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Supply Chain Risks in the Dairy Industry

Abstract

Purpose

- Supply Chain Risk (SCR) has been extensively explored in various sectors, yet there is a notable scarcity of SCR studies in the dairy industry. This study aims to identify the primary and distinctive risks in the dairy supply chain (DSC), propose a typological model for SCR, highlight challenges specific to the DSC, and offer mitigation strategies.

Design/methodology/approach

- We employ a systematic literature review to collect and review relevant research articles published between 2010 and 2019 to identify the main risks and mitigation strategies associated with the DSC, enabling to construction of a typological model of DSC risks.

Findings

- Results of the systematic review of the SCR literature show that the main DSC risks include on-farm risk (e.g., risks originating from the farming system), off-farm risk (e.g., supply risk, demand risk, and manufacturing risk), and inherent SCR (e.g. logistics risk, information risk, and financial risk). Notably, we find that the farming system plays a key role in today's agricultural supply chain operations, indicating the importance of considering on-farm risk in the entire DSC. Additionally, mitigation strategies are located in response to the identified DSC risks by the typology of DSC risks.

Originality/value

- This paper is the first attempt to develop a typological model of SCR for the dairy industry by a systematic literature review. The findings contribute to providing a comprehensive understanding of DSC risks by bridging the gap of ignoring the on-farm risks of the DSC in the existing literature. The typology may serve as a guide in practice to develop mitigation strategies in response to DSC risks.

Keywords: dairy supply chain risk, risk identification, dairy farm

1 Introduction

Globalization has significantly increased the complexity and risk for organizations (Bhattacharyya, 2011, Guillot et al., 2024). Most businesses rely on their supply chain networks to maintain competitiveness in the marketplace (Christopher and Peck, 2004, Wang et al., 2016). In recent years, factors like climate change, geopolitical shifts, economic fluctuations, and global pandemics have highlighted supply chain risks (SCR) across various industries (Wang, 2023). These risks can stem from both internal supply chain operations and the external environment (Wang et al., 2015a). To navigate unforeseen "black swan" events, firms must develop resilient strategies. Effectively managing SCR is crucial to fostering resilience in supply chains across diverse sectors (Wang et al., 2023). Notably, SCR management requires targeted analysis of specific industries or supply chains to generate insights relevant to researchers and managers, enhancing understanding, prioritization, and mitigation of associated risks (Wang, 2018). This paper focuses on the dairy industry, one of the most significant sectors globally.

The dairy industry, a critical component of the global food supply chain, plays an essential role in providing key products to consumers worldwide (Chouinard et al., 2008). As the industry continues to evolve, it faces numerous challenges that require robust risk management strategies. The dairy supply chain (DSC) has drawn increasing attention due to the rising global demand for dairy products: dairy is a valuable source of essential nutrients for maintaining a healthy life. It is projected that demand for dairy will increase by approximately 63% from 2007 to 2050, driven by population growth and rising incomes (Alexandratos, 2012). The major increase in per capita dairy consumption is anticipated in developing countries like India and China (Alexandratos, 2012). In developing nations, the dairy industry plays a multifaceted role, contributing to food security, economic growth, poverty reduction, and sustainable agriculture. In developed countries, the dairy industry's importance extends beyond nutritional value, encompassing economic, cultural, and environmental dimensions (Ibrāhīm et al., 2020). For instance, the IDFA's 2021 Economic Impact Study revealed that the US dairy industry accounted for 3.5% of the nation's GDP. In the UK, milk represented 16.4% of the total agricultural output, with a market value of £4.4 billion in 2020. New Zealand leads globally as the top exporter of milk, with exports valued at 7.8 billion US dollars in 2022. The DSC involves all stages of production, processing, distribution, and retailing of dairy products. It plays a crucial role in delivering dairy products from farms (the point of origin) to final consumers (the endpoint of consumption) (Ibrāhīm et al., 2020).

The DSC is a complex system encompassing stakeholders such as farmers, milk processors, distributors, retailers, and end consumers (Mor et al., 2018, Maina et al., 2020). The DSC may include both drinking milk dairies and cheesemaking dairies, with the former also producing cream, butter, soured products, and milk powder (Sonesson and Berlin, 2003, Maina et al., 2020). The business-to-business (B2B) model plays a vital role in the DSC (Maina et al., 2020, Guillot et al., 2024). The DSC is subject to strict food quality controls, covering factors like temperature, humidity, and sanitation. This research focuses on the entire DSC, from farm to consumer (see Figure 1).

Although SCR has long been recognized as a challenge for businesses (Zsidisin, 2003b, Tang and Nurmaya Musa, 2011, Sodhi and Tang, 2021), most studies have centered on the manufacturing sector (Thun et al., 2011, Grötsch et al., 2013, Blackhurst et al., 2008, Ho et al., 2015). Traditional SCRs in food supply chains range from macro-level to operational management and information management levels, spanning supply and demand risks (Diabat et al., 2012, Prakash, 2017). Given the increasing global emphasis on environmental awareness, the DSC faces additional risks, including those related to food safety (Dani and Deep, 2010), consumers (Tostivint et al., 2017), reputation (Chen et al., 2014), the value chain (Ibrāhīm et al., 2020), and climatic uncertainty (Jaffee et al., 2010), beyond conventional SCRs (Sodhi and Tang, 2012, Jüttner et al., 2003, Christopher and Lee, 2004). SCR management can be approached through

either B2C or B2B models (Guillot et al., 2024). It is essential to take a comprehensive view when assessing end-to-end SCRs in the dairy sector. As previously mentioned, prioritizing specific industries for SCR management is key to creating effective and impactful strategies (Wang, 2018, Wang and Jie, 2020). Effective management of DSC risks is essential to building a resilient supply chain for dairy products. However, risks specific to the DSC have received limited attention, with relatively few studies dedicated to addressing these challenges. Globally, there is a strong demand for research in the DSC. To address this gap, this paper aims to develop a typology of DSC risks by identifying primary risks, significant challenges, and risk mitigation strategies. This research is part of the New Zealand DSC Research Project, designed to address challenges and support the New Zealand dairy industry. We propose the following research questions:

RQ1 What are the key SCRs in the dairy industry?
RQ2 What are the major challenges in mitigating the DSC risk?
RQ3 What are the mitigation strategies for SCR in the DSC?
RQ4 How are the insights and findings important in creating a resilient DSC?

This investigation begins with a systematic literature review on supply chain management and SCR within the dairy sector, focusing on research published between 2010 and 2019. We then identify concerns and obstacles associated with managing SCRs in the dairy industry. Finally, we outline risk mitigation strategies from relevant studies reviewed in the literature. This contributes to bridging the gap in understanding and managing DSC risks. By systematically reviewing pertinent studies, this paper proposes a typology for DSC risks, covering both on-farm and off-farm risks. Note that, for scope management, details regarding farm-level risks have been excluded. For further details, refer to Boehlje and Eidman (1984) and Leppälä et al. (2012).

This study aims to illuminate the various risk dimensions within the DSC and examine contemporary risk management strategies adopted by industry stakeholders. From farm-level production challenges to distribution network vulnerabilities, each stage of the DSC involves unique risks that require careful consideration and strategic planning. This paper contributes to the body of knowledge on dairy SCR management and aims to provide valuable insights for industry professionals, policymakers, and researchers working to enhance the resilience and adaptability of the DSC in a constantly evolving global context.

The remainder of the paper is structured as follows: Section 2 presents background information on SCR, while Section 3 outlines the research methodology. Sections 4 and 5 contain an analysis of the reviewed literature and the results. The final section offers the study's conclusion and implications.

2 Supply chain risk

The concept of risk is closely tied to uncertainty (Wang et al., 2015a). The International Organization for Standardization (ISO 31000) defines risk within the context of risk management as "The effect of uncertainty on objectives. An effect is a deviation from the expected." This definition highlights how risk reflects the potential impact of uncertainty on achieving organizational goals, emphasizing the dynamic nature of risk management. ISO 31000 offers a comprehensive framework that includes principles, a structured approach, and processes to help organizations effectively manage risks.

In supply chain literature, risk is frequently described as a multidimensional concept (Jüttner et al., 2003, Wang et al., 2023). It can refer to risk drivers, sources, and consequences, with potential effects being either positive or negative (Tang and Nurmaya Musa, 2011, Sodhi and Tang, 2012, Wang et al., 2015b). Importantly, the structure of supply chains can vary significantly across industries, which affects the nature of associated risks. For instance, the courier(Wang,

2018), pharmaceutical (Wang and Jie, 2019a), forest (Wang et al., 2023), and meat industries (Wang and Jie, 2019b) all have distinct supply chain structures. This variation necessitates industry-specific approaches to effective SCR management.

A supply chain is a network of organizations involved in producing goods and services to meet consumer needs (Christopher and Peck, 2004). SCRs are not confined to individual firms but also involve coordination and cooperation across organizational boundaries (Jüttner, 2005). SCR can encompass both operational risks and disruption risks (Tang, 2006). Disruption risks can lead to major supply chain interruptions, such as those caused by natural disasters or pandemics. In contrast, operational risks are tied to business processes and activities that can impact supply chain efficiency and effectiveness (Sodhi and Tang, 2012). Managing SCRs is increasingly vital for the DSC (Ibrāhīm et al., 2020).

SCRs can be categorized from various perspectives (Guillot et al., 2024, Ho et al., 2015). Christopher and Peck (2004) proposed three primary categories of risk: internal to the firm, external to the firm but internal to the supply chain network, and external to the network. They further divided these into five subcategories: process, control, supply, demand, and environmental risks. Tang and Nurmaya Musa (2011) categorized major SCRs into material, information, and financial flows. Wang et al. (2015b) divided supply chain uncertainty and risk into three categories: company-side, customer-side, and environmental uncertainties. Another classification differentiates between risks originating within the company (internal) and those from outside (external). Internal SCRs include operational, financial, and quality-related risks, while external SCRs involve risks linked to supply chain partners and the external environment, such as supply, demand, and environmental risks (Wang and Jie, 2019a, Wang et al., 2022). Sodhi and Tang (2021) highlighted widespread challenges and risks in supply chains. Studying SCRs is essential for the dairy industry, as it enables stakeholders to understand key challenges and to address them through both proactive and reactive risk mitigation strategies.

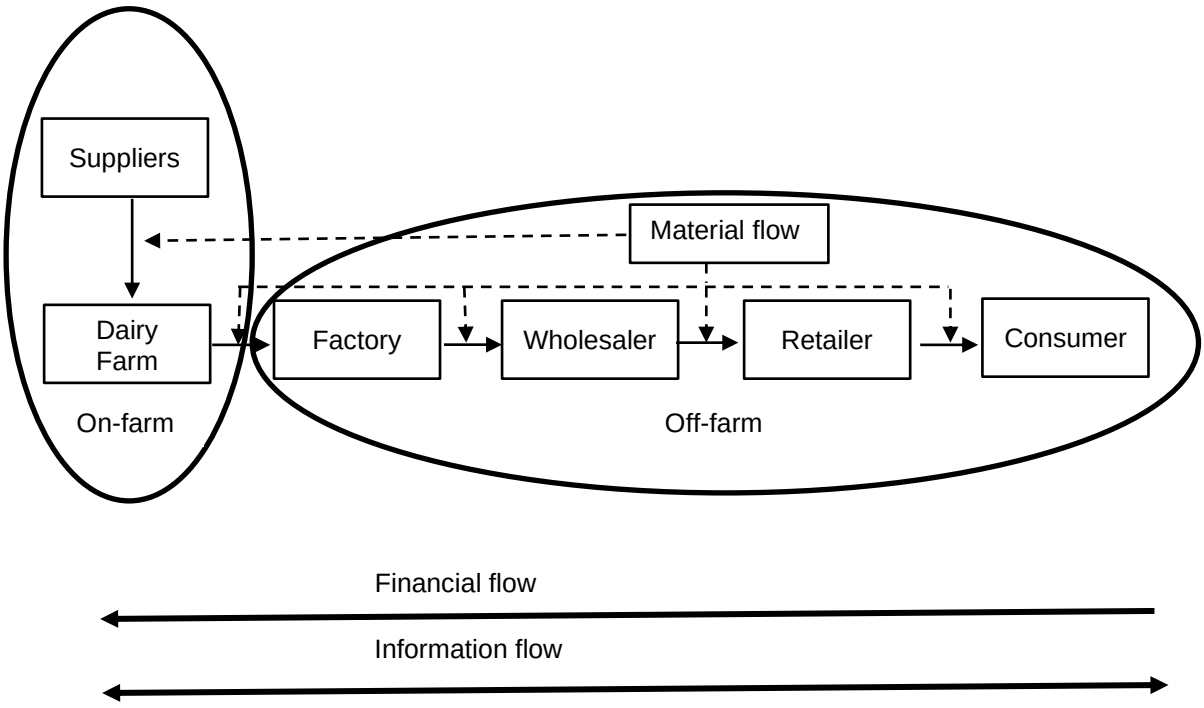

Figure 1. A typical dairy supply chain (Source: Authors' work)

3 Research methodology

The paper examines pertinent literature on dairy SCR management, specifically focusing on English articles published in the past decade, spanning from 2010 to 2019. Systematic reviews use explicit and rigorous criteria to identify, critically evaluate, and synthesize all the literature on a particular topic. Although they require significantly more effort than traditional reviews, systematic reviews yield consistent results, demonstrating that the findings are robust and generalizable (Kitchenham, 2004).

The search for articles was conducted across several scientific electronic databases, including Google Scholar, Scopus, Web of Science, Emerald, and ScienceDirect. The initial search utilized the keyword "dairy supply chain risk," which yielded only 38 results on Google Scholar. To broaden the search scope, a pilot search led to the inclusion of additional keywords: "dairy supply chain," "dairy industry," and "supply chain risk." These terms were used to search titles, abstracts, author keywords, and Keywords Plus. Figure 2 presents the database search process used in this study.

The relatively low number of publications highlights a research gap in the existing literature. The researchers screened the search results, evaluating titles, keywords, abstracts, and full articles, while excluding irrelevant and duplicate studies. A total of 69 full-text articles were reviewed, with some excluded due to a lack of alignment with the research objectives. The final database search was completed in the first week of February 2020, resulting in a total of 50 articles being included in the study.

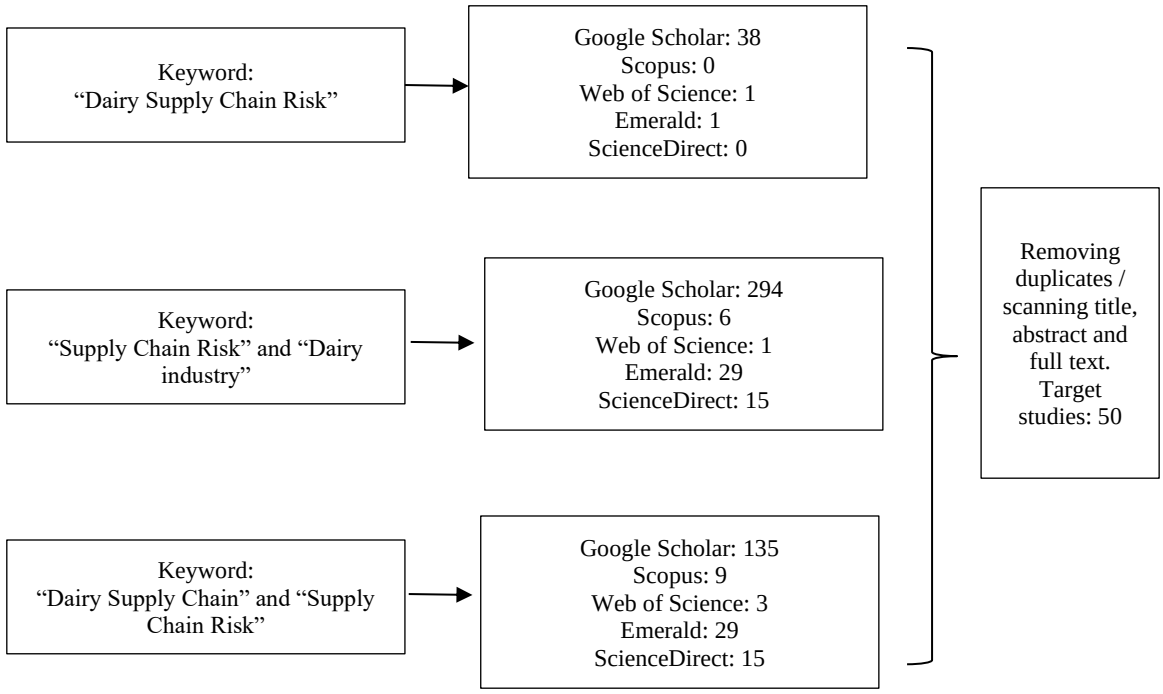

Figure 2 Literature keyword search process (Source: Authors' work)

Figure 3 presents a systematic review flow diagram for this study, visually depicting the process of conducting a systematic review - a research methodology used to rigorously analyze and synthesize the existing literature on a specific topic or research question (Liberati et al., 2009). The PRISMA flow diagram provides transparency and clarity regarding the stages of the review process, helping readers understand how studies are identified, screened, assessed for eligibility, and included in the final analysis.

The process begins with identifying relevant studies through comprehensive literature searches across various databases, journals, and other sources. After the initial identification, duplicates are removed, and the remaining studies are screened based on predefined inclusion and exclusion criteria. This stage involves reviewing titles and abstracts to determine whether a study meets the initial eligibility criteria. Studies that pass this screening undergo a detailed assessment to determine their suitability for inclusion in the systematic review, often involving a full-text review of the selected studies.

Only studies that meet the inclusion criteria are incorporated into the systematic review, with the flow diagram typically indicating the number of studies included at this point. Studies that do not meet the inclusion criteria are excluded from the review. Relevant data from the included studies are then systematically extracted, including study characteristics, methodology, results, and other key information. The findings are synthesized to develop a DSC risk framework, allowing for overall conclusions regarding the research question.

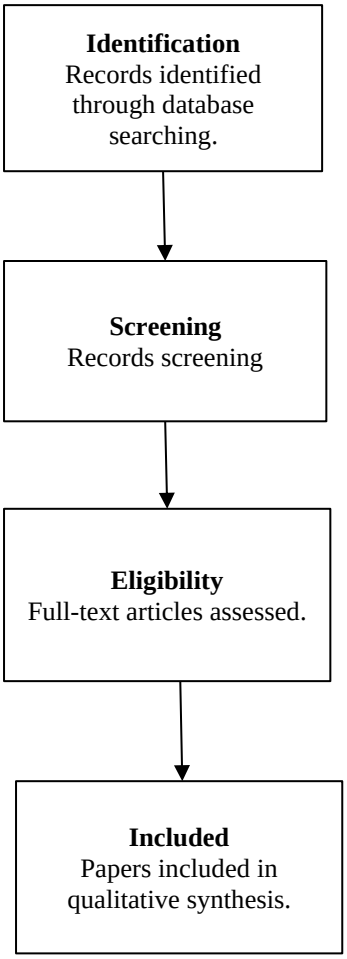

Figure 3 Systematic review flow diagram (Source: Liberati et al. (2009))

4 Analysis and synthesis

In this section, the analysis of the publications aims to provide an overview of the literature, with the papers being thoroughly analyzed and synthesized. The characteristics of the publications, such as publication date and source, are presented. Notably, the study was conducted before the outbreak of the COVID-19 pandemic, which helps mitigate any potential bias related to assessing the impact of COVID-19, as the pandemic has significantly increased interest in research on SCRs. The rise in publications, illustrated in Figure 4, indicates a growing interest among researchers and practitioners in the field of SCR within the dairy sector from 2010 to 2019. Table 1 lists the primary journals referenced during the sampling process.

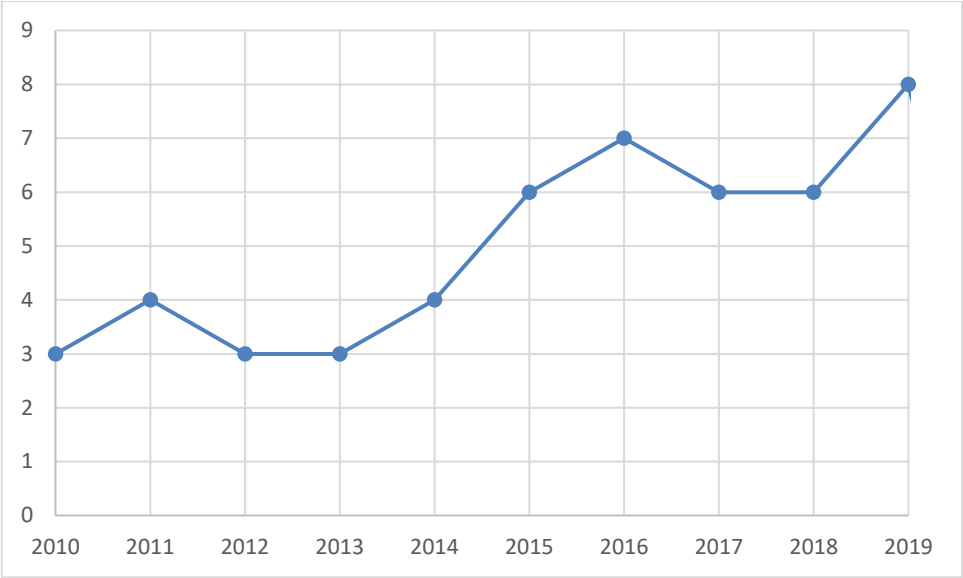

Figure 4 Number of articles by year of publication (Source: Authors' work)

Table 1 List of key Journals for literature review

Journal
• *International Journal of Production Economics* • *International Journal of Production Research* • *Supply Chain Management: An International Journal* • *Journal of Cleaner Production* • *Benchmarking: An International Journal* • *European Journal of Operational Research* • *International Journal of Logistics Management* • *Journal of Supply Chain Management* • *British Food Journal* • *Production Planning & Control* • *Management Science* • *Omega*

DSC risks have been identified and scattered in previous studies. For example, Mishra and Shekhar (2011) identified 14 risks from a dairy industry perspective. Zubair and Mufti (2015) explored 28 risks in the dairy products sector. Yu and Huatuco (2016) identified 13 risks in the DSC. Prakash et al. (2017) emphasized the importance of identifying risks in the supply chain of milk and milk-based products. Their study classified SCRs into four categories: environmental risk, supply risk, demand risk, and process risk, based on previous SCR research (Christopher and Peck, 2004, Manuj and Mentzer, 2008). Liu et al. (2019) conducted a case study identifying 9 types of DSC risks in the New Zealand dairy industry. It is insightful to integrate these SCRs within the dairy industry context. The DSC risks from the selected 13 dairy risk studies are summarized in Table 2.

Table 2 Summary of relevant DSC risks (2010-2019)

Authors	Risks	Methods
Dani and Deep (2010)	Type I risks have a direct influence on food safety. Type II risks are all other risks affecting the food supply chain, which influence indirectly on food safety.	Secondary data research
Leppälä et al. (2011)	Detailed dairy on-farm risks, including preparation for the milking process risks, feeding process risks, milking process risks, washing and Cleaning risks, and closing the milking process risks. The main risks for the whole DSC include risks that are associated with environmental effects, the image of farming, animal health and disease, milk quality, profitability and welfare for suppliers, and milk production interruptions	Case study, semi-structured interviews
Mishra and Shekhar (2011)	Low milking cattle, Illiteracy of the milk Producers, Non-remunerative price of milk, Logistical risks, Hazard risks, Demand Unpredictability, Lack of product Reliability, High cost of fodder and medicines, Lack of leadership skills of secretaries, Delivery risks, Product shortages, Seasonal fluctuations in production, Process/control/quality risks, Incompatible price w.r.t quality	Questionnaire survey
Diabat et al. (2012)	Macro-level risks, Demand management risks, Supply Management Risks, Product/Service Management Risks, Information Management Risks	Case study, Interpretive Structural Modeling (ISM)
Nasir et al. (2014)	Financial risk, technological risk, human resource risk, government policy and support, political risk, mismanagement of staff, and natural risk.	Interview
Daud et al. (2015)	Production risks, animal condition risks, personal risks, and input and output market risks.	Case study, observations, informal interview
Zubair and Mufti (2015)	Demand-side risk, supply-side risk, logistics-side risk, external risk, informational risk	Questionnaire survey
Manning and Soon (2016)	Internal organizational and external SCR	Literature review
Yu and Huatuco (2016)	Demand risk, supply risk, operational and control risks, environmental risks	Case study, semi-structured interviews
Chari and Ngcamu (2017)	Disaster risks included natural disaster risks and political and economic meltdown in the country; for example: drought, cyclones, floods, animal diseases, and crop pests.	Mixed method approach, structured questionnaires, semi-structured interviews, and observations.
Prakash et al. (2017)	Four categories of risk were identified: environment risks, supply risks, demand risks, and process risks	Integrated approach for risk analysis and mitigation (IARAM), case study.
Mithun Ali et al. (2019)	lack of skilled personnel, poor leadership, failure within the IT system, capacity, and poor customer relationship	DEMATEL method
Liu et al. (2019)	Raw milk quality risk, Milk solids price risk, Raw milk volume risk, Raw material quality risk, Customer order risk, Process stability risk, Product quality risk, Product price risk, Product delivery time risk	Case study

We found that very few supply chain studies use a common approach to identify SCRs in supply chains (Tang, 2006, Simangunsong et al., 2012). However, DSC is distinct from other supply chains due to its specific risk structures, which are influenced by the critical agricultural sector (Bachev, 2013). Farming plays a central role in the DSC, and we have included on-farm risks in the framework. On-farm risks may directly affect upstream suppliers, such as quality, food safety, and supply, making it essential to consider on-farm risks in the overall DSC system. This broadens the scope to include all key stakeholders in the DSC.

Researchers have proposed valuable risk classifications within the DSC. Jaffee et al. (2010) introduced an agricultural SCR framework, covering both on-farm risks related to climate, environment, and biophysical factors, as well as off-farm risks involving market conditions, logistics, infrastructure, management, operations, and public policy. Leppälä et al. (2011) examined on-farm risks and risk management in the DSC, highlighting that dairy production involves complex external supply chain operations (e.g., emissions) and requires precise internal operations (such as quality control and farmer expertise). Mishra and Shekhar (2011) studied various risks in the dairy industry, categorizing them by their impact as high, medium, or low. Diabat et al. (2012) classified food SCRs into five categories: macro-level risks, demand management risks, supply management risks, information management risks, and product/service management risks. Nasir et al. (2014) investigated the main risk factors in the dairy industry. Daud et al. (2015) identified key sources of risk in a DSC, including the quality of milking animals, feed availability, milking handling practices, milk bulking practices, and milk transportation. Zubair and Mufti (2015) prioritized 28 SCRs in the dairy products sector. Chaudhuri et al. (2016) examined sourcing-related risks, logistics risks, production risks, and storage risks in food processing supply chains. Nakandala et al. (2017) highlighted volatile demand, supply quality risk, and supplier delivery delays as major risks in fresh food supply chains. Chari and Ngcamu (2017) explored the impact of disaster risks on DSC performance, with major consequences including job losses, food insecurity, reduced milk productivity, and overall slow growth in dairy businesses. Bilska and Kołozyn-Krajewska (2019) developed a risk management model for dairy product losses. Kataike et al. (2019) investigate dynamics of supplier–buyer relationships within the DSC.

Although generic SCR frameworks have been introduced in DSC risk (Yu and Huatuco, 2016, Prakash et al., 2017), agricultural SCRs result from a range of factors including the vagaries of weather, unpredictable nature of biological processes, seasonality of production, geographical separation of production, and the uncertain political economy of food and agriculture (Jaffee et al., 2010). The main sources of risks include the quality of the milking animal (Daud et al., 2015), feed availability (Daud et al., 2015), milking process practices (Nasir et al., 2014), etc. appear in the dairy farm, which plays a vital role in a DSC.

A typical DSC comprises on-farm and off-farm stages in the supply chain network (Kataike et al., 2019). Farming is a critical part of the food supply chain, where disruptions in production processes can have severe consequences (Leppälä et al., 2012). On-farm internal and external risk factors directly influence the entire DSC. The consideration of both internal organizational and external SCRs within the food supply chain has been applied to SCR models (Manning and Soon, 2016). Additionally, quality risks arising from dairy farm practices (Leppälä et al., 2011) are significant. Thus, we have included the on-farm risks in the typology. Moreover, the risks related to the flow of physical goods, information, and finances are considered logistics risk, information risk, and financial risk (Tang and Nurmaya Musa, 2011, Ho et al., 2015). These are inherent SCRs that persist along the entire supply chain. By separating these risks from on-farm and off-farm risks, we provide a clear and logical framework for identifying and measuring different types of risks for various purposes within a complex DSC system.

4.1 A typology of dairy supply chain risk

In this section, we detail the on-farm, off-farm, and inherent SCRs in the DSC. A typology encompassing various DSC risks has been proposed (Figure 5). The major SCRs are examined under both the on-farm and off-farm stages as follows.

4.1.1 On-farm supply chain risk

The on-farm SCRs refer to risks associated with dairy farming systems that create uncertainty regarding the ability to ensure a consistent supply of products that meet desired quantity, quality, and safety standards for consumers (Wang et al., 2012, Bachev, 2013, Daud et al., 2015). On-farm SCRs involve challenges and uncertainties that directly impact agricultural operations, from cultivation to the early stages of the supply chain. These risks can significantly affect farmers, influencing crop yields, production efficiency, and overall farm sustainability. Risks within the on-farm segment increase the vulnerability of the DSC (Ibrāhīm et al., 2020). Most previous studies focus on distribution (off-farm) and farming (on-farm) risks separately. This paper proposes a typological model that incorporates both on-farm and off-farm risks, promoting a more integrated, systemic approach to supply chain management.

From the dairy farm's perspective, on-farm risk can either be internal, originating from within the farm, or external, stemming from broader factors affecting the farm. The on-farm SCRs are summarized in Table 3.

Table 3 On-farm SCRs

On-farm SCRs	
Internal risk	Internal factors within a dairy farm can affect the reliability, cost-effectiveness, and efficiency of production, processing, and marketing activities throughout the entire DSC. These risks include plant and animal diseases, technological challenges, milk quality and quantity issues, risks related to the milking process, farm management and operational risks, as well as the illnesses of the owner or laborers (Jaffee et al., 2010, Manning and Soon, 2016).
External risk	External factors are often beyond the control of the dairy farm. On-farm external risks include biological and natural environmental risks, such as global warming, extreme weather, drought, flooding, and other natural disasters, as well as public policy and institutional risks (Prakash, 2017, Bachev, 2013, Jaffee et al., 2010).

4.1.2 Off-farm supply chain risk

The off-farm SCRs refer to risks arising from processors, traders, distributors, and consumers (Bachev, 2013). The off-farm risk classification is adopted from the fresh food supply chain (Nakandala et al., 2017) and traditional SCR literature (Zsidisin and Ritchie, 2009, Wang, 2018, Tang and Nurmaya Musa, 2011, Sodhi and Tang, 2012, Ho et al., 2015, Diabat et al., 2012). Off-farm risks include supply risk, demand risk, manufacturing risk, and environmental risk in the

dairy industry (Diabat et al., 2012, Dani and Deep, 2010, Prakash, 2017, Bachev, 2013, Jaffee et al., 2010). The off-farm SCRs are summarized in Table 4.

Table 4 Off-farm SCRs

	Off-farm SCRs
Supply risk	Zsidisin (2003a) defined supply risk as the likelihood of an event occurring within the inbound supply chain, such as individual supplier failures or disruptions in the supply market, that prevents the purchasing firm from meeting customer demand or poses threats to customer safety and well-being. Off-farm supply risks are related to sourcing (Zsidisin, 2003b), procurement (Mishra and Shekhar, 2011), supplier selection (Anggrahini et al., 2018), and availability (Dani and Deep, 2010).
Demand risk	Demand risk refers to the uncertainty and risk arising from the downstream supply chain system. It involves uncertainties emerging downstream of the supply chain that could disrupt the company's supply (Yu and Huatuco, 2016). Retailers face market risk, which represents the demand risk for the entire supply chain (Leat and Revoredo-Giha, 2013). Factors contributing to demand risk include price fluctuations (Yu and Huatuco, 2016), consumer trust (Li et al., 2019), and forecasting challenges (Daud et al., 2015).
Manufacturing risk	Manufacturing risk is associated with internal operational and control risks. It can be defined as "the risk of loss resulting from inadequate or failed internal processes, people, and systems, or external events" (Yu and Huatuco, 2016). These risks may arise from internal processes or interactions with external factors, including quality (Tse and Tan, 2012), process issues (Prakash et al., 2017, Mishra and Shekhar, 2011), products (Diabat et al., 2012), and services (Bachev, 2013).
Environmental risk	Off-farm environmental risk refers to events that can directly impact the company or its upstream and downstream dairy supply system. Stakeholders in the supply chain generally have limited control over off-farm environmental factors, so they must design appropriate strategies to manage these risks (Leat and Revoredo-Giha, 2013). Environmental risks include factors such as policy and politics, macroeconomic conditions, societal trends, technological changes, and natural environmental events (Mason-Jones and Towill, 1998, Diabat et al., 2012, Nasir et al., 2014, Wang et al., 2022). Off-farm environmental risks do not conflict with on-farm external risks, which primarily focus on environmental risks within the farm itself.

4.1.3 Inherent supply chain risk

Supply chain management considers three main flows, including the material flow, the information flow, and the financial flow (Christopher, 2005, Ho et al., 2015). Accordingly, the major SCRs are inherent in the material, information, and financial flows (Tang and Nurmaya

Musa, 2011). We can define them are logistics risk, information risk, and financial risk. The inherent SCR may arise from any component within its supply chain. The inherent SCRs are summarized in Table 5.

Table 5 Inherent SCRs in the Dairy Industry

Inherent SCRs	
Logistics risk	Dairy products, such as milk and yogurt, are highly perishable and prone to expiration and spoilage. To maintain product quality, raw milk must be preserved through a cold chain, a temperature-controlled supply chain. The inherent characteristics of dairy commodities and their production processes add complexity to milk logistics, creating distinct risks and challenges that differ from those associated with other goods (Anggrahini et al., 2018, Liu et al., 2019, Jaffee et al., 2010). As a result, the DSC requires customized logistics solutions. Mishra and Shekhar (2011) found that logistical-related risks account for more than two-thirds of the risks at the processing plant level. The logistics risks include delays, operational risks (Dani and Deep, 2010, Jose, 2019), and infrastructure-related risks (Mishra and Shekhar, 2011).
Information risk	Information risk refers to the likelihood of loss due to incorrect, incomplete, or unauthorized access to information (Wang et al., 2015b). In the DSC, information risk is linked to various stakeholders, including farms (Jose, 2019), processors (Mishra and Shekhar, 2011), and customers (Li et al., 2019). This may also encompass digital risks within modern supply chain systems. It is crucial to evaluate information risks from multiple perspectives to ensure comprehensive risk management.
Financial risk	The level of financial risk is determined by a company's profitability and liquidity, reflecting its ability to repay loans and interest, as well as its capacity to maintain ongoing capital investments for sustainable growth (Manning and Soon, 2016). This risk can occur at both on-farm and off-farm stages and is a critical consideration for farmers and business owners. Additionally, the unpredictability of milk production poses another financial risk, potentially leading to financial losses for the dairy industry (Nasir et al., 2014).

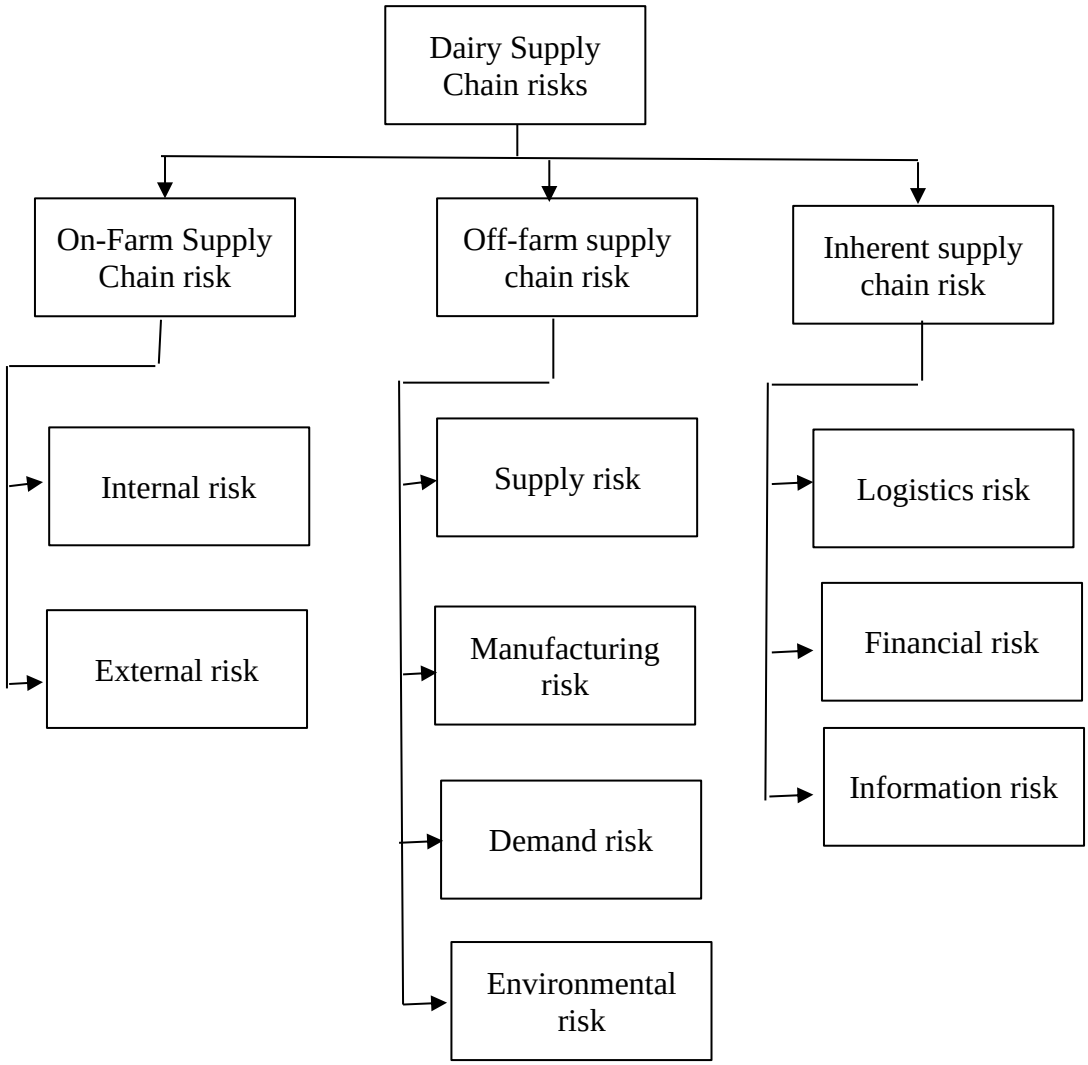

Figure 5. A conceptual risk framework of DSC (Source: Authors' work)

4.2 Key challenges and issues in the dairy supply chain

The DSC is complex, with each country facing unique challenges. Leppälä et al. (2011) identified several key issues in the DSC, including environmental, social, ethical, and economic challenges. Bachev (2013) categorized these challenges into four generic risk types: natural, market, private, and social. For instance, Yu and Huatuco (2016) highlighted the challenges faced by the Chinese DSC following the 2008 melamine scandal, which resulted in increased costs, reduced sales, and greater market uncertainty, further exposing vulnerabilities in the supply chain. Similarly, Mor et al. (2018) identified challenges in the Indian dairy industry, such as issues with information systems, the perishable nature of dairy products, traceability of quality-related concerns, milk adulteration risks, cold chain inefficiencies, demand fluctuations, and inadequate logistics and infrastructure.

A systematic review of the literature reveals that numerous factors contribute to the challenges in the DSC, including natural disasters, weather fluctuations, policy shifts, technological failures, infectious diseases, terrorism, and food scandals. These challenges are closely related to

sustainability in the DSC. For example, adhering to environmental protection, animal welfare, and food safety regulations is critical for sustainability. Strategies for reducing food waste, improving packaging efficiency, and promoting recycling also contribute to environmental sustainability. Sustainability in the DSC encompasses managing and optimizing various factors to ensure the long-term viability of the industry, balancing environmental, social, and economic considerations. Given the global nature of this study, it emphasizes the importance of contextualizing the DSC framework to make informed decisions regarding risk management in different settings.

4.2.1 Food Safety

Food safety is a major concern of food SCR management (Nakandala et al., 2017, Dani and Deep, 2010) as it directly impacts human health and even lives. Contamination, poor food quality, and animal diseases can lead to public health emergencies, both domestically and internationally. Among the threats, food adulteration is one of the most serious concerns (Levi et al., 2020) and it has been widely recognized as a significant challenge in the dairy industry. For example, the 2008 Fonterra and Sanlu infant formula scandal, where melamine contamination led to the deaths of six babies and affected 30,000 victims in China, underscores the importance of ensuring food safety (Dani and Deep, 2010). This event sparked increased research into the risks of adulteration across all stages of the DSC. Tse and Tan (2011) argue that quality risks may arise from raw materials, manufacturing processes, or logistics operations at any tier of the supply network. Nasir et al. (2014) emphasized that adulteration is a major risk factor associated with distribution and is considered an unethical social risk. The Sanlu incident, in particular, revealed that the decentralized and dispersed supply chain sourcing model contributed to ineffective quality control and supervision (Chen et al., 2014), highlighting the need for robust quality management in the DSC.

Food safety risks can arise at any stage of the DSC (Mor et al., 2018, Daud et al., 2015, Bachev and Nanseki, 2008). Effective food safety management and traceability are critical for the success of milk supply chains (Sellitto et al., 2018, Li et al., 2019). Previous studies on food supply chains have identified three main categories of food safety risks: biological, chemical, and physical hazards. It is essential to manage these risks throughout the entire DSC to ensure safety and quality (Yu and Huatuco, 2016).

4.2.2 Food Waste

Food waste has been a key topic in agricultural supply chain studies. Product losses and service risks leading to food waste may occur at various stages, from production and processing to distribution and consumption (Parfitt et al., 2010, Tostivint et al., 2017). Food waste is a significant issue with profound economic, social, and environmental consequences. The Food and Agriculture Organization (FAO) estimates that one-third of all perishable food produced globally is wasted before reaching consumers (Parfitt et al., 2010). Food waste has direct implications for food security, surplus production, and greenhouse gas emissions (Papargyropoulou et al., 2014). Dairy products are particularly susceptible to spoilage, given their perishable nature, making effective logistics and supply chain management essential to minimize waste. Efficient DSC risk management can help reduce food waste by improving the supply chain's effectiveness.

Moreover, food waste may be considered a resource (Papargyropoulou et al., 2014). The waste can be reused and recycled in supply chain systems. In the DSC, the food waste may be recycled into animal feed, this requires good DSC management to integrate and collaborate with the stakeholders and manage the risks across the DSC from farm to folk. Understanding and addressing food waste is crucial for promoting sustainability, reducing environmental impact, and ensuring global food security. Educational programs at all levels can contribute to changing attitudes and behaviors toward food consumption and waste. Addressing food waste requires a

multi-faceted approach that involves collaboration among stakeholders, technological innovations, policy interventions, and changes in consumer behavior.

4.2.3 Health and Environmental Consciousness

Growing concerns about environmental pollution and animal welfare issues have led to increased consumer demand for products with "credence attributes," such as eco-friendly and animal welfare certifications (Yang and Renwick, 2019). Seen as an opportunity with potential price premiums, the market signal also challenges the DSC. Dairy farms need to have lower environmental impacts. For example, to deliver products with credence attributes, such as organic and carbon-neutral, dairy farmers are expected to change or adapt to reduce environmental footprints (e.g., carbon emissions and nutrient pollution), which are associated with high mitigation costs (Yang et al., 2020). Similarly, the processors and distributors need to keep those attributes "intact" throughout the supply chain.

Besides, challenges may come from the blind spot of the dairy industry that alternative dairy products, i.e. "lab-grown" milk or synthetic milk, have been on the way to the market. The pioneering firms of synthetic milk claim that animal-free milk is better for the environment and healthier than cow's milk as it is free of lactose, hormones, antibiotics, gluten, and cholesterol. Although consumers' attitudes toward the "new" products have not been clear, the traditional dairy industry needs to prepare for it from on-farm to off-farm practices, requiring the readiness of each process of the DSC. Moreover, practices that promote the health and well-being of dairy animals contribute to sustainability and align with consumer expectations for responsible farming.

4.3 DSC Risk Mitigation

SCR management is a systematic process of managing the risk events that can cause negative impacts in the supply chain, and their likely incidence and consequences (Jaffee et al., 2010). Effective risk management requires coordination among supply chain members to ensure profitability and continuity while reducing overall vulnerability (Christopher, 2005, Tang, 2006). No single universal solution exists for managing the diverse types of risks in the DSC (Bachev, 2013). However, there are several primary risk management strategies, including avoidance (eliminating or withdrawing from risk), reduction (optimizing or mitigating risk), sharing (outsourcing or insuring risk), and retention (accepting and budgeting for risk) (Zsidisin and Ritchie, 2009). Qualitative assessments can assist risk managers in prioritizing risks, making decisions, and allocating resources effectively (Wang et al., 2012).

Several studies have discussed risk mitigation strategies for the DSC. Leppälä et al. (2011) emphasized the importance of farm-level risk management in ensuring the sustainability of the food supply chain. Nasir et al. (2014) suggested that the most supported mitigation strategy in DSC risk management is technological development. Technology plays a vital role in DSC risk management. Various innovative solutions were explored to tackle SCRs (Wang et al., 2020). For example, tracking and tracing technologies can improve the visibility and traceability of food supply chains (Wang and Li, 2012). Nasir et al. (2014) suggested that the DSC risk mitigation strategies include technological development, insurance management, human resource management, government support, feed management, disease management, and transport management in Bangladesh. Yu and Huatuco (2016) recommended increased collaboration with partners, improved system flexibility, and the establishment of buffers at critical nodes across the supply chain in China. Food safety, product quality, and associated economic benefits in the dairy industry can be achieved through technological innovation (Mor et al., 2018). A high level of collaborative working across supply chains can significantly help mitigate risk (Peck, 2006, Yu and Huatuco, 2016). Table 6 presents an overview of DSC risk mitigation strategies.

Table 6 Dairy Supply Chain Risk Mitigation

Techniques of risk managing	Risk mitigation strategies	Studies
Risk avoidance (eliminates, withdraws from, or does not become involved)	• Initiative to remove political uncertainty • Hiring skilled staff • Supply chain collaboration • Innovation • Motivational and incentive facilities for staff • Assurance of adequate institutional credit • Support with a low rate of interest	Nasir et al. (2014), Yu and Huatuco (2016), Mor et al. (2018)
Risk reduction (optimize)	• Adoption of improved technology (Milking machine, feed mixture, grass cutting, improved processing facilities) • ICT application • Acquisition and integration • Reduction of risks through merger	Nasir et al. (2014), Yu and Huatuco (2016) Prakash et al. (2017) Mor et al. (2018)
Risk sharing (transfers – outsource or insure),	• Buying insurance against production loss • Conjoint venture • Development of Guanxi ("relationship") with supplier • Pooling strategy • Decentralized approach to building specialized capacity	Nasir et al. (2014), Yu and Huatuco (2016)
Risk-retention (accepts and budget)	• Focus on product diversification and value creation. • Promote information sharing, cooperation, and better coordination. • Increasing system flexibility	Nasir et al. (2014), Yu and Huatuco (2016)

4.4 Creating a resilient Dairy supply chain

In the aftermath of the pandemic, there is growing consensus among companies about the importance of effectively managing SCRs and building resilient supply chains (Dohale et al., 2021). Managing DSC risks plays a crucial role in creating a resilient supply chain for dairy products. This study provides a comprehensive understanding of DSC risks, which supports the development of a resilient and sustainable supply chain (Wang and Wang, 2023). Our findings suggest both reactive and proactive approaches to strengthen the DSC's resilience. Implementing risk mitigation strategies enables professionals, policymakers, and researchers in the dairy industry to address SCRs and minimize their impacts. Proactively recognizing potential disruptions, applying mitigation strategies, and enhancing the agility and adaptability of the supply chain are critical to ensuring a steady supply of dairy products, meeting consumer demand despite challenges or uncertainties.

Furthermore, innovative technologies and methods hold significant potential to transform the dairy industry, driving efficiency, sustainability, resilience, and competitiveness in an increasingly dynamic global market. For instance, blockchain technology offers enhanced transparency and traceability throughout the DSC by securely recording and sharing information about each stage of production, processing, and distribution (Wang et al., 2021). This improves food safety, quality control, and consumer trust by providing immutable records of product origin, handling, and certification. Automation technologies, including GPS systems, robotic systems, automated

feeding systems, and health monitoring devices, streamline farm operations and reduce labor requirements (Amin-Chaudhry et al., 2022, Lunner-Kolstrup et al., 2018). These technologies not only improve efficiency but also enable more consistent management practices and better animal welfare. Advanced data analytics and predictive modeling allow dairy farmers to make data-driven decisions regarding herd management, feed optimization, disease prevention, and resource allocation (Taneja et al., 2020). Supply chain digitalization can significantly enhance business performance (Wang and Prajogo, 2024) and enhance agility (Wang et al., 2024). By leveraging historical data and predictive algorithms, farmers can anticipate challenges, optimize performance, and mitigate risks more effectively. However, adopting new technologies may introduce additional risks and costs for farmers, potentially creating opportunities for further research in the coming years.

5. Results

The study provides a comprehensive framework for understanding risks within the DSC. While the research was conducted in New Zealand, the findings and risk framework are not limited to this context and can be broadly applied across different countries. The research also offers valuable insights into the key risks within the DSC, along with strategies to enhance its resilience and sustainability. The following results outline the major risk categories identified, their impacts, and the potential solutions proposed in the study.

On-farm risks were further subdivided into internal risks and external risks. Internal risks refer to factors inherent to the dairy farming operation, impacting the reliability, costs, and efficiency of production, processing, and marketing activities (Maina et al., 2020). These include challenges such as plant and animal diseases, technological disruptions, variations in milk quality and quantity, milking process risks, farm management issues, and illnesses among farm laborers. External risks encompass factors beyond the immediate control of the farm, including biological and environmental threats such as global warming, extreme weather, drought, and other natural disasters, as well as policy and regulatory uncertainties (Sodhi and Tang, 2021). These risks can significantly affect farm output and the overall resilience of the supply chain, potentially leading to disruptions in the consistent supply of dairy products.

Off-farm risks, which pertain to actors beyond the farm level (processors, distributors, and consumers), were categorized into four key areas: supply risk, demand risk, manufacturing risk, and environmental risk (Ho et al., 2015, Guillot et al., 2024). Supply Risk was associated with uncertainties in the procurement process, including supplier reliability and raw material availability. This was highlighted as a critical area, as disruptions in supply can directly impact the ability to meet consumer demand. Demand Risk focused on uncertainties arising from market demand, such as price fluctuations, changes in consumer preferences, and inaccurate forecasting. These factors contribute to unpredictability in production planning and inventory management. Manufacturing Risk involved internal operational risks during processing and product manufacturing, including quality control, production processes, and service disruptions. These risks were found to directly affect product consistency and safety. Environmental Risk concerned external factors that impact the DSC, such as political changes, economic shifts, technological advancements, and environmental changes. These risks highlighted the vulnerability of off-farm operations to broader, uncontrollable forces.

The analysis identified inherent risks within the DSC, which relate to the core flows of the supply chain: material, information, and financial (Guillot et al., 2024). Logistics Risk was found to be particularly critical, given the perishable nature of dairy products. The need for cold chain management, the risk of spoilage, and infrastructure limitations were highlighted as key logistical challenges. These risks emphasize the necessity for specialized transportation and storage solutions. Information Risk examines the accuracy, availability, and security of information shared

within the supply chain. Financial Risk focuses on the economic challenges faced by supply chain actors, such as fluctuating milk prices, financial liquidity, and investment in sustainable practices. This category underscores the importance of financial planning and risk management in maintaining a stable supply chain. As DSC often involves B2B relationships, it is significant to consider SCR management within B2B models (Guillot et al., 2024, Tiwari et al., 2024).

The study identified several pressing challenges that impact the global DSC, emphasizing the importance of sustainability, food safety, and adaptation to changing consumer preferences. Food Safety emerged as a top priority (Kataike et al., 2019), given its direct impact on consumer health. Risks associated with contamination, adulteration, and traceability were highlighted as key concerns that require stringent quality control measures throughout the supply chain. Food Waste was another significant issue, with the study noting that a considerable amount of dairy products are lost before reaching consumers. Addressing food waste was linked to enhancing supply chain efficiency, adopting recycling practices, and reducing environmental impact. Health and Environmental Consciousness reflected growing consumer demand for sustainably produced dairy products. This area focuses on reducing the environmental footprint of dairy farming, ensuring animal welfare, and adapting to innovations like synthetic milk. These challenges necessitate shifts in both farming practices and supply chain operations to meet evolving consumer expectations.

The study highlighted several strategies that can be implemented both proactively and reactively to mitigate the identified risks and build a more resilient DSC: Technological advancements were identified as critical tools for managing risks in the DSC. Blockchain technology, for instance, was noted as a promising solution for enhancing traceability and transparency throughout the supply chain (Wang et al., 2021). By securely recording and sharing information at every stage of production, processing, and distribution, blockchain technology can improve food safety, quality control, and consumer trust. Automation technologies, including GPS systems, robotic systems, and automated health monitoring, were found to improve efficiency and resilience in dairy farming operations (Amin-Chaudhry et al., 2022, Lunner-Kolstrup et al., 2018). These technologies reduce labor requirements and ensure more consistent management practices, leading to better animal welfare and reduced operational risks. The study emphasized the role of advanced data analytics and predictive modeling techniques in making data-driven decisions for herd management, feed optimization, disease prevention, and resource allocation(Taneja et al., 2020). By leveraging historical data and predictive algorithms, farmers can anticipate challenges and mitigate risks more effectively, optimizing performance and minimizing potential disruptions.

The research further identified several key drivers essential for building a resilient DSC: Proactively addressing SCRs and improving the agility and adaptability of the supply chain emerged as fundamental strategies for ensuring a steady supply of dairy products, even in the face of disruptions (Wang and Wang, 2023). Supply chain digitalization is a key driver in enhancing agility and resilience (Wang et al., 2024). These measures ensure that the supply chain can respond quickly to changing market conditions, environmental factors, and unforeseen challenges. Increased collaboration among supply chain stakeholders was identified as crucial for risk mitigation. By working together, dairy producers, processors, and distributors can improve operational efficiency, share critical information, and address risks more effectively (Peck, 2006; Yu and Huatuco, 2016). The role of government and policy interventions in supporting risk mitigation strategies within the DSC was also highlighted. Policymakers can play a crucial role in establishing regulations that support sustainability, food safety, and environmental responsibility across the DSC.

6. Conclusion

SCRs and their management have been extensively discussed in previous studies (Wang and Jie, 2019a, Ho et al., 2015, Tang and Nurmaya Musa, 2011). However, limited research has specifically focused on the risks associated with the DSC. As emphasized earlier, understanding SCRs requires a focused approach within specific industries, particularly when considering practical applications. This paper examines both on-farm and off-farm SCRs in the dairy industry through a systematic literature review of key research published between 2010 and 2019. It provides a comprehensive framework for understanding these risks and proposes a typological model of DSC risks. Understanding these risks is essential for managers to effectively oversee the entire DSC. The risk framework developed in this study offers farm managers and DSC practitioners actionable insights to improve both supply chain and farm management within the dairy industry. Technological advancements and innovative practices are key to enhancing efficiency in dairy production, reducing resource consumption, and mitigating environmental impacts.

The study also highlights that many of the challenges within the DSC are linked to sustainability. Addressing these challenges is crucial to building a more resilient and sustainable dairy industry. Additionally, the paper underscores the importance of proactive risk management within the DSC. The typological model provides a foundation for developing and testing hypotheses regarding the impact of these risks on the industry. Moreover, transparent supply chains enable consumers to trace the origin of dairy products, promoting accountability and verifying sustainability claims. Consumer awareness and demand are essential for sustainable practices to thrive. This study provides valuable insights for both practitioners and researchers in understanding risks and risk management within the DSC. Future research could explore the refinement of SCRs from different perspectives. An empirical investigation, such as a survey of DSC management, could help validate and test the typological model proposed in this paper. Additionally, it is crucial to investigate the risks associated with digitalization, as it is a growing trend. With an increasing number of technologies being integrated into supply chains, effectively managing digital risks will become increasingly significant in the near future.

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