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Review article

<https://doi.org/10.31784/zvr.14.1.30>

Received: 26. 1. 2026.

Accepted: 29. 4. 2026.

WEATHER RISK IN FOOD SUPPLY CHAINS: A SYSTEMATIC LITERATURE REVIEW AND RESEARCH AGENDA

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ABSTRACT

Climate change, increasing weather variability, and the rising frequency of extreme weather events pose a growing challenge to the stability and resilience of food supply chains (FSCs). Weather-related shocks increasingly propagate beyond primary agricultural production, affecting multiple stages of the FSC and influencing food availability, price volatility, and supply security. Despite the systemic nature of these risks, the academic literature on weather risk in FSCs remains fragmented, with a predominant focus on agri-food producers. This paper presents a systematic literature review of research on weather risk in FSCs. By reviewing the literature along the stages of the FSC, structural differences in risk exposure and management practices between actors are highlighted. For producers, weather risk is largely associated with direct impacts on yields and product quality. For processors and retailers, however, weather-related losses are mainly indirect and arise through supply shortages, input price volatility, logistical disruptions, and changes in consumer behaviour. Based on the review synthesis, the paper develops an integrated conceptual framework that captures how weather risk is transmitted, amplified, and redistributed along the FSC. Building on this framework, the study formulates a set of conceptual research propositions that constitute a research agenda to address the existing knowledge gap and provide directions for future empirical research. By adopting a supply chain (SC) perspective, this study contributes to a more holistic understanding of weather risk. It offers guidance for both researchers and practitioners seeking to enhance the FSC resilience, price stability, and food security under increasing weather uncertainty.

Keywords: *weather risk, food supply chains, food supply chain resilience, systematic literature review*

1. INTRODUCTION

Risk is increasingly emerging as a central research area in contemporary SC studies. According to a report by the World Economic Forum, increasing supply disruptions such as global pandemics, climate change, cyber threats, and geopolitical tensions, combined with growing demand-side disruptions, will continue to destabilise global value chains (WEF, 2021). In such uncertain times, strengthening FSC resilience is emerging as a key objective for SC management.

FSCs differ from industrial SCs in several key aspects, with direct implications for resilience. Agricultural production depends on biological processes. Crops and livestock take time to grow, and it is difficult to temporarily interrupt or postpone production once it begins. Agricultural production is also exposed to weather shocks, which lead to market volatility that cannot be fully predicted in advance. Although some agricultural commodities can be stored, many are characterised by seasonality and perishability, thereby reducing the ability to adjust delivery schedules in response to disruption (Hobbs, 2021). Given climate change and the increasing frequency of extreme weather events, FSCs face major challenges in maintaining supply continuity and ensuring product quality and quantity.

Weather risk in SCs is an exogenous shock that affects both the supply side (Miroudot, 2020) and the demand side (Cevik and Gwon, 2024; Qureshi *et al.*, 2024). Weather risk in the context of FSCs refers to the negative impacts of extreme (catastrophic) and non-catastrophic weather events on food production, warehousing, processing, logistics, and retail. Extreme weather events include droughts, floods, storms, strong winds, early frosts, heat waves and irregular rainfall. Negative consequences range from crop failure and reduced yields to disrupted growth and harvest cycles and altered ripening dynamics. Non-catastrophic weather events are less commonly perceived as a source of risk because they involve gradual, frequent changes in weather driven by climate change. However, the accumulation of smaller negative impacts can be equally devastating (Stulec *et al.*, 2016).

The FSC consists of five stages (Bourlakis and Weightman, 2008; Lyons and Ma'aram, 2014; Cao *et al.*, 2021): production or cultivation, handling and warehousing, processing and packaging, distribution and logistics, and retail. Consumption occurs as the final link in the SC. To clarify our study objectives, Table 1 describes the FSC stages.

Table 1. FSC stage coverage in weather risk research

SC stage	Description
Production	Agricultural production, farming, crop cultivation, livestock, aquaculture
Warehousing/Storage	Storage facilities, warehousing, inventory management, cold storage
Processing	Food processing, manufacturing, post-harvest processing, transformation
Logistics/Transportation	Transportation, distribution, delivery, freight, cold chain logistics
Retail	Food retail, grocery stores, supermarkets, food outlets, retail distribution
Consumption	Consumer behaviour, food access, purchasing patterns, consumption, disposal

Source: Authors

Based on an extensive review of 325 studies, Davis *et al.* (2021) conclude that weather shocks affect the FSC at all SC stages: from production, processing and storage to distribution, retail and consumption. Most adverse impacts on FSCs occur in production. Given that climate change and weather variability increasingly threaten global food security, and that FSCs are complex systems vulnerable at multiple stages, one can conclude that understanding weather risk throughout the entire SC is essential for FSC resilience. At the same time, few comprehensive reviews cover all stages of FSCs, and most focus on a single stage. Another conclusion is that the lack of an integrated analysis across food production, processing, logistics, warehousing, retail and consumption calls for a systematic synthesis of the recent and relevant literature.

The present paper offers a systematic review of the literature on weather risk in the FSC, highlighting current research gaps and outlining directions for future academic research. Following the findings synthesised by the literature review, a research gap was identified and defined for the research propositions as part of the future research agenda, with the following research questions:

RQ1. What is the current state of research on weather risk in FSC management?

RQ2. How do weather-related risks affect different stages of the FSC?

RQ3. What are the research gaps and future research directions?

As a method of study, a systematic literature review was conducted in accordance with the PRISMA guidelines. The remaining part of the paper is structured as follows. Section two explains the methods used in our analysis, with the main focus on the PRISMA flow. Section three outlines the results of our review, including an overview and content analysis of the reviewed studies and a synthesis of weather risk assessment across the FSC stages. Section four discusses the results. Section five outlines research propositions and a future research agenda. The closing remarks are provided in section six.

2. METHODOLOGY

A structured literature review was conducted, focusing on peer-reviewed publications indexed in the Web of Science and Scopus databases, covering the period from January 2000 to January 2026. The search was conducted on 11 February 2026. The search strategy was based on predefined keywords related to weather risk and FSCs. Specifically, the following search string was applied in both databases: (“weather risk” AND “food supply chain”). Boolean operators “AND” and “OR” were used where appropriate to refine the search.

The search string was defined at the FSC level rather than at the stage level, reflecting a system-level perspective in which weather-related disruptions are understood to propagate across interconnected SC stages. Including stage-specific keywords (e.g., production, logistics, retail) could introduce bias toward more frequently studied segments and limit the ability to capture cross-stage dynamics. Instead, SC stage classification was performed during the coding phase.

The inclusion and exclusion criteria used in the study are presented in Table 2.

Table 2. Inclusion and exclusion criteria

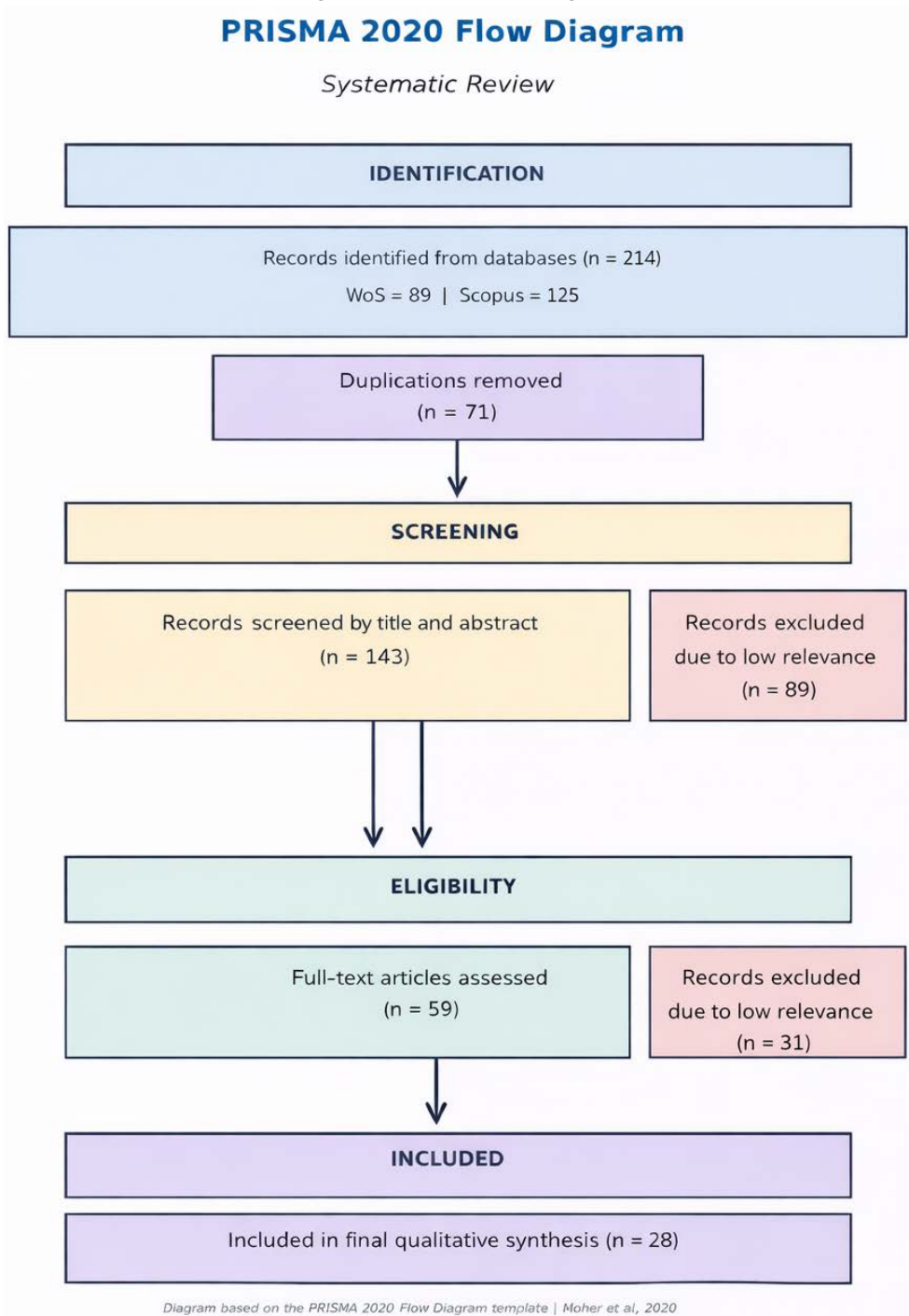
Inclusion criteria	Exclusion criteria
Indexation: Web of Science and/or Scopus	No access to full text
Language: English	Studies not addressing weather-related risks in FSCs
Publication date: January 2000 to January 2026	Studies irrelevant for understanding SC dynamics, incl. ones limited to a single stage without broader implications
Peer-reviewed publications	Studies citing weather and/or climate only tangentially
Paper type: Research articles, review articles	
Focus: Studies addressing the impact of weather-related risks in FSCs	

Source: Authors

Single-stage studies were not automatically excluded; they were included when they offered cross-stage insights. This approach ensured both analytical depth and comprehensive coverage of the topic. The initial search yielded 214 records (89 from Web of Science and 125 from Scopus). After removing duplicates ($n = 71$), 143 unique records remained. The screening process was conducted in two stages. In the first stage, titles and abstracts were screened, resulting in the exclusion of 84 records as irrelevant. In the second stage, full-text articles were assessed for eligibility, leading to the exclusion of an additional 31 papers. Two independent reviewers conducted the screening and selection process. Any disagreements were resolved through discussion and consensus. Relevance was assessed using both primary and secondary criteria. Under the primary criteria, studies were considered highly relevant if they explicitly addressed weather-related risks as a central focus in relation to FSCM, and included empirical or analytical content. Secondary criteria included the comprehensiveness of the study, recency of publication, scientific impact, and methodological rigour. A total of 28 papers were ultimately selected for in-depth analysis, in accordance with the inclusion criteria and research objectives. Following selection, a structured coding framework was applied. Each study was classified according to (1) SC stage (e.g., production, processing, distribution, and retail) and (2) type of weather-related risk (e.g., drought, floods, and temperature extremes). Stage-specific studies were used to inform this classification and to enrich the interpretation.

This study adopts a semi-systematic (structured) literature review approach with PRISMA-informed reporting. While the review follows a transparent and structured process, including predefined search strings, inclusion and exclusion criteria, and a multi-stage screening procedure, it does not aim to meet all criteria of a fully systematic review (e.g., exhaustive database coverage or protocol registration). The use of PRISMA-informed reporting enhances transparency in the identification, screening, and selection of studies and supports a structured, replicable review process. The PRISMA flow diagram is presented in Figure 1.

Figure 1. PRISMA flow diagram



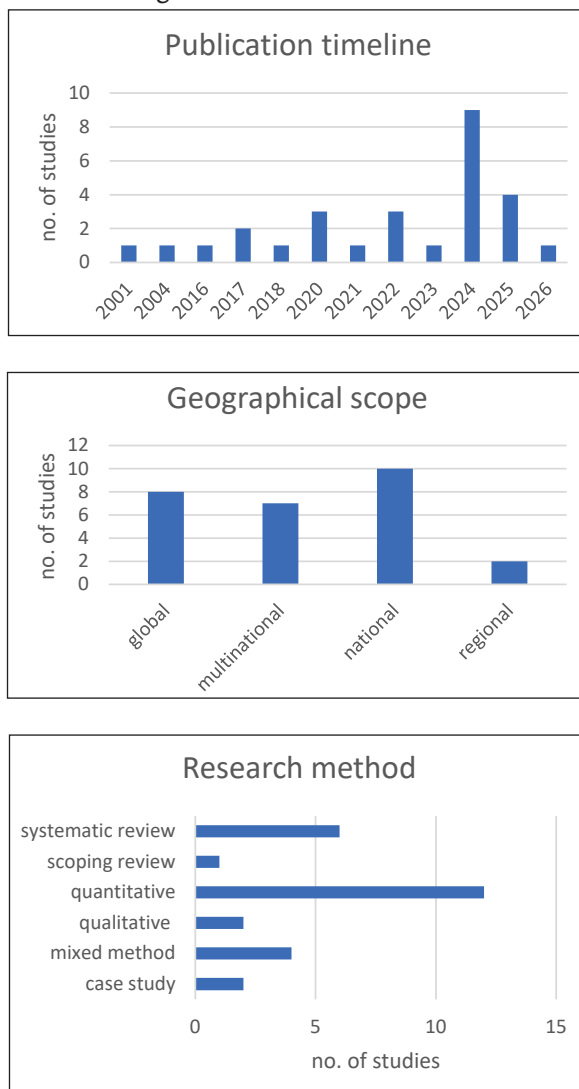
Source: Authors

3. RESULTS

3.1 Overview of studies

Figure 2 provides an overview of studies. Interest has grown notably, peaking in 2024. Most studies are conducted at the national level, followed by the global and multinational levels. Only two studies cover the regional level (a region within a country). Quantitative research was shown to be the most suitable method, as almost half of the studies employed it, thus emphasising a data-driven approach to the subject. Other research methods employed include systematic and scoping reviews, mixed-methods, case studies, and qualitative studies.

Figure 2. Overview of studies



Source: Authors

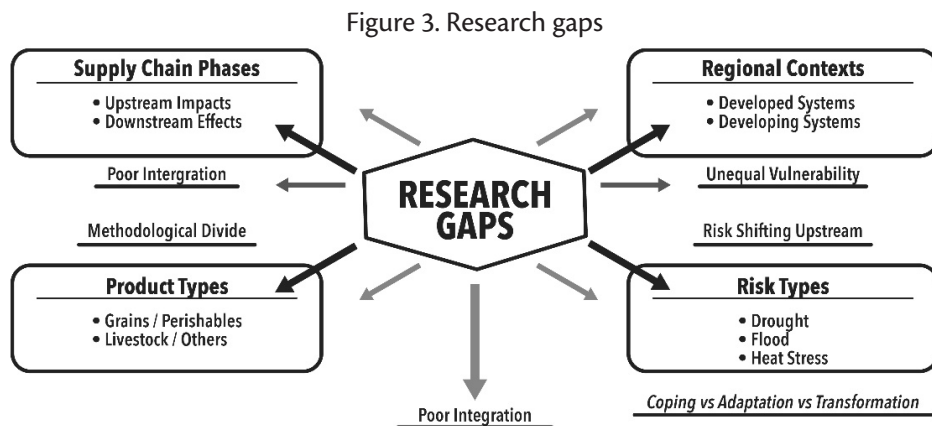
3.2 Content analysis of reviewed studies

The composition of each selected publication for systematic review is outlined. Table 3 categorises selected publications by title, year of publication, weather risk type, methodology used, data type, geographical focus, food category, key findings, and proposed adaptation strategies to weather risk.

Key findings suggest that adverse weather reduces yields, productivity, and crop quality, causing cascading disruptions downstream: logistical delays, stock shortages, price volatility, and food insecurity. Rural areas and small farmers are among the most vulnerable. Among adaptation strategies for weather risk management, some operating techniques are most widely advocated: crop rotation and diversification, irrigation, shade management, flexible sourcing, route diversification, early warning systems, weather-adaptive scheduling, safety stock maintenance, and predictive analytics. Noticeably fewer studies advocate strategic solutions such as risk pooling, risk transfer mechanisms through insurance and financial instruments, and increasing social capital through cooperation, integrated approaches and collective action.

The literature converges on four claims: (i) weather risks are highly unequal across stages where the upstream actors are usually the first and hardest hit; (ii) the nature of resilience differs by regions, reflecting infrastructure, institutional capacity, and market structure; (iii) commodity traits strongly shape disruption pathways, especially around perishability and substitutability; and (iv) hazard types matter, as drought, floods, storms, heat and frost produce different cascade dynamics. Hence, the integrated framework is genuinely new, as it brings these four dimensions into a single analytical structure and shows how they interact. Its contribution is therefore not merely broader coverage but a clearer explanation of why similar weather shocks generate different outcomes across food systems and why effective adaptation must be stage-specific, commodity-sensitive, regionally grounded, and governance-aware.

Climate-related SC risk research remains fragmented, examining individual dimensions in isolation, such as SC stages, regional contexts, product types, or specific climate risks, without developing a comprehensive framework that integrates these elements and captures their interdependencies (Figure 3).



Source: AI-generated visualisation

Table 3. Categorisation of publications included in the systematic review

ID	Article Title	Reference	Weather Risk Type	Methodology	Data Type	Geographical Focus	Food Category	Key Findings	Adaptation Strategies
1	Analysis of the Factors Influencing Grain Supply Chain Resilience in China Using Bayesian Structural Equation Modeling	Yao <i>et al.</i> (2025)	extreme weather: storms, floods, droughts	structural equation modeling; Bayesian estimation	primary	China	grain	It is necessary to improve grain SC resilience due to extreme weather. Well-developed infrastructure can reduce uncertainty and from seasonal and cyclical climate fluctuations.	Water conservancy infrastructure.
2	Risk Transfer Mechanism for Agricultural Products Supply Chain Based on Weather Index Insurance	Fu <i>et al.</i> (2018)	adverse weather: mild winter, cold spring, drought and heavy rain	two-echelon decision-making model	secondary	/	general crops	A risk-reward contract that considers a weather index (temperature) and farmers' loss aversion can mitigate distortions in sustainable investment levels and motivate farmers to participate in sustainable agricultural practices.	Risk-reward contracts are designed to hedge against adverse weather risks.
3	Towards food supply chain resilience to environmental shocks	Davis <i>et al.</i> (2021)	extreme weather, general climate	Scoping review of the literature	secondary	/	maize, rice, wheat	Extreme weather events damage infrastructure and slow food shipments, increasing risks of spoilage.	Increased access to irrigation. Crop and index insurance. Shifting planting times and patterns.

4	Addressing food supply chain and consumption inefficiencies: potential for climate change mitigation	Porter and Reay (2016)	general weather	case study	primary	UK	milk, meat, dairy products, cereals, fruits, vegetables	Primary causes of food waste include losses from weather events, which are less controllable.	NA
5	Risk analysis of the agri-food supply chain: A multi-method approach	Zhao <i>et al.</i> (2020)	extreme weather	multi-method approach (thematic analysis, TISM, and fuzzy MICMAC analysis)	primary and secondary	France, Spain, Italy and Argentina	vegetables fruits	Extreme weather conditions are among the biggest threats to FSC, causing poor agricultural infrastructure. Mitigating the effect of extreme weather conditions is a key focus for FSC managers.	Large agri-food companies should take weather insurance. Small and medium-sized companies should apply for disaster relief emergency funding.
6	Impact of extreme weather events on the US domestic supply chain of food manufacturing	Yim and Dall'erba (2025)	drought	two-stage instrumental variable analysis	secondary	US	meat and fish, cereal grains, vegetables fruits and soybeans; manufactured agri-food	The resilience of the food manufacturing sector relies on flexible sourcing, trade volumes, and input substitution. Local droughts reduce productivity and exports volumes, while increasing imports.	Diversify sourcing from broader and geographically dispersed set of states. Invest in infrastructure to improve reliability and climate resilience of national FCSs. Form resilience plans and pacts among top suppliers.

ID	Article Title	Reference	Weather Risk Type	Methodology	Data Type	Geographical Focus	Food Category	Key Findings	Adaptation Strategies
7	Synergies and trade-offs in drought resilience within a multi-level UK food supply chain	Vicario <i>et al.</i> (2023)	drought	online survey; interviews	primary	UK	potatoes	Weather extremes are top challenge FSCs due to agriculture's sensitivity. Droughts impact growers first. Retailers are less directly exposed to drought risk than growers.	Increase geographical spread of supply. Increase reliance on forward contracts. Apply efficient irrigation technology.
8	Agri-food supply chain performance: an empirical impact of risk	Nyamah <i>et al.</i> (2017)	rainfall, extreme drought, flooding, extreme wind	cross-sectional survey data	primary	Ghana	pineappleschicken and vegetables	Weather-related risks significantly undermine agri-food SC performance. Unrestrained weather-related risk sources can hinder yield, debt repayment, transportation, and sales of goods.	Invest in acquiring weather-related technologies and historical meteorology data. Carefully assess and address persistent weather-related risks.
9	Managing climate change risks in global supply chains: a review and research agenda	Ghadge <i>et al.</i> (2020)	heatwaves, droughts, floods, cold spells, storms, hurricanes	thematic and descriptive analysis	secondary	/	wheat, rice, and maize	Global warming leads to food availability issues, loss, and wastage. Extreme weather events cause short-term impacts like shortages, disruptions, delays, and contaminations. Heat waves and hurricanes cause material shortages and logistical breakdowns.	Implement early warning systems to control potential disruptions to global SC networks. SC managers must redesign networks for future resilience to unforeseen future disruptions.

10	Food supply chain resilience in major disruptions	Found et al. (2024)	natural disasters, climate change	review	secondary	/	general food	Natural disasters are a factor of vulnerability in FSCs. Climate change is identified as key uncertainty in agricultural SCs.	NA
11	Supply chain resilience: the whole is not the sum of the parts	Sá et al. (2020)	drought	qualitative study (in-depth interviews)	primary	Brazil	sugarcane, oranges	Drought caused huge productivity losses for farmers. Processors reported no negative impact. Indirect impacts were supply shortages for orange processors, and low fruit quality. Downstream stages were resilient as upstream impacts caused no disruptions for end customers.	Processors and manufacturers should invest in new processes and strategies to mitigate future extreme weather events. Examples include drilling new wells, crop management, and water conservation projects.
12	Optimizing Cold Food Supply Chains for Enhanced Food Availability Under Climate Variability	Hernandez-Cuellar et al. (2025)	climate variability	weather scenarios based on climate models	secondary	California	strawberries	Reduced rainfall and lower yields necessitate sourcing from more distant locations, increasing transportation costs.	Evaluating facility relocation and optimizing transportation logistics are key to enhancing supply chain resilience.

ID	Article Title	Reference	Weather Risk Type	Methodology	Data Type	Geographical Focus	Food Category	Key Findings	Adaptation Strategies
13	Market structure and resilience of food supply chains under extreme events	Hadachek <i>et al.</i> (2024)	natural disasters, extreme weather	conceptual model	secondary	US	meat	Extreme weather can reduce yields, cause livestock fatalities, negatively impact farm supply, and lead to consumer stockpiling. Capacity remains stable unless facilities are damaged.	Diversifying production and processing across multiple regions. However, regional diversification may come at the cost of reduced production efficiency.
14	Agricultural Supply Chain Risk Management Under Price and Demand Uncertainty	Ray (2021)	floods, droughts	optimisation model	secondary	/	fruits and vegetables	Agricultural SCs encounter more risks due to seasonality, perishability, and weather conditions, complicating global food security.	Design irrigation channels to mitigate rainfall deficiency.
15	Climate-based measures of supply chain resilience	Tack <i>et al.</i> (2024)	extreme heat, droughts, floods, and cyclones	resiliency metrics	secondary	USA; China	maize, soybeans, rice	Weather events are significant drivers of supply shocks, particularly in agriculture.	Mitigate localised weather outcomes by redistributing resources through international trade. Robust and flexible trade agreements and policies can offset weather-induced supply shocks.

16	Assessing the vulnerability of food supply chains to climate change-induced disruptions	Tchonkouang <i>et al.</i> (2024)	droughts, heat waves, floods, storms, wildfires	scoping review	secondary	/	general food	Increased temperatures and droughts hamper global food production and yield. Extreme weather events and climatic changes profoundly influence the food system.	Improve water usage efficiency. Adopt climate-resilient crops and improved farming techniques. Implement weather forecasting and warning systems. Diversify production systems.
17	Designing sustainability comprehensive indicator for the food supply chain under climate change: A systematic literature review	Mirzaei <i>et al.</i> (2024)	droughts, flood, heat waves	systematic literature review	secondary	/	general food	Climate change significantly impacts food production, processing, distribution and consumption. Weather variations and extreme events worsen food security, quality, nutrients and prices.	NA
18	Smallholder farmer resilience to extreme weather events in a global food value chain	Thompson <i>et al.</i> (2023)	extreme weather, hurricanes	mixed-method (workshop; survey)	primary	Dominican Republic	bananas	Farming production loss due to damage from hurricanes. Significant infrastructure damage occurred.	Crop diversification, intercropping, income diversification, flood damage prevention and training, and insurance.

ID	Article Title	Reference	Weather Risk Type	Methodology	Data Type	Geographical Focus	Food Category	Key Findings	Adaptation Strategies
19	Agricultural Supply Chain Coordination under Weather-Related Uncertain Yield	Shi and Wang (2022)	rainfall	model	secondary	/	maize	Weather- and market-demand-related yield uncertainty hinders agricultural SC performance and sustainability. The revised revenue-sharing contract can achieve SC coordination and improve profit for all members.	Retailer sharing yield risk and sales revenue improves the supplier's profit and willingness to participate. Irrigation of crops.
20	Impacts of climate change and extreme weather on food supply chains cascade across sectors and regions in Australia	Malik et al. (2022)	climate change, extreme weather	modelling (input-output analysis)	secondary	Australia	fruit, vegetable, livestock, grains and cereals, meats, milk, oil and fats	Extreme weather events adversely impact crop and livestock production, leading to indirect SC repercussions. Heatwaves cause a drop in dairy and cattle farming output, as well as in apple and pear crops.	Policymakers need to implement effective adaptation and management strategies.
21	Climate's Imprint on America's Food Lifeline: A Critical Analysis of Supply Chain Adaptations in the Face of Environmental Shifts	Raffington and Adesyan (2024)	extreme weather, climate variability	mixed-method approach (qualitative data; business case insights from experts)	primary	US	general food	Extreme weather events can damage infrastructure and delay transportation. Unpredictable weather patterns threaten crop yields and quality.	Diversify crop production to mitigate risks from regional climate events. Invest in climate-resilient infrastructure.

22	Multi-level impacts of climate change and supply disruption events on a potato supply chain: An agent-based modeling approach	Rahman <i>et al.</i> (2022)	drought, frost	multi-echelon SC simulation model	secondary	US	potatoes	The price hike for fresh potatoes was much higher than that for processed potatoes during disruption events. Early frost caused 31% to 64% higher delivery lead times.	NA
23	Compound shocks to agricultural food supply chain transport and trade in the United States	Zhang <i>et al.</i> (2026)	floods, draught	freight analysis framework database	secondary	US	live animal and fish, cereal grains, agricultural products, animal feed, eggs, honey, meat, poultry, fish, seafood, bakery products, fats, and oils.	Extreme weather events, like droughts and floods, had strong but different impacts on agricultural production and transportation, often more severe but shorter-lived than trade conflicts or pandemics.	Investments in routing flexibility facilitates SC's response to disruptions caused by floods. Enhanced storage enables commodity-dependent states to manage weather-driven demand fluctuations. Diverse and stable mix of domestic and international suppliers.

ID	Article Title	Reference	Weather Risk Type	Methodology	Data Type	Geographical Focus	Food Category	Key Findings	Adaptation Strategies
24	Sustainability assessment and climate change resilience in food production and supply	Melkonyan <i>et al.</i> (2017)	climate change	participatory systems mapping	primary	/	general food	Climate change and its regional impacts imperil agricultural systems. It will severely stress rural economic and ecological productivity.	Conceptual integration to improve food security by examining critical SC system compartments and service levels.
25	Exploring the effect of climate change on food supply chains in Africa: a systematic review with a focus on South Africa	Naicker <i>et al.</i> (2025)	extreme weather	systematic review	secondary	South Africa	tomatoes, spinach, and cabbage	Climate change disruptions lead to crop damage and shortages, increasing food prices and undermining smallholder farmers' livelihoods and food security. Floods and temperature extremes damage processing and storage infrastructure, causing bottlenecks and price hikes.	Altered farming practices. Water management. Crop diversification. Drought-resistant varieties. Adjusted planting calendars.
26	The Role of Artificial Intelligence in Coping with Extreme Weather-Induced Cocoa Supply Chain Risks	Effah <i>et al.</i> (2024)	floods, drought, heatwaves, storms, cold waves	interview; cognitive mapping	primary	Ghana	cocoa	Midstream of cocoa SC is most vulnerable to extreme weather events. Extreme weather has the greatest impact on cocoa transportation, cultivation, and market demand.	AI-powered optimisation algorithms enable rerouting shipments, modifying production schedules, and reallocating inventories as part of a disaster response strategy.

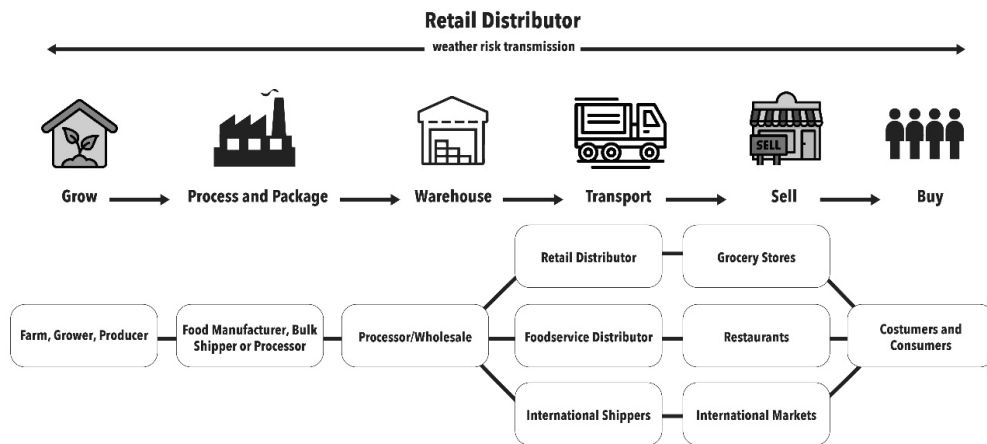
27	Disruptions in the food supply chain: A literature review	Rojas-Reyes <i>et al.</i> (2024)	global	literature review	secondary	/	extreme weather, drought, floods, hurricanes, natural disasters, and rains	Least-developed countries lost about US \$108 billion in 2008–2018 due to declines in agricultural and livestock production following natural disasters.	Targeted policies to support businesses and households confronting weather-related disruptions.
28	Modeling the critical causal factors of postharvest losses in the vegetable supply chain in eThekweni metropolitan municipality: The log-linear regression model	Qange <i>et al.</i> (2024)	storms, droughts, excessive rainfall, weather variability	mixed-methods approach	primary data	eThekweni municipality	vegetables	Adverse weather conditions directly impact crop yields, exacerbate logistical challenges, and reduce the effectiveness of postharvest management. Weather changes (temperature, precipitation, humidity) directly affect vegetable quality throughout growth and postharvest handling.	Developing and promoting climate-resilient postharvest practices and technologies is crucial for future research on adaptation strategies for weather risks.

Source: Authors

3.3 Weather risk assessment across FSC stages

Despite its growing importance, SC climate risk literature remains scarce (Ghadge *et al.*, 2020). Weather risk in the FSC does not manifest as an isolated production shock but as a multi-level, network-propagating, and structural systemic risk that affects all actors from primary production to consumption and disrupts the entire flow of the FSC (Zhao *et al.*, 2020). Its effects are not limited to primary production; through the interdependence of actors in the SC, logistic links and market transmission mechanisms are transferred and multiplied through processing, storage, distribution, and retail, all the way to the final stage of consumption (Figure 4). Such dynamics confirm that weather risk is complex and interdependent, and manifests as simultaneous, correlated disruptions to supply, capacity, and demand, whereby weather events acquire the characteristics of structural systemic vulnerability across the entire food system. However, the intensity of research attention to weather risk in FSCs, the level of methodological rigour, the use of a mixed-methods approach, and access to data vary significantly across the stages of the FSC.

Figure 4. Weather risk transmission in the FSC



Source: AI-generated visualisation

Agricultural producers are the most exposed and vulnerable segment of the FSC to weather-related risks (Qange *et al.*, 2024). The FSC faces additional risks due to seasonality, perishability, demand fluctuations, and short shelf lives, all of which pose significant challenges (Ray, 2021). These risks are predominantly direct, but have immediate consequences for crop yields, product quality, income stability, and long-term production sustainability (Tchonkouang *et al.*, 2024). Adverse weather events, such as droughts, floods, heatwaves, and unseasonal frosts, can significantly reduce yields and impair the physical and nutritional quality of agricultural outputs. Such impacts diminish the marketability of produce, shorten storage life and shelf life, and often result in price reductions or outright rejection by buyers. In addition to yield shocks, producers, particularly small family farms, face significant income volatility due to seasonal and climate variability (Naicker *et al.*, 2025). Supply chain inefficiencies vary across

food commodities and regions, with differences between developed and developing countries (Porter and Reay, 2016). With limited capacity to absorb losses or diversify income sources, many producers remain trapped in cycles of vulnerability, which, in the long term, raise concerns about food security and economic sustainability. In the research by Tchonkouang *et al.* (2024), production was identified as the phase most represented in the analysed studies (59% of the studies refer to it), confirming that research is still concentrated on farm-level risks. Climatic extremes (droughts, floods, heat waves) cause soil degradation, the spread of pests and yield decline. A study by Yeboah Nyamah *et al.* (2017) empirically confirms the negative impact of weather-related risks on agri-FSC performance, while deficit and excess precipitation are ranked as high-risk events. Zhang *et al.* (2026) confirm that both drought and floods have severely reduced yields of several key agricultural commodities in the US, leading to disruptions in regional SCs and increased imports.

Although food processors are not directly exposed to extreme weather, they are still significantly affected by their upstream supply chains. However, the processing stage of FSCs has received comparatively limited attention in the weather risk literature, representing a significant research gap. Weather-induced disruptions at the production level often manifest as indirect risks that compromise the operational stability and economic performance of processing firms (Yim and Dall'Erba, 2025). A systematic literature review conducted by Rojas-Reyes *et al.* (2024) confirms that the processing phase of the FSC is marginalised, even as extreme weather events simultaneously reduce the availability of agricultural inputs and limit processing capacity. This implies the existence of a double effect – a quantitative reduction in the raw material base and an operational limitation of industrial facilities – that remains insufficiently conceptualised in existing risk assessment models.

Storage is the least researched operational phase, despite its key role in stabilising supply. A review by Rojas-Reyes *et al.* (2024) explicitly states that post-production phases, including storage, are significantly under-represented compared to primary production. Empirical works on post-harvest losses further confirm the relevance of this phase. Analyses show that weather conditions are a statistically significant determinant of post-harvest losses, confirming that temperature variability, humidity, and extreme events directly affect spoilage and product quality degradation. Thereby, storage becomes a critical transmission point through which the initial climate shock from production is transformed into quantitative and qualitative losses. Additionally, research by Tack *et al.* (2024) on climate-based financial risk management implicitly indicates the need to integrate storage capacity into resilience and risk management models. Overall, weather risk in the storage phase amplifies the initial production shock, increases spoilage and total food losses, and represents a research-neglected yet structurally key segment of the FSC. Food loss and waste have environmental and socioeconomic consequences in the FSC from agricultural production to consumption, particularly in developing countries (Mirzaei *et al.*, 2024).

Weather disruptions also impact distributors. Variability in crop yields may compel distributors to contract with alternative suppliers in distant regions, thereby reconfiguring established SCs. These adjustments often result in elevated operational costs and logistical complexity

(Hernandez-Cuellar *et al.*, 2025). Retailers encounter weather-related risks primarily through market transmission mechanisms and shifts in consumer behaviour, rather than through direct exposure to severe weather events. These risks typically manifest as price volatility, fluctuating demand, and disruptions in product availability, particularly for perishable goods (Vicario *et al.*, 2023). Unlike primary producers or logistics, the retail sector is rarely physically affected by extreme weather events in production; however, it is the only phase of the FSC that simultaneously feels the effects of weather disturbances from both upstream and downstream. Retail absorbs upstream shocks resulting from reduced yields, processing disruptions, logistical delays, and increased procurement costs. These effects are manifested through reduced product availability, price volatility and changes in the assortment structure.

Weather-related disruptions in logistics, especially in transport (Rahman *et al.*, 2022), such as blocked routes, delayed deliveries, high transport costs (Malik *et al.*, 2022) or infrastructure damage, can cause stockouts, reduce product freshness, and lead to revenue losses (Ghadge *et al.*, 2020). Weather-related risks affect not only individual stakeholders within the FSC but also logistical operations, such as transport and warehousing, which influence the functioning of the entire chain. Extreme weather can severely disrupt food distribution by damaging existing infrastructure or slowing down shipments. This increases the risks of food damage, spoilage, or contamination (Davis *et al.*, 2021). However, these localised disruptions often trigger cascading effects that extend beyond individual nodes. For example, a drought-induced harvest failure can reduce transport volumes, overload storage infrastructure, and delay distribution timetables. Extreme weather can also disrupt transport routes, cold chain logistics, and inventory turnover, particularly for perishable goods. These logistical disruptions undermine just-in-time supply strategies and compromise downstream service levels. As disruptions propagate, systemic vulnerabilities emerge in the form of bottlenecks, risk redistribution, supply-demand mismatches (Hadachek *et al.*, 2024) and demand uncertainty (Shi and Wang, 2022). Consumers play a pivotal role in shaping sustainable food supply systems, influencing everything from distribution channels to demand (Melkonyan *et al.*, 2017).

Weather risk in the FSC is a complex transmission process rather than isolated shocks. Building resilient food systems requires integrated strategies that encompass not only farm-level adaptation, but also robust logistical planning, inter-sectoral coordination, and SC-wide risk governance. Fu *et al.* (2018) propose a weather risk-reward contract to enhance the resilience and sustainability of FSCs against weather-related disruptions. This contract shares the farmers' production risk through risk subsidies, thus supporting a stable supply of agricultural products. Yao *et al.* (2025) stress the importance of government aid as the most critical factor influencing FSC resilience, noting its potential to provide a robust support mechanism that buffers against extreme weather events. Found *et al.* (2024) advocate investing in adaptability and flexibility as vital for enhancing resilience during abnormal times, rather than the economies of scale that might suffice during standard periods. Furthermore, the authors find that vertical and horizontal collaboration among FSC actors can significantly reduce SC vulnerability. However, the degree to which individual actors are aware of weather

risk and their capacity to anticipate disruptions are key factors for SC resilience (Sá *et al.*, 2020). Emerging technologies, especially artificial intelligence (AI), are crucial for managing weather risk, as AI can develop advanced weather models for data analysis, identify FSC risks, provide early warnings, and assess impacts (Effah *et al.*, 2024).

4. DISCUSSION OF RESULTS

The review confirms direct and indirect impact of weather risk on FSCs. The agricultural production is directly and most severely affected by weather and climate risk. Extreme weather events result in crop losses, reduced yields and compromised product quality (Tchonkouang *et al.*, 2024, Vicario *et al.*, 2023, Thompson *et al.*, 2023).

Extreme weather creates cascading effects across FSCs, with the initial disruption propagating through processing, logistics, and retail (Malik *et al.*, 2022) and simultaneously affecting distant locations via global SC dynamics. Weather risks in FSCs result in significant economic and social consequences that reach beyond direct production loss. Price volatility is consistently observed across studies, affecting both producers and consumers (Raffington and Adesiyani, 2024). The distribution of economic effects is uneven, placing a greater burden on poorer countries (Adom, 2024).

We strongly advocate building resilient FSCs that incorporate weather risk management into their operations. Scientific studies and reports from leading global institutions support our advocacy. The resilience of FSCs is defined as their ability to survive in the long term, adapt to changing circumstances, and recover from various types of disruptions, including short-term (e.g., extreme weather events and logistical disruptions), long-term (such as climate change and geopolitical crises), and systemic disruptions (pandemics and economic crises). In this context, robustness, adaptability and recovery are identified as three fundamental components of a resilient SC (Hobbs and Hadachek, 2024).

Synthesising the adaptation strategies proposed in the literature (Table 3), it is evident that most studies continue to focus on short-term solutions to weather-related risks and climate change disruptions. Even though operational measures deliver quick results in the short and medium term, they often lack proactive adaptation to weather-related risks. In comparison, strategic solutions tend to be sustainable over the long term, providing a foundation for proactive, resilient weather-risk adaptation and enabling effective upgrades to operational measures. Financial tools such as weather insurance, crop and index insurance, disaster relief funding, and risk-reward contracts are proposed to hedge against weather risks and stabilise farmer incomes. Forward contracts and investment in weather-related technologies and meteorological data also support better risk assessment and planning. International trade and robust trade agreements can mitigate localised weather shocks by redistributing resources globally. Large agri-food firms are encouraged to prioritise climate risk management, while smaller firms should rely on emergency relief mechanisms when needed. Collaboration and resilience planning among major suppliers are also emphasised.

In line with the IPCC framework of climate vulnerability (IPCC, 2022) and the FAO concept of climate-smart agriculture (FAO, 2013), strategic measures of adaptability act as a key instrument for long-term exposure reduction and strengthening of the adaptive capacity of agriculture, whereas operational measures tend to have limited and mostly short-term effects.

5. FUTURE RESEARCH AGENDA

Despite growing research interest, some gaps remain. Research is imbalanced, with agricultural production most widely studied rather than other stages of the SC (Tchonkouang *et al.*, 2024), limiting insight into the whole food system and integrated adaptation planning. Methodologically, many studies focus on single stages or isolated extreme weather events, thereby limiting the potential to learn about cascading and system effects (Malik *et al.*, 2022). There is a need to broaden research beyond specific hazards (e.g. droughts, extreme rainfall, and heat waves) and production as a stage of the FSC to encompass the whole FSC and diverse types of weather risk.

Geographically, the research is concentrated in developed countries, while developing regions remain understudied and are more vulnerable, lacking adaptive capacity (Adom, 2024), therefore limiting the generalisability of findings. Most studies focus on short-term extreme events, with insufficient attention to long-term, incremental climate change and its cumulative effects on SC structures. Data limitations, combined with a lack of longitudinal studies, further constrain empirical analysis. Finally, the literature remains fragmented across disciplines, underscoring the need for an integrated interdisciplinary approach that combines climate science, SC modelling, and socio-economic analysis to address the complexity of weather risk in FSCs.

Future research should shift from partial and reactive approaches to integrated and proactive risk management across the entire FSC, with vulnerability assessment at all stages to account for the cascading effects of weather disruptions.

While sourcing diversification and SC cooperation are common resilience strategies, financial instruments such as weather derivatives (Chen and Yano, 2010; Štulec, 2017) and innovative agreements (Fu *et al.*, 2018; Sarkar *et al.*, 2023) can complement operative adaptation measures if contextually adjusted and integrated in broader risk management strategies. Policies and measures should encourage collaboration, knowledge sharing, and the fair distribution of adaptation costs, and strengthen social capital, especially in small and medium-sized enterprises. Empirical findings confirm the importance of FSC collaboration for effective weather risk management (Ali and Golgeci, 2021). The specificity of weather risk is that it is not caused by human action, and its negative effects cannot be eliminated. However, good planning and operational organisation can reduce them. A more effective solution is to transfer the risk to entities outside the FSC. The potential of such weather-risk transfer solutions, predominantly weather derivatives and index insurance, remains under-researched. The conventional understanding of weather risk protection in the FSC, through weather derivatives or index insurance, is that the exposed actor purchases the protection

instrument and uses the payment received as compensation for financial losses caused by adverse weather. However, given that the effects of adverse weather are passed on to other participants in the SC, an innovative approach to weather risk protection in the FSC should include transferring the realised benefits to other actors in the SC. In this case, the shared benefits do not necessarily have to be financial compensation; they can include flexible delivery times, price discounts, guaranteed purchase quantities, etc. The assumption is that such an approach to weather risk management will strengthen trust in the SC and contribute more strongly to its resilience than if only one actor had access to protection.

Building on dynamic capabilities theory (Teece *et al.*, 1997), weather risk management can be understood as a firm's ability to sense, monitor, and respond to environmental disruptions, while the relational view emphasises the role of inter-organisational trust and collaboration in achieving SC performance. In light of the reviewed studies, synthesised findings and deduced research gap, we formulate two research propositions.

RP1: The systematic integration of weather risk management practices into FSC operations, through risk identification, monitoring, and mitigation mechanisms, is positively associated with SC resilience, as reflected in reduced disruption impact, faster recovery time, and increased adaptive capacity.

RP2: The adoption of innovative weather risk transfer and sharing mechanisms (e.g., weather derivatives, index-based insurance, and contractual risk-sharing agreements) is positively associated with inter-organisational trust and collaborative behaviour among FSCs actors.

Future research should empirically examine integrated weather risk management in FSCs, emphasising the under-researched financial and non-financial benefits of using financial instruments and innovative contractual agreements among FSC actors. The existing research remains fragmented, examining climate risks across isolated dimensions while neglecting their interactions, distributional effects, and methodological integration, thereby limiting a systemic understanding of SC resilience.

6. CONCLUSION

Weather risk in the FSC operates as a multi-level, dynamic transmission process that gradually intensifies across its different phases. It initially manifests during the primary production phase, when adverse weather conditions (e.g., droughts, heat waves, extreme precipitation) disrupt crop physiology and quality, increasing their susceptibility to mechanical damage and microbial deterioration. Weather risk increases further during storage, especially under elevated temperatures and changes in relative humidity, which accelerate product respiration, shorten shelf life, and increase post-harvest losses. Insufficient logistics infrastructure and limited cold chain capacity further amplify the effect of the initial climate shock. In the logistics phase, risks are compounded by infrastructural and organisational weaknesses, such as insufficient transport capacity, extended product transit times, and unfavourable distribution conditions. Here, weather risk takes on a network dimension, as disruptions at one point in the chain can cascade downstream along the FSC. Finally, weather risk manifests

itself in the FSC at the retail stage through reduced product availability, price volatility, and potential disruptions to food safety. The results of the literature review confirm the need for an integrated and systematic approach to the assessment of weather risk along the FSC and point to two propositions: (1) the integration of weather risk management in FSCs contributes to strengthening the resilience of the SC, reducing systemic vulnerability and increasing the ability to adapt to climate disturbances and (2) the application of innovative solutions for weather risk management (e.g. weather derivatives, index insurance, risk sharing contracts) encourages trust building, strengthens cooperation and improves coordination among actors in the FSC.

ACKNOWLEDGMENT

This research was financed by European Union funds - NextGenerationEU within the framework of the Call IIP-581-2025, as part of the project „Integrating weather risk management into food supply chain management to enhance resilience and trust – IntegFSCM“. The views and opinions expressed are solely those of the authors and do not necessarily reflect the official views of the European Union or of the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

NOTE

This paper was presented at the scientific conference Transport & Logistics 2026, organized by the University of Applied Sciences of Rijeka and the Croatian Scientific Society for Transport, held in Opatija, Croatia, on 16–17 April 2026.

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Pregledni rad

<https://doi.org/10.31784/zvr.14.1.30>

Datum primitka rada: 26. 1. 2026.

Datum prihvaćanja rada: 29. 4. 2026.

VREMENSKI RIZIK U PREHRAMBENIM LANCIMA OPSKRBE: SUSTAVNI PREGLED LITERATURE I ISTRAŽIVAČKA AGENDA

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SAŽETAK

Klimatske promjene, sve veća promjenjivost vremena i učestalost ekstremnih vremenskih događaja predstavljaju sve veći izazov za stabilnost i otpornost prehrambenih lanaca opskrbe. Šokovi povezani s vremenskim prilikama sve se više šire izvan primarne poljoprivredne proizvodnje i utječu na više faza prehrambenog lanca opskrbe, utječući na dostupnost hrane, volatilnost cijena i sigurnost opskrbe. Unatoč sistemskoj prirodi ovih rizika, akademska literatura o vremenskom riziku u prehrambenim lancima opskrbe ostaje fragmentirana, s pretežnom usmjerenošću na proizvođače poljoprivredno-prehrambenih proizvoda. Ovaj rad predstavlja sustavni pregled literature o istraživanju vremenskog rizika u prehrambenim opskrbnim lancima. Pregledom literature duž faza opskrbnog lanca ističu se strukturne razlike u izloženosti riziku i praksama upravljanja između aktera. Za proizvođače, vremenski rizik uvelike je povezan s izravnim utjecajima na prinose i kvalitetu proizvoda. Međutim, za prerađivače i trgovce na malo, gubici povezani s vremenskim prilikama uglavnom su neizravni i nastaju zbog nedostatka opskrbe, volatilnosti cijena proizvoda, logističkih poremećaja i promjena u ponašanju potrošača. Na temelju sinteze pregleda, rad razvija integrirani konceptualni okvir koji objašnjava kako se vremenski rizik prenosi, pojačava i preraspodjeljuje duž prehrambenog opskrbnog lanca. Nadovezujući se na ovaj okvir, studija formulira skup konceptualnih istraživačkih prijedloga koji čine istraživačku agendu koja se bavi jazom u postojećem znanju i pruža smjernice za buduća empirijska istraživanja. Usvajanjem perspektive opskrbnog lanca, ova studija doprinosi holističkom razumijevanju vremenskog rizika i nudi smjernice i istraživačima i praktičarima koji žele poboljšati otpornost prehrambenog lanca opskrbe, stabilnost cijena i sigurnost hrane u uvjetima sve veće neizvjesnosti vremenskih prilika.

Ključne riječi: vremenski rizik, prehrambeni lanci opskrbe, otpornost prehrambenih lanaca opskrbe, sustavni pregled literature