). Considering how intertwined most risks are, keeping an eye on those with negative dependencies is essential.

The fourth phase concerns monitor and control. Since risk is not a fixed phenomenon, it is important to monitor its manifestations and propose new approaches to manage them when necessary (Norrman & Wieland, 2020).

2.3 | Five-dimensional sustainability approach

The notion of sustainability is highly dependent on the combination of the impacts of many aspects of the development of supply chains. One of the prerequisites of sustainability is to make the definition of a category of core sustainable development indicators. "Sustainable development" is a term used to describe an approach to progress that takes long-term effects into account. The scope of this idea varies between contexts and theoretical frameworks.

All three of these factors—economic, social, and environmental—are highlighted in the triangle model of sustainable development (Dwivedi et al., 2019). This traditional model lacks proper insights into the sustainability of the organization. Hence, to consider other significant aspects of sustainability, Iddrisu and Bhattacharyya (2015) propose a model considering all five dimensions of sustainability, that is, social, environmental, institutional, economic, and technical. Figure 1

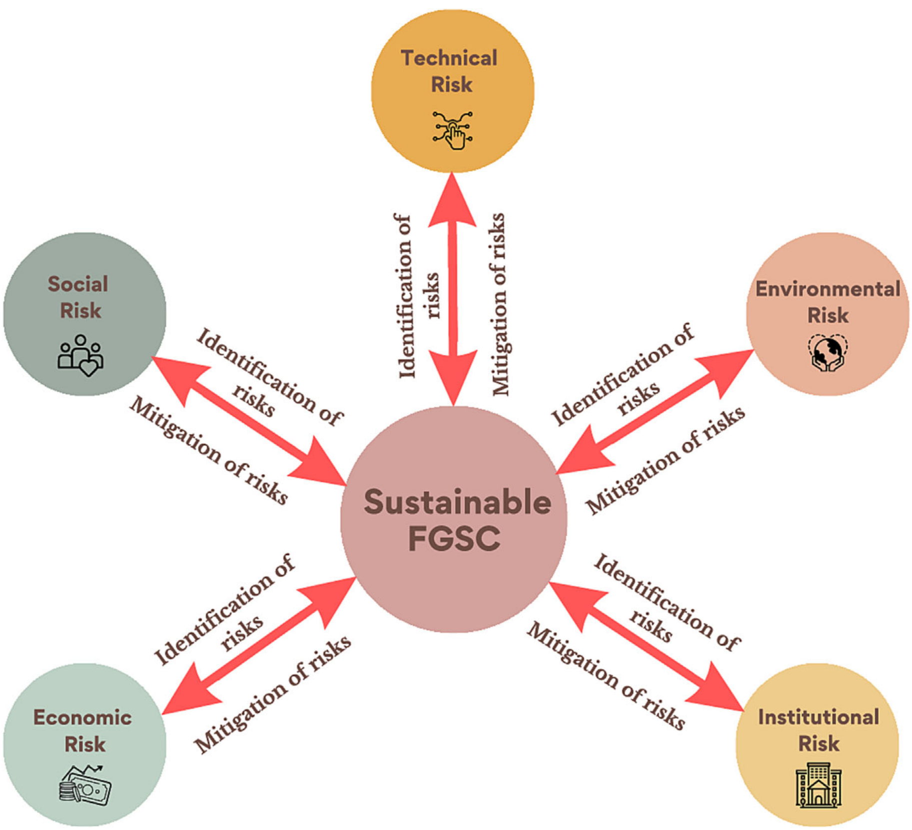

FIGURE 1 Five-dimensional sustainability approach in FGSC.

shows the five-dimensional sustainability approach adopted to evaluate the risk factors in the Indian FGSC:

A. Social Sustainability: This aspect illustrates the positive effects that supply chain activities have on society. It may be useful for evaluating the degree to which a society accepts the system.
B. Environmental Sustainability: This means caring for the world so that future generations can satisfy their requirements. This approach focuses on an organization's negative repercussions.
C. Economic Sustainability: This assures the commercial feasibility of the system to stimulate investment in sustainability.
D. Technical Sustainability: This factor is useful for ensuring the system's technical viability by analyzing relevant technological concerns. As well as inputs and outputs, it considers the organization's underlying technological infrastructure.
E. Institutional Sustainability: This factor concentrates on evaluating the facilities, infrastructure, strategic planning, and so forth of a particular organization.

The five-dimension sustainability method is created after the examination of the respondent data; it is based on frameworks and current literature on sustainability in relation to supply chain management (Moktadir et al., 2021). On the basis of their conceptual similarity and compatibility with the literature, the five variables that emerged from the exploratory factor analysis (EFA) are also compared and matched with the sustainability dimensions. Hence, although it is not assumed that the five sustainability dimensions and the five elements from the EFA would match, the process of matching them is based on a thorough and educated methodology. As a result, the sustainability strategy created in this study is theoretically informed as well as empirically established, offering a strong framework for future research. Table 3 shows the 11 risk mitigative strategies identified for sustainable development of the FGSC.

2.4 | Research gaps

We recognize some research gaps based on the literature evaluation; these provide opportunities for further study.

(1) Despite the fact that it is a significant source of food supply and has a significant influence on the Indian and worldwide economies, there are relatively few empirical studies that identify the risks connected with FGSC and also recommend risk reduction strategies (Nyamah, Jiang, & Enchill, 2017; Zhao et al., 2020). Behzadi et al. (2018) highlight that there is a need of extensive research of analyzing other risks beyond weather changeability and demand side disruptions in the agri-food supply chain. The evaluation of many unique risk factors (carrying cost of buffer stock and low integration in the national food grain market) on the sustainability of the FGSC, as far as the authors know, has not been addressed. Hence, a mixed approach of both qualitative and quantitative research may convey better insights about the impact of the risk factors and mitigatory strategies (Zhao et al., 2020).

(2) The majority of literature currently available (see Table 1) follows a single methodology and takes either a qualitative or a quantitative approach. For instance, current research mostly uses qualitative methodologies for risk assessment and mitigation (Dani & Deep, 2010; Diabat et al., 2012; Nyamah, Jiang, & Enchill, 2017; Ritchie & Brindley, 2007; Tummala & Schoenherr, 2011). There is a focus on either synthesizing risk reduction techniques or looking at the significance of risk factors. However, Rathore et al. (2020) have carried out some research on the evaluation of the risks associated with the Indian FGSC. However, the risks and vulnerabilities examined are only around the Food Corporation of India (FCI). They consider only 14 risk factors in FGSC, with the study based on five dedicated problems in PDS with FCI. The authors do not consider the other aspects of supply chain risk. They consider the risks with FCI in the procurement session, the risk related to an imbalance in annual supply and demand of food grains, risks sticking to obsolete technology, risks related to lack of coordination between central operations and state, and risks related to malfunctions in PDS. They do not address the risk and uncertainty induced by the carrying cost of buffer stock, non-utilization of current storage capacity, political instability, and so forth; these all have a substantial impact on the sustainability of FGSC (Das et al., 2021; Kumar & Kalita, 2017; Meena et al., 2019). Moreover, this research also lacks any insights into the threats from the five sustainability dimension levels considering the entire supply chain. Hence, there is a need for a thorough risk assessment and a risk mitigation plan which India urgently requires for the sustainability of its FGSC.

(3) There are important theoretical and knowledge gaps in the current literature. Very few studies categorize risk factors in different dimensions (e.g., production risk, storage and distribution risk, and logistic risk). Few recommend risk mitigation strategies (Kumar, Mangla, et al., 2021; Sharma et al., 2020), (Ali & Gölgeci, 2021; Govindan & Chaudhuri, 2016; Hofmann et al., 2014). No study explores, evaluates, and empirically validates the risk factors from the five-dimensional sustainability perspective.

Hence, the empirical research on the risk factors under five-dimensional sustainability in India over the course of a year is what makes this study unique and adds to the growing body of empirical literature on this topic. To fill the research gaps identified, we conduct an analysis to evaluate the risk factors and suggest a risk mitigation plan with a priority ranking revealing the impact level of each risk with empirical data collected from experienced food supply chain practitioners across India.

3 | RESEARCH METHODOLOGY

A three-step process is used to find and analyze the risks. First, a thorough search of relevant literature is made to learn about the risks in FGSC. Then, using EFA, the risks are put into five groups based on the five-dimensional criteria. Second, the weightage of the risk factors is obtained through FAHP. Third, FTOPSIS is adopted to find the ranking of the solutions. Finally, the results are verified by performing a

TABLE 3 Strategies to mitigate risk in FGSC.

Initiatives to reduce risk	Benefits	Risk mitigative strategies according to the SCRM stages	References
Transparent buffer stocking and liquidation policy	• Facilitates export of food grains • Govt expenditure is reduced • Better price availability to farmers	• Risk mitigating actions • Monitoring and control	(Pillay & Kumar, 2018; Singha Mahapatra & Mahanty, 2020)
Strengthening the existing research, awareness, and training component	• Diversified farming for better price availability and income • Awareness of the new tools and strategies to reduce risk • Promoting negotiable warehouse receipt systems (NWRs)	• Risk identifications • Risk evaluations • Monitoring and control	(Ali et al., 2021; Ye et al., 2022)
Stringent quality testing at procurement centers	• Better grain storage management • Better price availability • Better grain quality and nutrition	• Risk evaluations • Monitoring and control	(Akila & Shalini, 2018; Rathore et al., 2020)
Encourage private sector participation in the supply chain	• Better storage, management, distribution, and transportation • Reduced storage, operational, and transit loss • Govt. expenditure is reduced • Risks are distributed among supply chain entities • Custom farming (better price availability) • Facilitates containerized movement of grains	• Risk mitigating actions	(Das et al., 2021; Moazzam et al., 2018)
Provide direct/subsidized financial help to farmers in a distressed situation	• Subsidized agricultural input • Subsidized export • Sponsoring insurance premium (finance load is shared by insurance companies) • Direct benefit transfer. • No leakage and expenditure is saved in targeting	• Risk mitigating actions • Monitoring and control	(Kumar & Kalita, 2017; Rathore et al., 2020)
Provide mechanized facility at railway sidings	• Timely movement of grains • Reduced loading and unloading time • Worker's safety • Better utilization of resource	• Risk mitigating actions	(Devi et al., 2021; Rathore et al., 2020; Rathore et al., 2020)
Implementing end-to-end computerization through Agri 4.0	• Advanced technology like Agri 4.0, IoT, and blockchain will prevent leakage in the supply chain • Better governance • Smooth flow of information among the stakeholders • Better forecasting • Better reachability	• Risk identification • Risk evaluations • Risk mitigating actions • Monitoring and control	(Devi et al., 2021; Mending et al., 2018; Shahid et al., 2020)
Introduce agriculture extension services	• Cropping & plant protection Inf. Alert on risk, weather & harvest • Facilitates integrated pest management (IPM). • Reduced field losses. • Customized advice reaching instantly to the needful • Better quality and price • Better exposure to the global market	• Risk identification • Risk mitigating actions • Monitoring and control	(Ali et al., 2021; Behzadi et al., 2018; Talari et al., 2022)

TABLE 3 (Continued)

Initiatives to reduce risk	Benefits	Risk mitigative strategies according to the SCRM stages	References
Introduce modern markets like public procurement and public warehousing	• No distress selling. • Buffer stock liquidation • Earning probability will increase. • Huge Govt. expenditure is saved, services improved, and costs reduced	• Risk mitigating actions	(Ahmed et al., 2022; Singha Mahapatra & Mahanty, 2020)
Development of advanced storage structures for bulk handling at local level	• A scientific way of storing foodgrains • Reduced loss • Better quality and price	• Risk mitigating actions • Monitoring and control	(Akila & Shalini, 2018; Kumar & Kalita, 2017)
Price stabilization system	• Price security in case of an imbalance in supply and demand • Better engagement of the farmers. • Better price availability • Better economical sustainability	• Risk mitigating actions • Monitoring and control	(Alexandratos & Bruinsma, 2012; FAO, 2017; Moazzam et al., 2018)

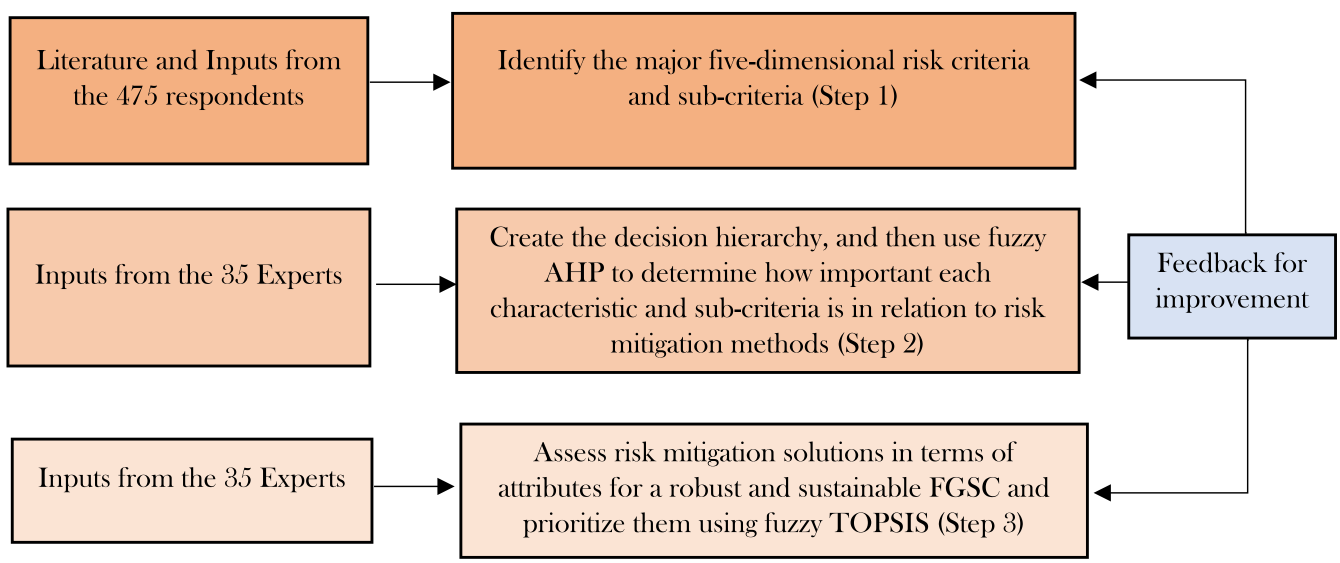

FIGURE 2 Proposed research methodology for the sustainable development of Indian FGSC.

sensitivity analysis. Figure 2 depicts the proposed research methodology for prioritization of the solutions to mitigate risk in FGSC.

3.1 | Data collection

Data are collected in two steps. In the first phase, we collect data through a questionnaire survey (Appendix A) to finalize the major risk attributes and the sub-criteria identified from existing literature. In the second phase, we collect data for priority selection of the major attributes, sub-criteria, and the risk mitigative strategies using FAHP and FTOPSIS.

In the first phase, to gather relevant data, we conduct a survey among industry experts, academicians, and farmers, yielding a total of 475 complete responses out of 1000. The survey was carried out between August 2021 to May 2022. The survey reveals that the replies from North India accounted for 10.55% of the total; the responses from Central and Western India combined contribute 25.27%; the south of India and East India regions provide 23.05% and 41.12% of the replies, respectively. Table 4 shows the demographic profile of the 475 respondents. The data collected are used to categorize the factors into five sustainability dimensions using EFA. According to Luthra et al. (Hofmann et al., 2014), data analysis is suitable if the valid responses from the respondent are 20% or more. In this study, 47.5% of participants in the survey provide

TABLE 4 Demographic statistics of the respondents.

Characteristics	Profile	No. of respondents	Percentage
Sector/profile	Executive director	45	9.47
	General manager	75	15.78
	Deputy general manager	53	11.15
	Assistant general manager	56	11.78
	Divisional manager	59	12.42
	Depot manager	43	9.05
	General manager	45	9.47
	Academicians	52	10.94
	Farmers	50	10.52
Experience in years	Less than 5 years	225	47.36
	Between 5 to 10 years	157	33.05
	More than 15 years	93	19.57
Qualifications	Graduates	290	61.05
	Postgraduates	77	16.21
	PhD	71	14.94
	Non-graduates	37	7.78
Gender	Male	416	87.57
	Female	59	13.68

TABLE 5 Profile of the 35 experts chosen for integrated FAHP-FTOPSIS.

Profile	No. of experts	Experience in years	Role in organization
Executive director	5	25	Monitor all operations and maintenance, including employee efficiency, shipments, and grain storage.
Divisional manager	5	15	They gather data but also analyze and report on the status of zones, regions, and districts.
General manager	5	16	Maintains divisional records and documentation and keeps track of inventory
Depot manager	5	15	Principal duties include acquiring, storing, transporting, and delivering the product.
Assistant general manager	7	15	Maintains stock quality under his domain
Sales manager	3	15	Maintains short- and long-term sales plan
Professors	5	23	Operations research

replies that may be considered as a good data set for possible analysis.

The supply chain risk questionnaire includes 32 different criteria for evaluation. We developed a survey guide to help participants stay on topic. Survey questions were also constructed to explicitly elicit participants' ideas and experiences with FGSC risk factors to ensure the validity and reliability of our data collection. Our objective is to identify the main risk factors impacting the FGSC in India by obtaining first-hand knowledge and viewpoints from professionals in business, academia, and the agricultural sector. Respondents are asked to rate the given statement based on a 1 to 9 Likert scale with 1 being “strongly disagree” and 9 being “strongly agree.” However, the problem of common method bias (CMB) is a potential pitfall of surveys. Industries involved in the agri-food supply chain throughout many states in India are targeted for CMB reduction. Besides Hindi, Bengali, and Oriya, several regional languages are spoken across India. So, the surveys are translated into appropriate regional languages. Appendix A includes a literal translation of the questionnaire in English.

In the second phase, to further analyze the data, we employ the integrated FAHP and FTOPSIS methods (see Appendix B). From the pool of 475 respondents, we choose 35 specialists for consultation in order to confirm the authenticity of our results. Purposive sampling techniques are employed to gather the data for this study and are selected based on considerable industry expertise spanning more than 15 years. In Table 5, we present a thorough description of the 35 supply chain specialists involved in the risk assessment. We ask experts to rate the pairwise comparison among the sub-criteria. The detailed steps of EFA, FAHP, and FTOPSIS are discussed further.

3.2 | Exploratory factor analysis

EFA is a technique that is beneficial for gaining insight into the structure of multi-dimensional data. It involves rotating the factor solution to simplify the pattern of loadings and make the interpretation of the factors easier (Gorsuch, 1988). The goal of EFA is to identify the most meaningful underlying structure of the variables and provide insights into the relationships among them. The varimax factor rotation allows for a simplified pattern of loadings and a clearer interpretation of the factors. The evaluation of factor interpretation and exclusion of variables with low factor loadings or low Cronbach's alpha values helps ensure that the results of the EFA are meaningful and easy to interpret (Marsh & Hocevar, 1985).

3.3 | Fuzzy AHP

The AHP, as proposed by Saaty, is a relative measuring approach for qualitative and intangible criteria (Wind & Saaty, 1980). It is a widely used in multi-criteria decision-making (MCDM) technique that can handle complex and uncertain situations. The AHP method is chosen for this study for a number of compelling reasons. (1) It is useful for dealing with problems that have several factors and no clear framework; (2) it enables decision-makers to assess pertinent issues and divide them into more manageable and economical sub-systems; (3) it may be used with both quantitative and qualitative data effectively. (4) When addressing a complex problem, it employs a hierarchical presentation, offering the possibility of assessing the consistency of the evaluation; this is an important aspect of the evaluation.

However, experts' preferences are often murky and difficult to predict when faced with real-life choices. Hence, Zadeh (1996) presents fuzzy set theory as a way to deal with ambiguity and uncertainty in decision-making. Fuzzy numbers are used to represent a certain range for a certain value. Because of this fixed range, the respondent may more clearly express his or her own opinion. Hence, a single linguistic evaluation will be converted into a fuzzy number made up of many different values. The linguistic evaluation may thus be seen as a scale. Fuzzy numbers may take the form of either triangles or trapezoids; both are applicable in the context of fuzzy theory. According to Balli and Korukoğlu (2009), triangular fuzzy numbers (TFNs) are advantageous because of their computational simplicity and are helpful in boosting representation and information processing in a fuzzy setting. TFNs are defined as a set of three numbers (l, m, u) where the first two numbers reflect the minimum and maximum values for a fuzzy event, respectively. The membership function is shown in Figure 3.

$\mu_A = (x) : \mathbb{R} \rightarrow [0,1]$ is equal to the following Equation (1):

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{(x-l)}{(m-l)}, & l \leq x \leq m \\ \frac{(u-x)}{(u-m)}, & m \leq x \leq u \\ 0, & \text{otherwise,} \end{cases} \tag{1}$$

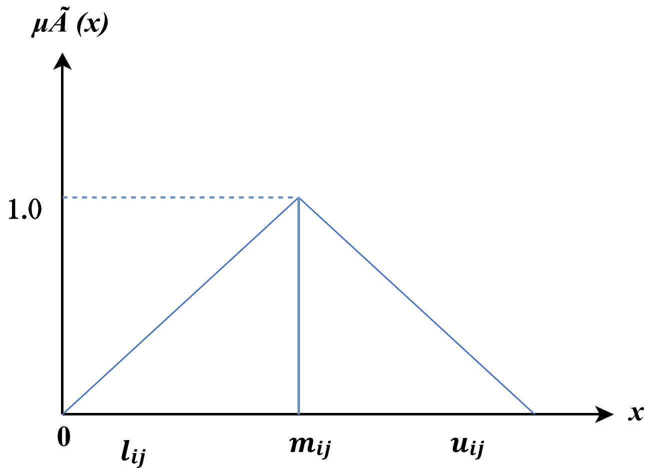

FIGURE 3 The membership function for the TFN.

When analyzing risk factors in an FGSC, the following steps should be followed:

Step 1: Finding the decision criteria or elements that are pertinent to the risk analysis of the FGSC is the first stage in fuzzy AHP. We first identify the criteria based on the five dimensions of sustainability—economic, social, environmental, technological, and institutional. We then develop a hierarchical structure of the criteria.

Step 2: The next step is to determine the relative importance of each criterion. Experts use the linguistic scale to generate a matrix of pair-wise comparisons. Table 6 represents the linguistic scale used for this study.

Step 3: In this step, the pair-wise judgment matrices at all stages of precedence are transformed into TFNs.

$$\tilde{A}^k = \left(\tilde{a}_{ij}^k\right)_{nxn} = \begin{bmatrix} (1.1.1) & \dots & \left(l_{12}^k, m_{12}^k, u_{12}^k\right) & \dots & \left(l_{1}^k, m_{1n}^k, u_{1n}^k\right) \\ \left(l_{21}^k, m_{21}^k, u_{21}^k\right) & \dots & (1,1,1) & \dots & \left(l_{2n}^k, m_{2n}^k, u_{2n}^k\right) \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \left(l_{n1}^k, m_{n1}^k, u_{n1}^k\right) & \dots & \left(l_{n2}^k, m_{n2}^k, u_{n2}^k\right) & \dots & (1,1,1) \end{bmatrix} \tag{2}$$

where $\tilde{A}^k$ means the fuzzy judgment matrix of kth expert and $\tilde{a}_{ij}^k$ is the TFN. For each row of $A = (\tilde{a}_{ij})_{nxn}$ is a fuzzy pairwise comparison matrix, where $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$, whose values can be obtained by using Equation (3):

$$l_{ij} = \frac{1}{l_{ji}}, m_{ij} = \frac{1}{m_{ji}}, u_{ij} = \frac{1}{u_{ji}} \tag{3}$$

Step 4: The following technique gives a normalized pair-wise comparison matrix:

The relative row-wise sum is calculated in every row of a symmetric matrix, $\tilde{\boldsymbol{A}}^k$

TABLE 6 Linguistic scale for the fuzzy comparison matrix (Zadeh, 1996).

Intensity of significance	Linguistic scale of significance for pair-wise comparison	Assigned triangular fuzzy numbers	Fuzzy reciprocal scale
1	Equally significant	(1,1,1)	(1,1,1)
3	Weakly significant	(2,3,4)	(1/4,1/3,1/2)
5	Fairly significant	(4,5,6)	(1/6,1/5,1/4)
7	Highly significant	(6,7,8)	(1/8,1/7,1/6)
9	Absolutely significant	(9,9,9)	(1/9,1/9,1/9)
2	The intermediate value between two adjacent scales	(1,2,3)	(1/3,1/2,1)
4		(3,4,5)	(1/5,1/4,1/3)
6		(5,6,7)	(1/7,1/6,1/5)
8		(7,8,9)	(1/9,1/8,1/7)

$$RS_i = \sum_{j=1}^{n} \tilde{a}_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij} \right) \quad i = 1,\ldots\ldots,n \tag{4}$$

Due to the lack of consistency in Chang's formulation, it is corrected with Wang and Elhag's (Chang, 1996; Wang & Elhag, 2006) modification and attains the normalized sum, rather than obtaining the relative row-wise sum $\tilde{S}_i$:

$$\tilde{S}_i = \frac{RS_i}{\sum_{j=1}^{n} RS_i} = \left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{j=1}^{n} l_{ij} + \sum_{k=1,k\neq i}^{n} \sum_{j=1}^{n} u_{kj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1,k=i}^{n} \sum_{j=1}^{n} m_{kj}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{j=1}^{n} u_{ij} + \sum_{k=1,k\neq i}^{n} \sum_{j=1}^{n} l_{kj}} \right) \tag{5}$$

From fuzzy weights, crisp weights are obtained in the next step using the following equation:

$$W_i = s_{ij}(\tilde{s}_{ij}) = \left(\frac{l_{ij} + m_{ij} + u_{ij}}{3} \right) \text{where } \tilde{s}_{ij} = (l_{ij}, m_{ij}, u_{ij}) \tag{6}$$

After the normalization process, the vector containing crisp weights is obtained.

$$W = (w1, w2, w3\ldots\ldots, wn) \tag{7}$$

Step 5: For the analysis of each pair-wise comparison matrix, consistency index (CI) and consistency ratio (CR) are calculated in this step using Equations (8) and (9), respectively.

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{8}$$

$$CR = \frac{CI}{RI(n)} \tag{9}$$

where "n" is the dimension of the matrix and λ_{max} is the eigenvalue of the most substantial Eigen vector of the pair-wise judgment matrix. Random index (RI) is a reference value used to determine the consistency of the AHP pairwise comparison matrix. The value of the RI depends on the size of the pairwise comparison matrix. According to the tolerance of the expert and the positional accuracy in the given problem, this threshold can be modified (Saaty, 1990). The possible ranges of RI values are shown in Table B1, (Appendix B).

Step 6: To compute the rank of all risk factors, global priority weights are evaluated. This is done by multiplying the local weight of alternatives with the local weights of their respective sub-criteria and criteria according to the hierarchical structure. The decisions of all experts are combined by a single representative matrix before starting the analysis as described below.

3.4 | Fuzzy TOPSIS

Prioritizing risk-mitigation strategies in the FGSC are obtained using FTOPSIS. FTOPSIS is an MCDM method first proposed by Hwang and Yoon (Lai et al., 1994). The steps in the process include defining the criteria and alternatives, deciding how much weight should be given to each, building the decision matrix, normalizing the decision matrix, figuring out the ideal and non-ideal solutions, computing the relative closeness, and ranking the alternatives. Following this procedure enables decision-makers to take well-informed actions that increase the FGSC's resilience to known risks. The result of this procedure is a ranked list of risk-mitigation strategies that may help managers decide which ones are best for reducing hazards in the FGSC.

Step 1: In this step, the identified risk mitigative strategies are compared with the finalized risk factors; a comparison matrix is thus created. However, to deal with the ambiguity, we adopt a linguistic scale for fuzzy comparison matrix. The linguistic variables should be rated according to the criteria. Table 7 shows the rating system employed.

Step 2: The aggregate fuzzy decision matrix may then be obtained by calculating the aggregate fuzzy weights for each criterion. If the Nth decision maker has a fuzzy rating of $X_{abN} = (l_{abN}, p_{abN}, u_{abN})$, where $a = 1, 2, \ldots, m$; and $b = 1, 2, \ldots, n$, then the aggregated fuzzy rating of each solution w.r.t criteria is given by $X_{ab}(l_{ab}, p_{ab}, u_{ab})$ where

TABLE 7 Rating based on linguistic variables.

Linguistic variables	Assigned TFN
Very low (VL)	(1,2,3)
Low (L)	(2,3,4)
Medium (M)	(3,4,5)
High (H)	(4,5,6)
Very high (VH)	(5,6,7)
Excellent (E)	(6,7,8)

$$a=\min\{l_{abN}\}, b=\frac{1}{N}\sum_{N=1}^{N} p_{abN}, c=\max(u_{abN}) \quad (10)$$

Step 3: The above obtained fuzzy matrix is normalized using Equation (11). The normalized matrix is denoted by $\tilde{\boldsymbol{R}}$

$$\tilde{\boldsymbol{R}}=\left[\tilde{r}_{ij}\right]_{m*n} \text{ where, } i=1,2,\ldots.,m; j=1,2,\ldots.,n$$

$$\tilde{r}_{ij}=\left(\frac{l_{ij}}{u_j^+},\frac{m_{ij}}{u_j^+},\frac{u_{ij}}{u_j^+}\right) \quad u_j^+=\max\,(uij)\,(\text{benefit criteria}) \quad (11)$$

$$\tilde{r}_{ij}=\left(\frac{u_j^-}{u_{ij}},\frac{u_j^-}{m_{ij}},\frac{u_j^-}{l_{ij}}\right) \quad u_j^-=\min\,(l_{ij})\,(\text{cost criteria}) \quad (12)$$

Step 4: The normalized matrix obtained above is multiplied with respective weights; the weighted fuzzy normalized matrix ($\tilde{\boldsymbol{V}}$) is obtained using Equation (13)

$$\tilde{\boldsymbol{V}}=\left[\tilde{v}_{ij}\right]_{m*n} \text{ where, } i=1,2,\ldots,m; j=1,2,\ldots.,n$$

$$\tilde{v}_{ij}=\tilde{r}_{ij}*\tilde{w}_j \quad (13)$$

Step 5: Fuzzy positive ideal solution is obtained by using the formula below:

$$A+=\{v1+,v2+,\ldots\ldots..vn+\}; \text{where } vj+ \text{ is max } \left(\tilde{v}_{ij}\right) \quad (14)$$

Step 6: The fuzzy negative ideal solution is obtained by using the formula below:

$$A-=\{v1-,v2-,\ldots\ldots..vn-\}; \text{where } vj- \text{ is min } \left(\tilde{v}_{ij}\right) \quad (15)$$

Step 7: The distance of alternatives ($d+$ and $d-$) from a fuzzy positive ideal solution and fuzzy negative ideal solution can be obtained by adding all the elements in the row of a particular alternative.

$$d+=\left\{\frac{1}{3}*\sum_{j=1}^{n}\left(v_{ij}-v_j^+\right)^2\right\}^{\frac{1}{2}}, i=1,2,\ldots\ldots,m \quad (16)$$

$$d-=\left\{\frac{1}{3}*\sum_{j=1}^{n}\left(v_{ij}-v_j^-\right)^2\right\}^{\frac{1}{2}}, i=1,2,\ldots.,m \quad (17)$$

Step 8: The closeness coefficient (cc) is calculated by

$$CC=\frac{d-}{(d+)+(d-)} \quad (18)$$

Step 9: Alternatives are ranked by organizing their closeness coefficient in ascending order of preference. The top ranking is based on the highest value of the closeness coefficient.

3.5 | Sensitivity analysis

Sensitivity analysis evaluates how input parameters or assumptions affect model or decision-making outputs. The decision-making process in MCDM entails choosing the best option or alternatives from a pool of accessible alternatives based on several, sometimes competing, criteria. To make it easier to choose the best option, MCDM approaches sometimes combine many criteria into a single score or rating. The input data, the weights given to the criterion, and the technique used to aggregate the criteria, all have a significant impact on the outcomes of the decision-making process. As a consequence, sensitivity analysis is carried out to assess the findings' robustness and to test the decision's sensitivity to changes in the input data, the weights of the criteria, or the decision-making processes. The influence of uncertainty or differences in the input data on the result or ranking of alternatives may be evaluated via sensitivity analysis (Luthra et al., 2016). Decision-makers may use this to pinpoint areas where further data or study are required to lessen ambiguity and enhance the decision-making process.

4 | MULTI-DIMENSIONAL RISK ANALYSIS AND PRIORITIZING THE RISK MITIGATIVE STRATEGIES

4.1 | Results of EFA

EFA is performed using a principal component analysis (PCA) with varimax rotation. Acceptable levels of explanation are also determined by measuring the communality of the scale, reflecting the amount of variance in each dimension. Items with factor loadings over 0.6 and cross-loadings below 0.4 are evaluated for factor interpretation. Items with Cronbach's alpha values below 0.8 are excluded since they cannot explain the data set's variability. All communalities measured in this study are over 0.5. The findings of the EFA indicate that the total variance for a single component is less than 50%; this indicates that CMB is not a problem in the data obtained (Muduli et al., 2020) and suggests that the data are well-suited for factor analysis. Kaiser–Meyer–Olkin's (KMO) sample adequacy (MSA) score, which measures how well-suited data are to factor analysis, is 0.938. In the end, the research produces a factor solution that leads to the discovery of five components for further analysis that together account for 87.7% of the data. However, the item "inadequate personal protective equipment" does not considerably load on any dimension after EFA. Hence, we finalize 31 sub-criteria for further analysis. The findings of this latest investigation demonstrate that the structure has five dimensions. The five major attributes that are found as being a part of this EFA fit with the theoretical arguments presented in Table 8. Factor 1 (TR) includes items TR1 to TR9, referring to technological risks. Factor 2 (IR) loads items IR1 to IR8 representing institutional risks. Similarly, factor 3 (FR) includes FR1 to FR5 representing economical risks. Factor 4 (ER) includes ER1 to ER4 referring to environmental risks. Finally, factor 5 (SR) includes SR1 to SR4 and represents social risks in the FGSC in India.

4.2 | Results of FAHP

After deciding on the attributes and sub-criteria, a hierarchical decision structure is created. Its structure is improved in consultation with supply chain specialists with the goals of boosting generalizability and lowering the likelihood of bias. The construction has four layers, as seen in Figure 4.

Level 1: Prioritization of the risk mitigative solutions in Indian FGSC (the aim of the study).

Level 2: Attributes of FGSC risk from the five-dimensional sustainability criteria.

Level 3: Sub-criteria of five-dimensional risk factors.

Level 4: Risk mitigative strategies.

TABLE 8 Extracted factors from EFA.

Risk	Sub-risk (code)	Cumulative variance	Factor loading	Cronbach's alpha
Technical risk (TR)	Lack of storage capacity (TR1)	27.7	0.962	0.983
	Improper storage conditions (TR2)		0.961	
	Non-utilization of existing storage capacity (TR3)		0.956	
	Improper inventory management (TR4)		0.951	
	Shift in consumer preference (TR5)		0.943	
	Inability to control field losses (TR6)		0.929	
	Poor quality control (TR7)		0.909	
	Improper tracking and traceability system (TR8)		0.902	
	Poor packaging system (TR9)		0.901	
	Poor handling of grains (TR10)		0.769	
Economic risk (FR)	Imbalance of supply and demand of food grains (FR1)	50.7	0.971	0.983
	Unbalanced demand in labor (FR2)		0.969	
	Political instability (FR3)		0.957	
	Carrying cost of buffer stocks (FR4)		0.953	
	Low integration among the national food grain markets (FR5)		0.945	
Institutional risk (IR)	Lack of a long-term approach for mitigating supply chain risks (IR1)	65.7	0.954	0.982
	Improper information transfer or information gap (IR2)		0.951	
	Lack of government supportive policies (IR3)		0.938	
	Lack of commitment of top management (IR4)		0.929	
	Non- availability of procurement and distribution centers (IR5)		0.925	
	Labor strike (IR6)		0.917	
	Timely availability of vehicles (IR7)		0.896	
	Lack of an internal auditing program (IR8)		0.859	
Environment risk (ER)	Natural disasters (ER1)	76.8	0.918	0.960
	Insect infestation (ER2)		0.900	
	Excess use of chemical fertilizers (ER3)		0.866	
	Unexpected climatic changes (ER4)		0.783	
Social risk (SR)	Safety issue related to workers (SR1)	87.7	0.961	0.911
	Theft and pilferage of food grains (SR2)		0.937	
	Exploitation of farmers by intermediaries (SR3)		0.915	
	Unavailability of agriculture inputs (SR4)		0.899	

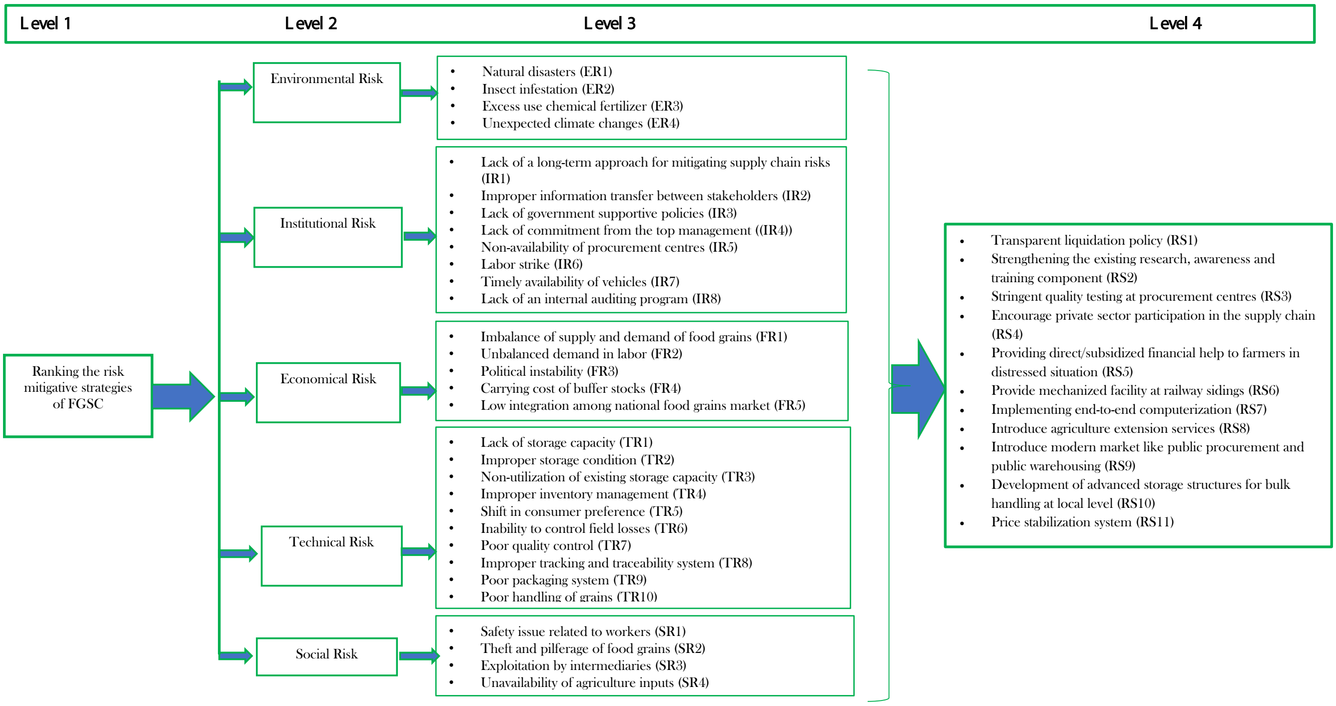

FIGURE 4 Identified decision criteria for the study.

TABLE 9 Ranking of the five-dimensional risk criteria in Indian FGSC.

	ER	IR	FR	TR	SR	Local priority weights	Ranks
Environmental risk (ER)	(1, 1, 1)	(1, 2.23, 4)	(1, 2.34, 4)	(1, 2.45, 4)	(1, 2.11, 4)	0.2922	2
Institutional risk (IR)	(0.25, 0.45, 1)	(1, 1, 1)	(5, 6.14, 8)	(0.17, 0.22, 0.33)	(4, 5.22, 6)	0.2065	3
Economical risk (FR)	(0.25, 0.43, 1)	(0.13, 0.16, 0.20)	(1, 1, 1)	(0.17, 0.24, 0.33	(6, 7.82, 9)	0.1200	4
Technical risk (TR)	(0.25, 0.41, 1)	(3, 4.56, 6)	(3, 4.23, 6)	(1, 1, 1)	(4, 5.43, 7)	0.3200	1
Social risk (SR)	(0.25, 0.47, 1)	(0.17, 0.19, 0.25)	(0.11, 0.13, 0.17)	(0.14, 0.18, 0.25)	(1, 1, 1)	0.0614	5

Once the group of 35 supply chain specialists approves the hierarchical decision structure, the priority weights of the attribute criteria are calculated. Using the scale shown in Table 9, the experts offer their inputs to create pairwise comparisons of the 31 risk factors and the five major risk attributes. The basis for the selection process is strengthened by this iterative procedure. The TFNs based on pairwise judgment matrices for each of the five criteria of each sub-criterion are included in Appendix B for completeness. The pairwise comparisons are examined using Chang's extent analysis (Chang, 1996) approach to estimate the priority weights of the attributes and sub-criteria shown. By multiplying the global weights of major criteria and local weights of sub-criteria, the overall priority of five-dimensional risk factors and sub-factors is determined. Figure 5 shows the weightage of the five-dimensional major risk criteria. After obtaining the global weights of the elements, 31 risk factors are ranked in a hierarchy shown in Table 10.

The rest of the pairwise comparison matrix with respect to each sub-criterion is included in Appendix B due to space constraints (see Table B2–B6).

4.3 | Validation of FAHP results through SA

The findings of sensitivity analysis show that ER1 receives the top rank after changing the weight from 0.1 to 0.4; TR8 receives the top rank after changing the weight from 0.5 to 0.9 (see Figure 6). In accordance with the findings of this study, ER1 receives the greatest weightage among the 31 sub-criteria, whereas TR8 receives the second-highest weightage. So, we may conclude that the outcomes are reliable, robust, and meaningful.

4.4 | Results of the FTOPSIS analysis

Using FTOPSIS and sensitivity analysis, data are examined and verified in this section. A fuzzy assessment matrix is developed by an expert panel utilizing linguistic data shown in Table 5. To create this matrix, we compare risk-mitigating strategies with risk factors. Due to space constraints, just one TFN expert assessment matrix is shown in Table 11. Using Equation (10), the aggregated fuzzy matrix of the

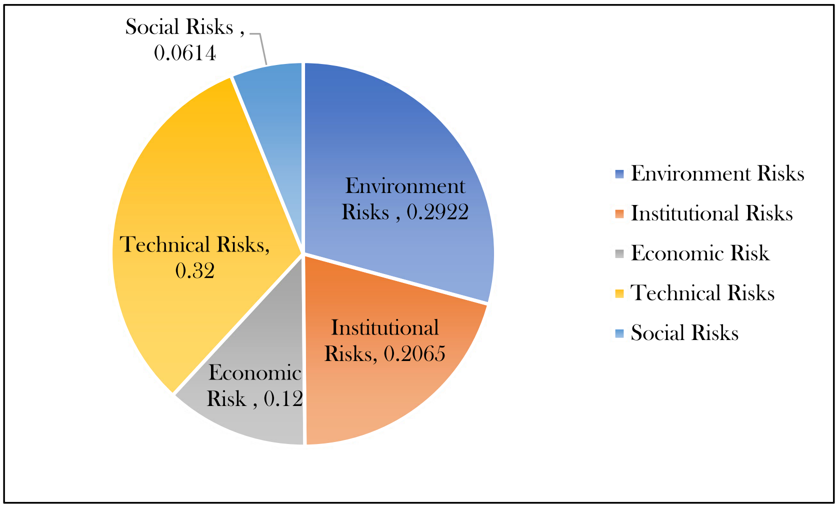

FIGURE 5 Weightage of the five-dimensional major risk criteria.

TABLE 10 Final ranking of the risks involved in Indian FGSC.

Risk	Weights	Sub-risk	Local priority weights	Global weights	Global rank
Environment risks (ER)	0.2922	Natural disasters (ER1)	0.5559	0.1693	1
		Insect infestation (ER2)	0.1127	0.0344	10
		Excess use of chemical fertilizers (ER3)	0.0644	0.0196	18
		Unexpected climatic changes (ER4)	0.2670	0.0689	4
Institutional risk (IR)	0.2065	Lack of a long-term approach for mitigating SC risks (IR1)	0.3052	0.0630	5
		Improper information transfer between stakeholders (IR2)	0.1006	0.0208	16
		Lack of government supportive policies (IR3)	0.2193	0.0453	7
		Lack of commitment from the top management (IR4)	0.1798	0.0371	8
		Non- availability of procurement and distribution centers (IR5)	0.1065	0.0220	15
		Timely availability of vehicles (IR6)	0.0190	0.0039	29
		Labor strike (IR7)	0.0094	0.0019	31
		Lack of an internal auditing program (IR8)	0.0603	0.0124	21
Economic risk (FR)	0.1200	Imbalance of supply and demand of food grains (FR1)	0.1234	0.0148	20
		Unbalanced demand in labor (FR2)	0.0672	0.0081	22
		Political instability (FR3)	0.0395	0.0047	26
		Carrying cost of buffer stocks (FR4)	0.5042	0.0605	6
		Low integration among the national food grain markets (FR5)	0.2658	0.0319	11
Technical risks (TR)	0.3200	Lack of storage capacity (TR1)	0.2898	0.0927	3
		Improper storage conditions (TR2)	0.0739	0.0236	13
		Non-utilization of existing storage capacity (TR3)	0.1098	0.0351	9
		Improper inventory management (TR4)	0.0697	0.0223	14
		Shift in consumer preference (TR5)	0.0606	0.0194	19
		Inability to control field losses (TR6)	0.0134	0.0043	27
		Poor quality control (TR7)	0.0126	0.0040	28
		Improper tracking and traceability system (TR8)	0.3426	0.1096	2
		Poor packaging system (TR9)	0.0103	0.0033	30
		Poor handling of grains (TR10)	0.0173	0.0055	25
Social risk (SR)	0.0614	Safety issue related to workers (SR1)	0.1174	0.0072	24
		Theft and pilferage of food grains (SR2)	0.1183	0.0073	23
		Exploitation of farmers by intermediaries (SR3)	0.3243	0.0199	17
		Unavailability of agriculture inputs (SR4)	0.4400	0.0270	12

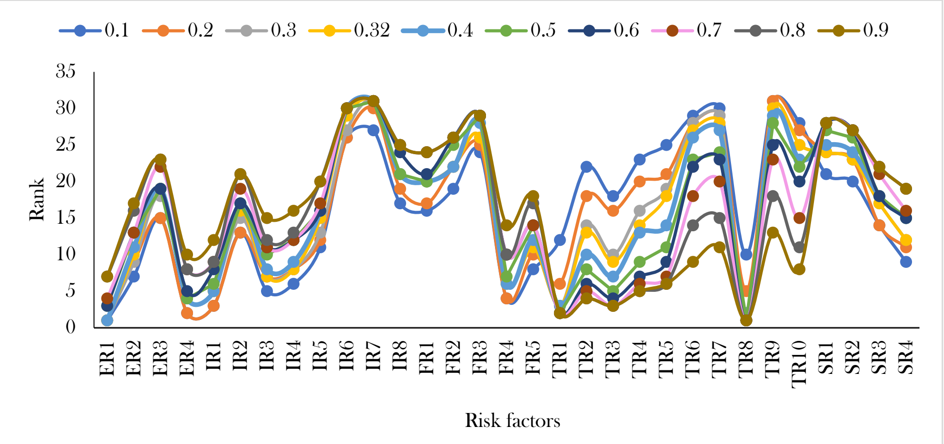

FIGURE 6 Sensitivity analysis on FAHP results.

TABLE 11 Comparison data from expert 1.

	ER1	ER2	ER3	...	...	SR2	SR3	SR4
Transparent liquidation policy (RS1)	H	L	M	...	...	H	VH	H
Strengthening of the existing research, awareness, and training component (RS2)	L	H	L	...	...	VH	L	L
Stringent quality testing at procurement centers (RS3)	VL	VL	L	...	...	H	VH	VH
---	...	...	...	...	...	---	---	---
---	...	...	...	...	...	---	---	---
Introduce modern markets like public procurement and public warehousing (RS9)	L	M	M	...	...	VH	VH	VH
Development of advanced storage structures for bulk handling at local level (RS10)	M	H	H	...	...	H	M	H
Price stabilization system (RS11)	L	L	VH	...	...	H	VH	VH

solutions is obtained, as shown in Table B7. The research employs the goal minimization strategy and normalizes the aggregate fuzzy matrix using Equation (12); this is shown in Table B8. A fuzzy weighted matrix is constructed by multiplying the sub-criteria weights acquired by applying FAHP using Equation (13); this is presented in Table B9. Each alternative's distance from the fuzzy positive ideal solution ($d+$) and the fuzzy negative ideal solution ($d-$) is obtained by using Equations (16)–(17); the coefficient of the closeness (CC) is calculated through Equation (18). The final ranking of the solutions is shown in Table 12.

4.5 | Sensitivity analysis on FTOPSIS results

The experts agreed on the selection of 31 trials for sensitivity analysis; the specifics are outlined in Table 13. To achieve this goal, we swap out the heavily weighted decision criteria while keeping the other weights the same. In the first trial, the weight of the ER1 is kept at 0.55, and the rest of the sub-criteria's weights are kept constant at 0.015. The CC value is obtained using FTOPSIS. Further, for the second run, the weightage of ER1 and ER2 are kept at 0.015 and 0.55, respectively; all other sub-criteria's weights are kept constant at 0.015. Again, the CC score is obtained. A similar process is followed for the rest of the trials. The details of the experiments are illustrated in Figure 7. This shows that RS9 (shown in thick grey line) has the highest value in 13 out of 31 experiments (3–5, 12, 15–17, 19–21, 27, 29, 31). Similarly, RS4 has the highest value in six experiments (10, 22–23, 25–26, 30). The final rank of the remaining risk mitigative strategies also changed. For this case at least, it appears that the final rank of the risk mitigative strategies for a sustainable FGSC is reasonably sensitive to the weights of the criteria.

5 | DISCUSSION ON FINDINGS

The suggested framework is created to prioritize risk-reduction strategies for the sustainable growth of the Indian FGSC. The findings of the study offer new perspectives by considering and analyzing the risk factors from the five-dimensional sustainability framework; this is distinctive and has never been previously done by researchers. Our findings indicate that technical risk has the most significant impact on the sustainable development of the Indian FGSC (see Figure 5). The expert team also explains how the FGSC is in a time of fast transition and modernization, with an increasing focus on digital solutions and technology developments; this may be a justification for the larger weighting given to technical risks. Our results also validate the claims

TABLE 12 Final ranking of the risk-mitigating solutions.

Solutions to mitigate risk in Indian FGSC	d^+ Avg	d^- Avg.	CC	Rank
Transparent liquidation policy (RS1)	7.19395	1.5148	0.1739	2
Strengthening of the existing research, awareness, and training component (RS2)	7.20562	1.5025	0.1725	11
Stringent quality testing at procurement centers (RS3)	7.20023	1.5062	0.1730	9
Encourage private sector participation in the supply chain (RS4)	7.20523	1.5129	0.1735	3
Providing direct/subsidized financial help to farmers in a distressed situation (RS5)	7.20142	1.5120	0.1735	4
Provide mechanized facility at railway sidings (RS6)	7.20567	1.5031	0.1726	10
Implementing end-to-end computerization (RS7)	7.19565	1.5199	0.1744	1
Introduce agriculture extension services (RS8)	7.19754	1.5111	0.1735	5
Introduce modern markets like public procurement and public warehousing (RS9)	7.19958	1.5102	0.1734	6
Development of advanced storage structures for bulk handling at local level (RS10)	7.19980	1.5101	0.1734	7
Price stabilization system (RS11)	7.20051	1.5076	0.1731	8

made by other researchers, in that technological factors have a substantial influence on the efficacy and efficiency of the agricultural supply chain (Rathore et al., 2021; Zhao et al., 2020). Furthermore, this study directly supports existing literature in that natural disasters and unexpected climate change may significantly affect the availability and pricing of food grains for consumers since they can disrupt the entire nation's food supply chain (Ali & Gölgeci, 2021; Tirado et al., 2010). Thus, it is essential for stakeholders to act proactively to address these risks and guarantee that food grains are accessible and affordable for everyone. Total computerization helps in preventing supply chain leaks and cutting-edge tools make it possible to predict weather data in advance. Hence, we can now prevent the devastating effect of natural disasters to a certain extent.

One of the key new findings from our study is that social risk is found to be the least weightage attribute (see Table 7). However, other SR parameters, such as the lack of agricultural inputs and the exploitation of farmers by intermediaries, are found to be critical for the sustainable development of FGSC. Researchers report that the unavailability of agriculture resources like labor, water, advanced equipment, and seeds hampers the production yield and also delays the next season of farming (Rathore et al., 2021; Sharma et al., 2020). These stressful situations force farmers to look for other alternative sources of income, making these farmers vulnerable to being exploited by other intermediaries in the supply chain. In interviews with experts, it is clear that the political and legal environment of a region or country is often linked to social risk factors. For example, the laws and rules that govern the workforce in a certain region can have a big impact on issues like labor practices and human rights. In some situations, dealing with social risk factors may require making big changes to these regulatory frameworks, which can be hard to do. In order to secure honest and ethical actions and preserve good relations with stakeholders, it is crucial to take social risks into account and handle them throughout the FGSC (Laeequddin et al., 2009; Noack & Pouw, 2015). However, depending on the particular setting and circumstances of the supply chain under consideration, the relative importance of social risks may change. Our findings also emphasize the importance of crucial ER parameters, such as carrying cost of buffer stock. It is reported by researchers that government has to lay out huge amounts of money due to the sharp rise in buffer stock in warehouses without serving any benefit. The government does not have any strategic planning or norms for liquefying buffer stock and saving capital on it (Mogale et al., 2020; Singh et al., 2015). Another noteworthy finding is lack of a long-term approach for mitigating supply chain risks; this is often limited to theory and not in practice, thereby exposing supply chains to greater risk (Alexandratos & Bruinsma, 2012; Varshney et al., 2021). Contrary to our study, a number of researchers neglect to include such crucial risk factors in their analysis. For example, risk factors like carrying cost of buffer stock, lack of integration in the national food grain market, and lack of a long-term approach for mitigating supply chain risks are not evaluated by the aforementioned studies (Bai et al., 2018; Behzadi et al., 2018; Dani & Deep, 2010; Kumar, Mangla, et al., 2021; Nyamah, Jiang, & Enchill, 2017; Rathore et al., 2021; Zhao et al., 2020). There is a danger that these risk factors can impact supply chain performance and raise the possibility of losing local as well as overseas clients. In the FGSC, piling up of buffer stock creates problems for storage, further increasing operational costs and food grain wastage. Buffer stocks may be liquefied and significant money can be saved with the implementation of legislation for public storage and public procurement (Prier & McCue, 2009; Sidhu, 2016; Zhou & Wan, 2007).

This study emphasizes prioritizing the risk mitigative strategies for better decision-making (see Table 9). The study findings suggest that end-to-end computerization has the potential to help the Indian FGSC overcome a variety of issues, including inadequate tracking and traceability systems, storage space shortages, climate challenges, and

TABLE 13 Sensitivity analysis calculation.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
ER1 = 0.55 and ER2-SR4 = 0.015	0.0429	0.0308	0.0310	0.0407	0.0439	0.0425	0.0426	0.0347	0.0376	0.0421	0.0385
ER1 = 0.015, ER2 = 0.55 and ER3-SR4 = 0.015	0.0383	0.0399	0.0381	0.0405	0.0436	0.0427	0.0287	0.0380	0.0358	0.0327	0.0338
ER1-ER2 = 0.015, ER3 = 0.55 and ER4-SR4 = 0.015	0.0383	0.0352	0.0354	0.0268	0.0438	0.0423	0.0287	0.0329	0.0449	0.0420	0.0293
ER1-ER3 = 0.015, ER4 = 0.55 and IR1-SR4 = 0.015	0.0386	0.0397	0.0355	0.0272	0.0295	0.0429	0.0287	0.0424	0.0451	0.0416	0.0336
ER1-ER4 = 0.015, IR1 = 0.55 and IR2-SR4 = 0.015	0.0247	0.0260	0.0341	0.0339	0.0253	0.0318	0.0280	0.0356	0.0443	0.0373	0.0248
ER1-IR1 = 0.015, IR2 = 0.55 and IR3-SR4 = 0.015	0.0378	0.0403	0.0466	0.0352	0.0384	0.0372	0.0440	0.0439	0.0468	0.0492	0.0379
ER1-IR2 = 0.015, IR3 = 0.55 and IR4-SR4 = 0.015	0.0319	0.0402	0.0360	0.0269	0.0442	0.0288	0.0289	0.0288	0.0315	0.0258	0.0341
ER1-IR3 = 0.015, IR4 = 0.55 and IR5-SR4 = 0.015	0.0268	0.0378	0.0356	0.0266	0.0440	0.0425	0.0285	0.0285	0.0311	0.0277	0.0337
ER1-IR4 = 0.015, IR5 = 0.55 and IR6-SR4 = 0.015	0.0338	0.0393	0.0352	0.0263	0.0439	0.0425	0.0282	0.0327	0.0380	0.0319	0.0288
ER1-IR5 = 0.015, IR6 = 0.55 and IR7-SR4 = 0.015	0.0355	0.0410	0.0446	0.0274	0.0302	0.0392	0.0292	0.0341	0.0317	0.0284	0.0298
ER1-IR6 = 0.015, IR7 = 0.55 and IR8-SR4 = 0.015	0.0434	0.0351	0.0403	0.0266	0.0342	0.0331	0.0285	0.0285	0.0358	0.0277	0.0337
ER1-IR7 = 0.015, IR8 = 0.55 and FR1-SR4 = 0.015	0.0359	0.0412	0.0373	0.0246	0.0411	0.0306	0.0332	0.0263	0.0445	0.0236	0.0382
ER1-IR8 = 0.015, FR1 = 0.55 and FR2-SR4 = 0.015	0.0382	0.0440	0.0399	0.0263	0.0439	0.0281	0.0282	0.0307	0.0380	0.0274	0.0380
ER1-FR1 = 0.015, FR2 = 0.55 and FR3-SR4 = 0.015	0.0388	0.0451	0.0408	0.0269	0.0300	0.0288	0.0315	0.0288	0.0315	0.0327	0.0389
ER1-FR2 = 0.015, FR3 = 0.55 and FR4-SR4 = 0.015	0.0307	0.0374	0.0325	0.0225	0.0253	0.0225	0.0243	0.0242	0.0443	0.0311	0.0324
ER1-FR3 = 0.015, FR4 = 0.55 and FR5-SR4 = 0.015	0.0416	0.0451	0.0456	0.0391	0.0300	0.0288	0.0289	0.0382	0.0457	0.0327	0.0369
ER1-FR4 = 0.015, FR5 = 0.55 and TR1-SR4 = 0.015	0.0252	0.0395	0.0400	0.0191	0.0257	0.0247	0.0247	0.0247	0.0429	0.0219	0.0383
ER1-FR5 = 0.015, TR1 = 0.55 and TR2-SR4 = 0.015	0.0433	0.0444	0.0312	0.0379	0.0295	0.0429	0.0378	0.0330	0.0383	0.0416	0.0411
ER1-TR1 = 0.015, TR2 = 0.55 and TR3-SR4 = 0.015	0.0436	0.0451	0.0408	0.0363	0.0346	0.0288	0.0383	0.0382	0.0457	0.0372	0.0437
ER1-TR2 = 0.015, TR3 = 0.55 and TR4-SR4 = 0.015	0.0368	0.0451	0.0408	0.0269	0.0346	0.0288	0.0411	0.0430	0.0457	0.0280	0.0389
ER1-TR3 = 0.015, TR4 = 0.55 and TR5-SR4 = 0.015	0.0416	0.0451	0.0436	0.0269	0.0442	0.0382	0.0431	0.0430	0.0457	0.0280	0.0369
ER1-TR4 = 0.015, TR5 = 0.55 and TR6-SR4 = 0.015	0.0311	0.0325	0.0444	0.0246	0.0274	0.0263	0.0394	0.0306	0.0383	0.0236	0.0269
ER1-TR5 = 0.015, TR6 = 0.55 and TR7-SR4 = 0.015	0.0228	0.0377	0.0406	0.0225	0.0330	0.0320	0.0345	0.0280	0.0383	0.0235	0.0247
ER1-TR6 = 0.015, TR7 = 0.55 and TR8-SR4 = 0.015	0.0248	0.0282	0.0399	0.0289	0.0317	0.0393	0.0421	0.0331	0.0331	0.0337	0.0312
ER1-TR7 = 0.015, TR8 = 0.55 and TR9-SR4 = 0.015	0.0311	0.0282	0.0444	0.0376	0.0410	0.0263	0.0394	0.0350	0.0288	0.0299	0.0360
ER1-TR8 = 0.015, TR9 = 0.55 and TR10-SR4 = 0.015	0.0314	0.0303	0.0448	0.0311	0.0440	0.0283	0.0424	0.0376	0.0310	0.0281	0.0344

(Continues)

TABLE 13 (Continued)

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
ER1-TR9 = 0.015, TR10 = 0.55 and SR1-SR4 = 0.015	0.0355	0.0368	0.0373	0.0332	0.0409	0.0263	0.0394	0.0331	0.0445	0.0243	0.0404
ER1-TR10 = 0.015, SR1 = 0.55 and SR2-SR4 = 0.015	0.0388	0.0308	0.0408	0.0391	0.0442	0.0288	0.0411	0.0362	0.0389	0.0358	0.0427
ER1-SR1 = 0.015, SR2 = 0.55 and SR3-SR4 = 0.015	0.0387	0.0447	0.0404	0.0268	0.0393	0.0427	0.0379	0.0373	0.0450	0.0417	0.0444
ER1-SR2 = 0.015, SR3 = 0.55 and SR4 = 0.015	0.0433	0.0444	0.0453	0.0363	0.0389	0.0427	0.0377	0.0423	0.0452	0.0416	0.0428
ER1-SR3 = 0.015, SR4 = 0.55	0.0384	0.0443	0.0448	0.0357	0.0390	0.0427	0.0377	0.0424	0.0453	0.0414	0.0431

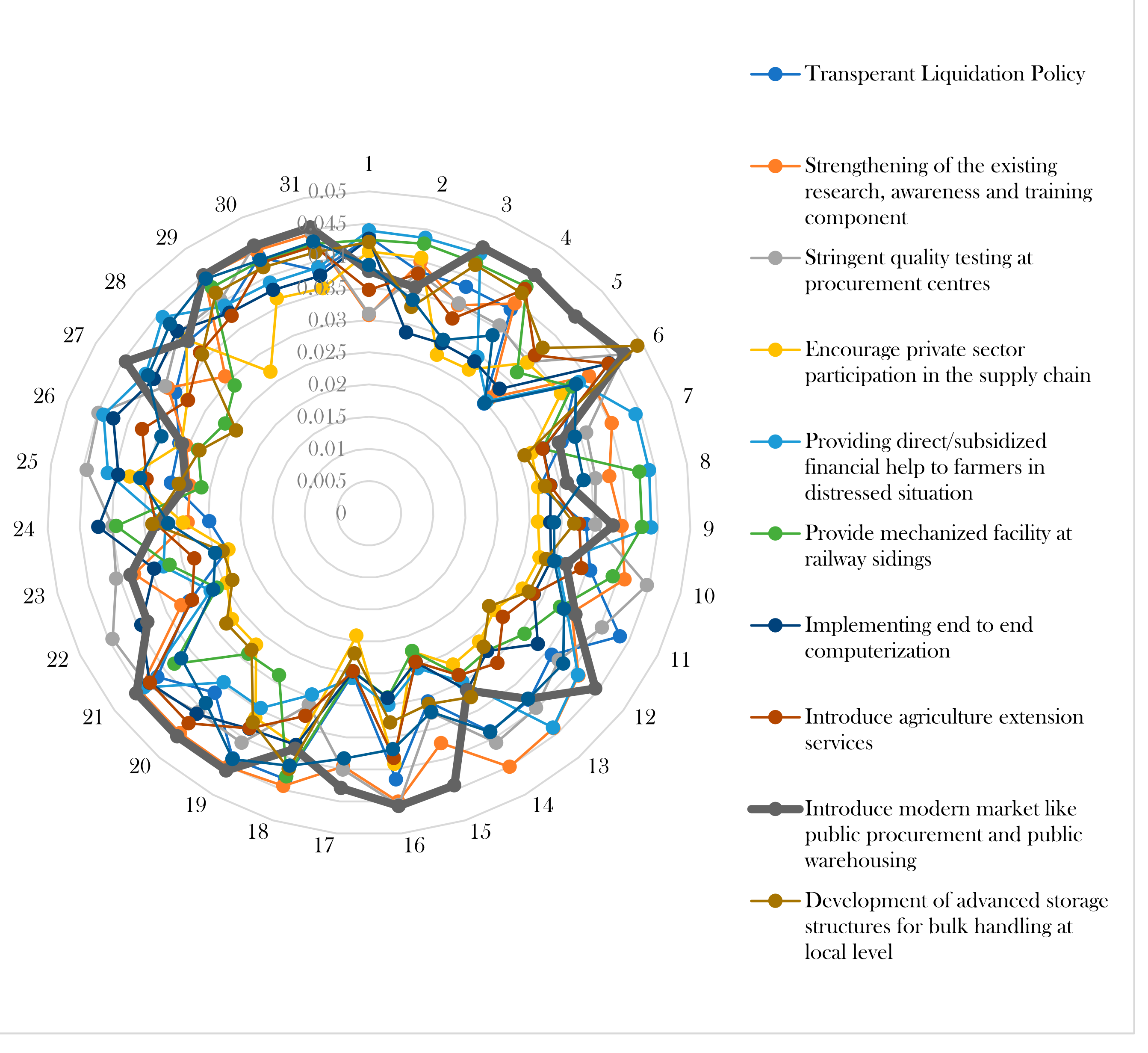

FIGURE 7 Sensitivity analysis on FTOPSIS results.

quality issues. The results are in line with Sharma et al. (2020). The whole supply chain may be monitored and controlled more efficiently, allowing improved inventory management and cutting waste, by setting up an efficient computerized system. Additionally, by setting up specific guidelines for the sale of surplus inventory, a transparent liquidation strategy can help to manage the carrying costs of buffer inventories. Encouraging private sector participation in the supply chain is found to be the third critical risk mitigative strategy. Promoting private sector involvement may improve effectiveness and competitiveness. Bringing private entities into the value chain will ensure better grain storage and management, cut government storage expenses, and create a more market-friendly environment. Our study results are in line with those of Das et al. (2021) and Rathore et al. (2021). Providing direct/subsidized financial help to farmers in a difficult situation and introduction of agriculture extension services are the fourth and fifth critical risk mitigative strategies. Providing direct or subsidized financial assistance to farmers in need can lessen the economic risks faced, particularly by small farms. Our study results are in line with those of Kumar, Mangla, et al. (2021) and Rathore et al. (2021). Similarly, the provision of agricultural extension services may also aid in enhancing farmers' knowledge and expertise. As crop producers learn to adapt to changing weather conditions, they should consider regional climate, agricultural capacity and demand, and cost-effective strategies. Governments can help by releasing forecast and climate data in graphical form in a variety of regional languages as an extension service. This will improve output and pricing for farmers. However, prior studies do not consider this risk mitigative strategy in their analysis (Behzadi et al., 2018; Rathore et al., 2021; Reshad et al., 2023). Moreover, contemporary marketplaces like public procurement and public transit may provide farmers, particularly those in distant locations, with greater access to markets (Pillay & Kumar, 2018; Prier & McCue, 2009; Singha Mahapatra & Mahanty, 2020). When combined, these risk mitigation techniques can greatly increase the effectiveness, adaptability, and sustainability of the Indian FGSC. They may also help small farmers maintain their way of life and strengthen India's food security.

6 | MANAGERIAL IMPLICATIONS

A critical problem in the business analytics field is the selection of risk-mitigative solutions for the sustainable growth of FGSC. Our suggested framework has important managerial ramifications. First, the study seeks to inform organizations on the strategies they can use to reduce supply chain risks and enhance overall supply chain performance. Second, on the basis of its applicability and effects on the supply chain, it may also assist managers in ranking various risk factors and risk mitigation strategies. Third, the study can assist businesses in more efficiently allocating resources by emphasizing the most important areas that need focus and investment. Fourth, the findings offer useful advice on how to put risk mitigation measures into practice and what difficulties organizations may encounter. Fifth, the study can be used as an industry benchmark, enabling organizations to evaluate how well their supply chain risk management capabilities are performing compared to industry competitors. Overall, the managerial implications of this research on risk mitigative solutions for SCRM can inform, guide, and improve decision-making and practices in organizations, leading to a more resilient and efficient supply chain.

7 | CONCLUSION

Millions of people rely on the Indian FGSC for their livelihood; it makes a significant contribution to the nation's economy. Lack of attention to the risks identified might lead to negative outcomes, including decreased agricultural yields, greater food waste, higher food costs, and food insecurity. The nation needs modern, market-oriented approaches to manage the associated risks. Authorities must understand commercial risk elements to strengthen sustainable processes. In this context, this study's initial goal is to identify and analyze the critical risk factors in the Indian FGSC theoretically and empirically. This research makes important contributions to the sector from a management perspective. The study can significantly help managers in a number of ways. The five-dimensional risk analysis for sustainable growth of FGSC in India is the first of its kind. This issue is important and demands further research. It also highlights key risk characteristics, sub-criteria, and risk mitigation tactics. The study finalizes five major attributes, 31 sub-criteria, and 11 risk-mitigation strategies based on existing literature and information from experienced supply chain specialists. This study will be a crucial resource for further research since it is the first to designate five-dimensional sustainability criteria in the existing literature. Finally, a risk-related fuzzy AHP-TOPSIS analytical framework is created. The approach is cutting-edge and rigorous; it works well for decision-making involving human judgments, which are by nature ambiguous and imprecise. The practical benefit of this proposed analytical framework is shown by a numerical case study. The case findings indicate that prioritizing risk and risk-mitigation strategies may be significantly impacted by the weights allocated to criteria. However, a thorough and cooperative strategy involving several stakeholders, including the government, the commercial sector, farmers, and other players in the supply chain, is required to put these risk mitigation strategies into effect. To support the successful use of these tactics, this strategy should also include capacity development, training, and awareness-raising initiatives.

However, the research is not without its limitations. The perspectives of operational staff and the general public may differ with the findings of the study. Workers on the ground, for instance, may see the viability and practicality of adopting such ideas in a different light from the wider public, who might have different priorities and requirements. This emphasizes how crucial it is to include all stakeholders in the SCRM process and take into account their viewpoints when putting risk mitigation methods into practice. The absence of cross-country comparisons is another limitation of this study. The conclusions of this research may not be entirely applicable to other nations with varying cultural, economic, and political circumstances since it is specifically focused on India's FGSC. A deeper knowledge of the difficulties and possibilities related to SCRM might be achieved by conducting further studies to examine the efficacy of the suggested risk-mitigating methods in other nations.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Das, S., Myla, A. Y., Barve, A., Kumar, A., Sahu, N. C., Muduli, K., & Luthra, S. (2023). A systematic assessment of multi-dimensional risk factors for sustainable development in food grain supply chains: A business strategic prospective analysis. *Business Strategy and the Environment*, 1–27. https://doi.org/10.1002/bse.3435