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Resilience of food supply systems to sudden shocks: A global review and narrative synthesis

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ABSTRACT

Global food supply systems (FSS) are increasingly tested by sudden shocks such as pandemics, geopolitical conflicts, and extreme weather events, that demand adaptive and transformative responses. This systematic review analyses 26 empirical studies published between 2016 and 2023, each examining an abrupt disruption in FSS. Of these, 22 focus on exposure to COVID-19 and four on natural disasters. Findings reveal that the most resilient food supply systems are those that combine strong operational, relational, and structural attributes with well-developed capacities at each shock phase (pre-, during-, and post-). These elements, taken together, not only enable effective recovery (returning to near-normal function) but also foster adaptation (dynamic adjustments to new conditions) and transformational shifts (permanent, beneficial reconfigurations) whenever disruptive events strike. However, many studies indicate that the capacity to "bounce forward" remains limited: short-term coping actions are often not converted into long-term structural reforms. This gap is particularly noticeable in settings with weak policy frameworks or resource constraints, undermining broader resilience gains. Although FSS often exhibit significant adaptability during disruptions, deeper transformation requires sustained efforts and alignment among governmental, private-sector, and community actors. The integrated framework of resilience proposed in this review clarifies how attributes underpin capacities that, when activated through concrete actions, shape resilience outcomes. By emphasising both short-term coping and long-term systemic change, stakeholders can strengthen future resilience strategies across diverse FSS contexts. Enhanced conceptual clarity, multi-scalar approaches, and expanded empirical evidence are crucial for guiding policy and practice, ultimately enabling FSS to withstand and learn from sudden shocks.

1. Introduction

Resilience in food supply systems (FSS) has garnered increasing attention (Kazancoglu et al., 2021). Disruptions such as pandemics and wars constrained food availability through lockdowns, labour shortages, and trade restrictions (Das and Roy, 2022), exacerbated by panic buying (Hobbs, 2021). Such acute shocks demand adaptive responses from diverse actors within these complex systems (Béné et al., 2021).

FSS complexity arises from diverse actors, interests, and varied economic and environmental risks (Hayes et al., 2021; Snow et al., 2021). Although long-term stressors like climate change (FAO, 2021) remain critical, sudden shocks require distinctive resilience strategies to maintain food security (Murphy et al., 2023). Rapid escalation makes preparedness and adaptive capacity essential (Kazancoglu et al., 2021). Tendall et al.'s (2015, p.19) definition is particularly apt: "capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate and accessible food to all, in the face of various and even unforeseen disturbances".

Despite growing scholarly interest, resilience lacks universal definition or evaluation model (Stone and Rahimifard, 2018). Approaches

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vary from single-indicator measures (Moran et al., 2020) and trade/-price data (Pu et al., 2021) to multi-attribute frameworks (Perrin and Martin, 2021). This methodological diversity leads to inconsistent findings: short supply chains may show relatively mild disruption in some contexts (Galanakis, 2020), whereas large-scale operations might benefit from economies of scale and centralized coordination (Hobbs, 2021). Consequently, the research landscape remains fragmented, limiting systematic efforts to enhance resilience capacities for vulnerable regions and supply chain actors (Eriksen et al., 2021). Complex adaptive system thinking (Pircher et al., 2021) can clarify how specific attributes and capacities reinforce resilience and guide more effective FSS strategies (Murphy et al., 2023).

This review addresses the central question: Which attributes and capacities are critical for FSS to recover, adapt, and potentially transform in response to acute shocks? While Ujjwal et al. (2024) provides a broad look at food systems' resilience assessment, our focus examines primary studies on FSS facing sudden disruptions to uncover the attributes (enduring features) and capacities (action-enabling capabilities) that underpin resilience across scales, geographies, and actors. By synthesizing these findings, we propose an integrative framework that can inform future empirical research and practical interventions for strengthening FSS resilience.

2. Theoretical premises of resilience in agrifood systems

Resilience was initially viewed through the lens of redundancy and the speed with which a system could return to equilibrium after disturbance (Folke, 2006). In ecology, this meant the ability to absorb change while retaining key functions (Holling, 1996). In social systems, adaptability and transformability became more salient (Fath et al., 2015). Resilience evolved beyond "bouncing back" to encompass redundancy, adaptability, and transformability (Béné et al., 2014).

Building on the ecological perspective, Gunderson and Holling's (2002) Adaptive Cycle (AC) model highlights four phases, i.e. growth, conservation, release, and reorganization, in shaping resilience within social and organizational contexts. Fath et al. (2015) adapted the AC framework to include innovation, highlighting how shocks can serve as triggers for renewal. This emphasizes that resilience is dynamic: systems may reconfigure and emerge stronger after crisis.

The socio-ecological framework further stresses human agency. Proactive monitoring and early intervention can redirect systems (Folke, 2006; Walker et al., 2004). Westley et al. (2013) showed that well-timed interventions (policy reforms, technological adoption) can amplify transformative capacity. Actors actively shape outcomes by aligning resources and networks, not just react to shocks.

Food supply research has moved from straightforward supply-chain models toward complex adaptive system thinking (Ruben et al., 2019). This shift captures a broader spectrum of stakeholders, interactions, and feedback loops (Gaitán-Cremascyhi et al., 2018). By acknowledging these complexities, researchers and practitioners can more accurately diagnose vulnerabilities and craft strategies that bolster resilience.

Overall, the theoretical premises indicate that resilience involves dynamic, multi-level processes combining environmental constraints with social innovations. Agrifood systems capable of redundancy, adaptability, and transformability do more than restore pre-shock conditions; they leverage disturbances to reconfigure and improve structures, processes, and relationships. Consequently, understanding and enhancing these capacities is pivotal for ensuring stable, equitable food systems able to withstand, and even benefit from acute shocks.

3. Methods

This study adopted a systematic review approach to synthesize empirical evidence on resilience in FSS facing sudden shocks. The methodology emphasized rigor, transparency, replicability, and inclusivity (Denyer and Tranfield, 2009). A detailed protocol was developed beforehand, specifying the review scope, search strategy, inclusion/exclusion criteria, and data extraction methods.

3.1. Scope of the review

We focused on English-language articles published since 2000 that assessed at least one dimension of FSS resilience when confronted with sudden shocks. These shocks included acute events (e.g., natural disasters, pandemics, or wars) with immediate, severe consequences. Studies of slow-moving stressors (e.g., chronic food insecurity or incremental climate change) were excluded, even though these stresses clearly shape the broader context in which shocks arise. Their potential role in fostering or exacerbating acute shocks is undoubtedly significant but beyond the scope of this review, meriting a dedicated systematic review. Eligible articles had to (1) examine a national or regional FSS, (2) focus on at least one abrupt disruption, (3) report empirical data collection methods, (4) include an explicit resilience assessment (attributes and/or capacities), and (5) be published in English.

3.2. Search strategy

We searched four databases - Business Source Complete, Food Science Sources, Scopus, and Web of Science - using Boolean operators and carefully constructed keywords (Table 1). The search terms spanned concepts of "food supply system", "resilience", and "shock". We initially ran searches in March 2022 and performed an update in February 2023 with a shortened string (Table 2). In each database, the search was restricted to fields such as Title, Abstract, or Keywords. Results from the update were integrated at the full-text screening stage.

3.3. Inclusion and exclusion criteria

Papers had to evaluate resilience in a clearly defined FSS during a sudden event that disrupted availability, distribution, or processing of food. Exclusion criteria targeted studies centered on slow-moving crises (as they do not reflect the same temporal urgency), conceptual or policy-only papers without empirical data, and non-English publications. During the title and abstract screening, we assessed whether the study appeared relevant to sudden shocks, addressed food systems, and defined and assessed resilience in some capacity. Full-text screening applied the same criteria more stringently, confirming that resilience dimensions (attributes or capacities) were explicitly measured or analyzed.

3.4. Screening process

All search results were imported into EndNote X9® and then DistillerSR®. After removing duplicates, a three-stage screening followed.

Table 1
Version 1 search string used to identify studies.

Category	Search string use
Food supply systems	("food suppl*" OR "food system*" OR "food distribution" OR "food chain" OR "food value" OR "food product*" OR (fish* AND (supply OR "value chain*" OR distribut*)) OR (Aquacultur* AND (supply OR "value chain*" OR distribut*)) OR (livestock AND (supply OR "value chain*" OR distribut*)) OR "farming system*" OR "agricultural system*" OR "agricultural supply" OR "agricultural resilience") NOT (bio?chemical OR biolog* OR transcrip* OR pharma*)
Resilience	resilien* OR resistance OR transform* OR panarchy OR agile OR agility OR flexib* OR absorb* OR withstand OR adapt* OR adjust* OR "bounc* back" OR recover* OR precarious* OR vulnerab* OR response* OR respond* OR "bounc* forward" OR robust OR impact OR effect* OR consequence OR imperil* OR dynamic OR lasting OR transition* OR reconfigure

Table 2
Version 2 search string used to identify studies (used for updating searches).

Category	Search string use
Food supply systems	(Agricultur* OR food OR seafood OR aquaculture OR fishery OR meat OR "fresh produce" OR fruit* OR vegetables OR dairy OR milk OR poultry OR chicken OR pork OR lamb OR sheep OR beef) AND (supply OR chain OR system)
Resilience	resilience OR resilient OR resiliency

1). Title Screening (Detailed in Table 3). An initial pilot test was conducted manually on 1000 titles by two reviewers. Conflicts were resolved through discussion or with a third reviewer. This manually screened dataset trained an AI model in DistillerSR®. The AI then generated confidence scores predicting inclusion or exclusion. Articles with high scores (≥0.9) were tentatively included, while those below set thresholds (≤0.7 initially) were excluded, subject to manual checks. Conflicts between AI and reviewers were resolved by at least two human reviewers. This led to subsequent stages of AI training (applying progressively to additional 1,000, 2,000, 4000 and 6000 titles) and manual quality checks and decisions on cut-off scores for manual screening. Titles in an intermediate range of confidence score (0.71–0.9) were all double-screened by human reviewers, with disagreements resolved through consensus.
2). Title and Abstract Screening. Articles passing the initial stage underwent further evaluation by six reviewers working in pairs. We considered whether the research included explicit resilience concepts and examined an acute shock in an FSS. Again, the AI assisted by predicting inclusion or exclusion, and disagreements were resolved manually.
3). Full-Text Screening. A total of 165 articles reached this stage. Each was read in full by at least one reviewer, applying the inclusion/exclusion criteria. Any ambiguous cases were discussed in the review team until agreement was reached. In total, 26 studies met all criteria.

Table 3
Process of screening on DistillerSR.

Stage	Task
I	1) Double manual screening 2) Conflict resolution
II	3) AI training using the manually reviewed set (1000) 4) AI Review – Map Exclusion with score≤0.7 5) Manual quality check on AI review exclusions 6) Double manual screening on remaining not excluded by AI
III	7) AI training using both reviewed sets (2000) 8) AI review – Map Exclusion (score≤0.7) & Inclusion Score≥0.9 9) Double manual quality check on AI inclusions and sample check on AI exclusions 10) Double manual screening on remaining (scored between 0.71 and 0.89) not reviewed by AI 11) Conflict resolution with AI and manual reviewer
IV	12) AI training using all reviewed sets (4000) 13) AI review – Map Exclusion (score≤0.8) & Inclusion Score≥0.9 14) Single manual quality check on AI inclusions and sample check on exclusions 15) Double manual screening on remaining (scored between 0.81 and 0.89) not reviewed by AI 16) Conflict resolution with AI and manual reviewer
V	17) AI training using all reviewed sets (6000) 18) AI review of all remaining unreviewed titles – Exclusion (score≤0.85) & Inclusion (Score≥0.9) 19) Double manual screening on remaining (scored between 0.86 and 0.9) not reviewed by AI 20) Double manual quality check on AI inclusions 21) Conflict resolution

Fig. 1 summarizes the screening flow: from 31,411 initial titles, 1397 proceeded to title-and-abstract screening, 165 were reviewed in full, and 26 were ultimately included.

3.5. Data extraction and analysis

All 26 included articles underwent a structured data extraction process, recorded in a shared Excel file. Key details included.

- Study Characteristics - Author, title, publication year, and journal.
- Contextual Data - Location(s), food system type (e.g., dairy, fisheries, horticulture), and shock(s) examined (e.g., pandemic, flood).
- Methodological Information - Study design (qualitative, quantitative, mixed methods), data collection techniques (interviews, surveys, secondary data), and sample size.
- Resilience Definition and Indicators - Whether resilience was framed as an attribute or capacity, and any outcome measures used (e.g., supply continuity, adaptive behaviors).

We then used an iterative coding scheme to categorize studies according to which resilience components they examined. The coded data enabled cross-study comparisons of how resilience was conceptualized and operationalized. Our categorisation of resilience outcomes (Resilient, Mixed, and Nor Resilient) emerged from detailed coding of each study's textual evidence on system performance and shock responses. Specifically, we examined statements on whether.

- Operations continued relatively undisturbed: For example, through effective multi-sourcing, rapid logistical adjustments, protective institutional or policy support.
- Actors faced partial disruptions yet maintained or restored functionality for certain segments: For example, situations where farmers struggled but processors adapted, or local markets thrived while export channels failed.
- Systems experienced significant breakdown (e.g., no adaptive measures were implemented or there was widespread collapse in distribution or production).

The research team synthesized results through thematic analysis, focusing on shared or divergent resilience attributes, capacities, and outcomes. We paid special attention to contextual factors (e.g., national policies, market structures, socio-economic conditions) that shaped each case. Throughout this process, the dynamic links between attributes, capacities, and actions were highlighted, aligning with our integrative framework.

3.6. Quality and rigor

To maintain rigor, we employed double screening at critical junctures, and resolved disagreements collectively. The use of AI, though novel, was carefully validated through iterative training and spot-checks (Table 3). We aimed for transparency in reporting how the final 26 articles were selected, acknowledging that methodological heterogeneity across studies (e.g., varying sample sizes, data collection tools, and definitions of resilience) could limit direct comparability.

3.7. Limitations of the method

Our review, focused on sudden shocks, may exclude studies dealing with protracted crises that nonetheless contain insightful resilience lessons. We also concentrated on peer-reviewed primary research articles, potentially omitting industry reports or grey literature that could offer additional perspectives. Nonetheless, by adhering to a structured protocol and rigorous screening, we provide a synthesized view of FSS resilience under acute disruptions. This approach enabled a targeted review of global FSS studies addressing resilience to sudden shocks,

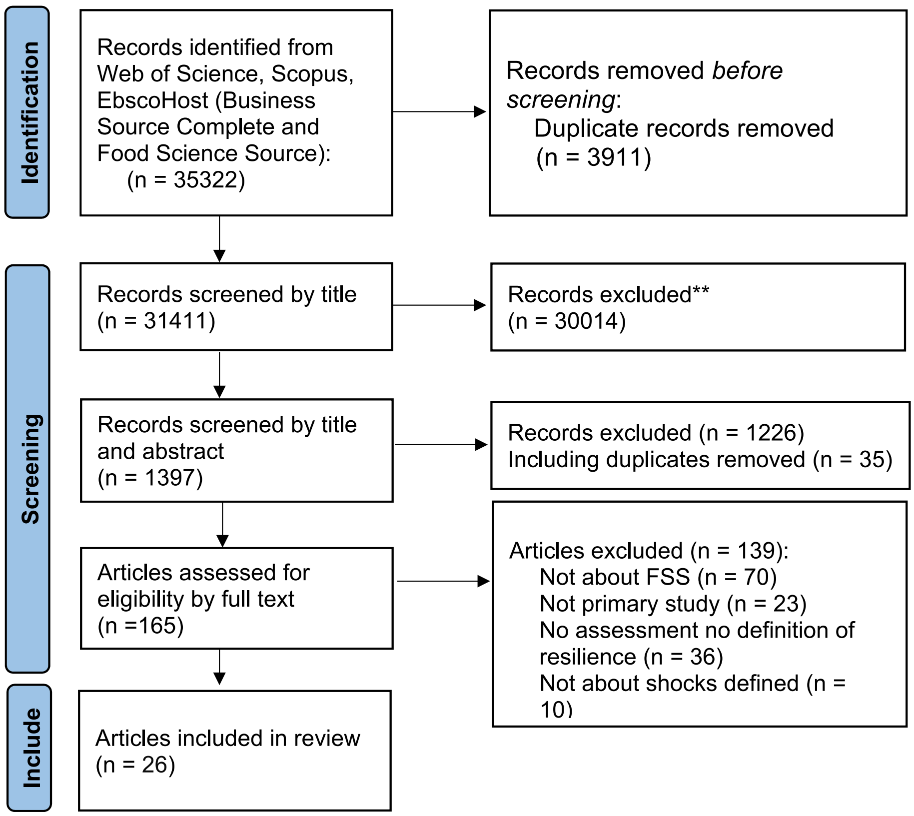

Fig. 1. Integrated resilience framework of food supply systems.

culminating in an integrative framework and critical synthesis of key findings.

4. Results

This section presents the key findings from the 26 included studies, grouped by (1) sources of evidence, (2) exposures addressed, (3) study design, (4) geographic coverage, (5) definitions of resilience, (6) how resilience was approached, and (7) evidence regarding resilience outcomes. While each study offers unique insights, we highlight commonalities and differences in how resilience was evaluated and what factors enabled or constrained it.

4.1. Sources of evidence

A total of 26 peer-reviewed articles met the inclusion criteria, drawn from 18 different academic journals. Five appeared in Agricultural Systems, with the rest dispersed across journals such as Frontiers in Sustainable Food Systems, Maritime Studies, Marine Policy, and others focused on agriculture, environment, or supply chain management. This diversity reflects the interdisciplinary nature of resilience research in FSS. Publication years ranged from 2016 to 2023, with most released post-2020, reflecting a heightened focus on crisis-related disruptions during the COVID-19 pandemic.

4.2. Exposures

Of the 26 studies, 22 addressed disruptions triggered by COVID-19. The remaining four focused on natural disasters including flooding in Queensland, Australia (Smith et al., 2016), drought in Brazil (Sá et al., 2020), hurricane in Puerto Rico (Orengo Serra and Sanchez-Jauregui, 2022), and earthquake and flooding in Pakistan (Umar et al., 2021). Although the pandemic context dominated, the inclusion of non-pandemic shocks still broadens our understanding of how FSS respond to sudden disasters.

4.3. Study design and sample size

All selected studies were published between 2016 and 2023, with 14 appearing in 2021 alone. Regarding research design.

- Mixed Methods (14 studies). These combined qualitative (e.g., interviews) and quantitative (e.g., surveys) approaches, enabling richer insights into how FSS actors perceive and manage disruptions.
- Qualitative Only (8 studies). These employed interviews, focus groups, case studies, or document analysis, offering detailed narratives but sometimes limited generalizability.
- Quantitative Only (2 studies). Ali et al. (2022a) and Mangano et al. (2022) used large-scale surveys, capturing broader patterns but grappling with complexities of measuring resilience numerically.
- Secondary Data (1 study). Love et al. (2021) relied primarily on trade and production statistics supplemented by a literature review.

Sample sizes varied considerably, from small-case analyses (e.g., six respondents in Goti-Aralucea et al., 2021) to broad surveys (e.g., 718 participants in Coopmans et al., 2021). Most studies used cross-sectional designs, capturing a "snapshot" of responses during or shortly after a shock. Consequently, understanding longer-term transformations, particularly the transition from immediate coping to structural reforms, was limited.

Researchers often relied on convenience sampling and online interviews during COVID-19 lockdowns, potentially skewing samples toward digitally connected actors. Many authors also noted difficulties in capturing informal supply chain segments. Yet these mixed and qualitative methods proved effective in revealing multi-layered adaptations (e.g., re-routing logistics, forging new partnerships) that are not easily captured by surveys alone.

4.4. Geographic coverage

Overall, the 26 studies collectively spanned data from 63 countries. Mangano et al. (2022) alone included inputs from 52 nations, while others concentrated on one or a few regions. Excluding Mangano et al. (2022), the remaining articles covered 35 countries. The United States and Argentina were each represented in six articles, Peru in four, and multiple nations (e.g., Brazil, Canada, Chile, China, India, Norway, Philippines) appeared in three articles apiece. Belgium, Bolivia, Colombia, Costa Rica, Ecuador, France, Germany, Italy, Mexico, New Zealand, Pakistan, Puerto Rico, South Africa, Spain, and the UK each featured in two studies.

4.5. Definitions of resilience adopted in the reviewed studies

All 26 studies conceptualized resilience as an ability, capability, or capacity. Yet each definition placed different emphasis on whether resilience was an outcome (e.g., continuity of supply) or a process (e.g., learning and adapting). Four studies (Bassett et al., 2022; Jones et al., 2022; Manlosa et al., 2021; Zollet et al., 2021) highlighted resilience as an inherent system property. They frequently used terms like "feature", "attribute", or "quality", suggesting a built-in capacity to reorganize while maintaining function. Others integrated "bounce back" and "bounce forward" concepts. For instance.

- Bounce Back - Some authors, such as Sá et al. (2020), viewed resilience as returning to a pre-shock state.
- Bounce Forward - Jones et al. (2021) advocated transformation, implying that resilience should foster system improvements rather than mere restoration.

Temporal frames also varied: some studies targeted immediate coping mechanisms, whereas others took a broader view, acknowledging shifts before, during, and after disruption (Carlson et al., 2021; Stoll et al., 2021). Consequently, outcome measures ranged from minimal supply chain continuity (Ali et al., 2022b) to full-scale transformation and learning (Bø et al., 2023).

4.6. How resilience was approached in the studies

Despite differing definitions, most articles examined resilience in terms of inherent system qualities (which some label "attributes") and dynamic, actionable abilities ("capacities"). Many studies also identified specific actions taken at different stages of a disruption, whether before, during, or after the shock.

- **Attributes** - Studies regularly cite traits like flexibility (Jones et al., 2022; Mishra et al., 2021), trust and collaboration (Ali et al., 2022a; Coopmans et al., 2021), and having multiple supply or market options (Smith et al., 2016; Carlson et al., 2021). Although these properties were not always grouped in the same way by different authors, most recognized that such enduring system qualities shape how and how quickly an FSS can respond to stress.
- **Capacities** - Many articles used a phased lens, distinguishing between pre-shock (anticipatory, readiness), during-shock (coping, responsiveness), and post-shock (recovery, learning, transformability) abilities. Examples include scenario planning or stocking reserves (Goti-Aralucea et al., 2021), rapidly switching to new transport modes or sales channels during the shock (Manlosa et al., 2021; Love et al., 2021), and learning from disruptions to "bounce forward" with permanent reforms (Orengo Serra and Sanchez-Jauregui, 2022; Tittonell et al., 2021).
- **Actions** - These capacities often translated into concrete interventions at each phase—e.g., setting up digital sales platforms pre-shock (Ali et al., 2022a), forging rapid alliances and resource-sharing during a crisis (Bachman et al., 2021), or institutionalizing novel practices (such as home-delivery schemes) in the aftermath (Snow et al., 2021).

Overall, the majority of the included studies adopted some version of this temporal approach, illustrating that resilience emerges through an ongoing process of preparing for, coping with, and learning from disruptions—rather than from a purely reactive stance once problems arise.

4.7. Evidence of resilience outcomes

We synthesized how studies assessed resilience outcomes, whether systems were deemed "resilient", "mixed", or "not resilient" (see first row in Tables 4 and 5). Although each article used different metrics (e.g., operational continuity, revenue maintenance, supply chain reconfiguration), three broad categories emerged.

- **Presence of Resilience** (12 studies) - Systems that demonstrated agility, solid governance support, and strong relational ties fared well (Ali et al., 2022; Bachman et al., 2021; Carlson et al., 2021; Snow et al., 2021). For example, some fishery cooperatives or localized agriculture networks reorganized quickly during disruption and then maintained or even improved performance afterward (Stoll et al., 2021; Tittonell et al., 2021). Bø et al. (2023) notes how Norwegian firms retained flexible delivery systems devised during the shock, illustrating a "bounce forward".
- **Low or No Resilience** (2 studies) - Goti-Aralucea et al. (2021) found German brown shrimp fisheries lacking essential redundancy and scenario planning, while Mangano et al. (2022) described aquaculture supply chains failing key elements like visibility and velocity. In both cases, minimal anticipatory planning or real-time coordination resulted in significant disruptions, underscoring the importance of proactive capacity-building.
- **Mixed Resilience** (12 studies) - These indicated partial or uneven resilience, with strong performance in some segments but weaknesses in others (Sá et al., 2020; Smith et al., 2016; Jones et al., 2021; Ferguson et al., 2022). For instance, Brazilian processors managed drought disruptions through multi-sourcing while local farmers lagged in preparedness (Sá et al., 2020). Smith et al. (2016) found short food chains coped effectively with Queensland floods, whereas large centralized retailers struggled. Similarly, Jones et al. (2021) saw local UK actors rapidly pivot during COVID-19 but showed limited capacity to institutionalize changes post-crisis. Many articles (e.g., Ali et al., 2022a; Mishra et al., 2021; Love et al., 2021) cited uneven distribution of resources, knowledge, or market access across supply chain tiers. Some nodes possessed diverse, flexible attributes and strong coping capacities, while others lacked robust networks or financial buffers. Governance structures, geographic constraints, and variations in socio-economic environments further influenced these fragmented responses.

5. Synthesis of key findings

Overall, the studies reveal that resilience in FSS rests on a multi-layered foundation of (a) operational, relational, and structural attributes, (b) capacities spanning pre-, during-, and post-shock phases, and (c) targeted actions aligned with each stage. Systems combining high diversity, strong social capital, adequate redundancy, and proactive planning demonstrated more robust outcomes. Key resilience enhancing themes can be grouped as below.

- Operational dimensions (agility, flexibility) are vital in ensuring immediate crisis response and limiting losses.
- Relational elements (collaboration, visibility) significantly boost coordination, enabling faster reorganization.
- Structural qualities (diversity, redundancy, local embedding) mitigate single points of failure and allow for reconfiguration.

Table 4
Resilience attribute identified from the reviewed studies.

Resilienceattributes	Numberofstudies	.Aliet al.(2022a) − M*	.Ali*et al*.(2022) − R	.Bachmanet al.(2021) − R	.Bassettet al.(2022) − M	.Bøet al.(2023) − R	.Carlsonet al.(2021) − R	.Coopmanset al.(2021) − M	.Sæt al.(2020) − M	.Favaet al.(2022) − R	.Fergusonet al.(2022) − M	.Goti − Araluceaet al.(2021) − NR	.Joneset al.(2022) − M	.Joneset al.(2021) − M	.Loveet al.(2021) − M	.Manganoet al.(2022) − NR	.Manlosaet al.(2021) − R	.Mishraet al.(2021) − M	.PerrinandMartin(2021) − R	.OrengoSerraandSanchez − Jauregui(2022) − R	.Smithet al.(2016) − M	.Snowet al.(2021) − R	.Stollet al.(2021) − R	.Tittonellet al.(2021) − R	.Umaret al.(2021) − R	.ZhanandChen(2021) − M	.Zolletet al.(2021) − M
Operational attributes																											
Adaptability	15	x	x	x	x					x	x	x	x	x	x		x		x		x		x		x		
Flexibility	13	x	x		x	x			x			x		x				x	x	x	x	x			x		
Agility	4															x			x						x		
Responsiveness	4							x													x					x	x
Velocity	3					x								x		x									x		
Autonomy	2			x															x								
Dynamic capabilities	1																	x									
Plasticity	1																					x					
Prudence	1											x															
Relational attributes																											
Connectivity	5		x									x	x		x				x								x
Cooperativeness	3	x	x			x																					
Cohesion	2											x									x						
Alignment	1																								x		
Social capital	1													x													
Visibility	5					x										x		x	x						x		
Structural attributes																											
Diversity	12			x	x		x					x	x	x	x		x		x		x		x	x			
Redundancy	7	x					x		x			x		x					x							x	
Agency	2				x																						x
Modularity	2										x	x															

Note: M = Mixed resilience outcomes; NR=Not resilient; R=Resilient.

Table 5
Resilience capacities and actions identified from the reviewed studies.

Resiliencecapacities	Numberofstudies	.Aliet al.(2022a) – M*	.Aliet al., 2022 – R	.Bachmanet al.(2021) – R	.Bassettet al.(2022) – M	.Bøet al.(2023) – R	.Carlsonet al.(2021) – R	.Coopmanset al.(2021) – M	.Saet al.(2020) – M	.Favaet al.(2022) – R	.Fergusonet al.(2022) – M	.Goti – Araluceaet al.(2021) – NR	.Joneset al.(2022) – M	.Joneset al.(2021) – M	.Loveet al.(2021) – M	.Manganoet al.(2022) – NR	.Manlosaet al.(2021) – R	.Mishraet al.(2021) – M	.PerrinandMartin(2021) – R	.OrengoSerraandSanchez – Jauregui(2022) – R	.Smithet al.(2016) – M	.Snowet al.(2021) – R	.Stollet al.(2021) – R	.Tittonellet al.(2021) – R	.Umaret al.(2021) – R	.ZhanandChen(2021) – M	.Zolletet al.(2021) – M
Pre-shock Capacities																											
Anticipatory capacity	1							x																			
Prudence	1											x															
Readiness capability	2	x	x																								
During shock Capacities																											
Coping capacity	3							x								x								x			
Responsive capacity	3	x	x					x																			
Post shock Capacities																											
Learning	3								x			x													x		
Recovering capabilities	2	x	x																								
Transformability	7	x	x		x									x						x		x	x				
Resilience Actions																											
During shock Actions																											
Adaptation	10			x				x	x	x	x		x	x	x		x		x								
Cooperation	4	x										x	x						x								
Coping - short-term	2														x		x										
Information sharing	1																		x								
Re-organising	2			x				x																			
Responses	4							x	x																	x	x
Post shock Actions																											
Adapting - long-term	1														x												

Note: M = Mixed resilience outcomes; NR=Not resilient; R=Resilient.

- Capacities that span the shock cycle—anticipation, coping, and transformability—are critical to preventing breakdowns and fostering system improvements.

However, lack of institutional support, insufficient collaboration, or an overemphasis on efficiency (at the expense of redundancy) repeatedly emerged as obstacles to sustaining resilience (Coopmans et al., 2021; Goti-Aralucea et al., 2021). Many studies also suggest the lack of transformative follow-through. While rapid coping measures can avert severe damage, deeper shifts or "bouncing forward" are not always achieved. For instance, certain short supply chains excelled in crisis adaptation (Smith et al., 2016), but whether they retain these adaptive practices or scale up improvements remains uncertain (Jones et al., 2021). In contexts lacking robust government support or social capital, short-term actions often fail to evolve into sustained resilience strategies (Ali et al., 2022a).

Taken together, the 26 studies provide nuanced evidence of how FSS worldwide cope with sudden disruptions. While many demonstrate considerable adaptability, reflecting the complexity and dynamism of food systems, and important gaps remain in terms of preparedness, sustained transformation, and universal equity in resource distribution. These findings inform the development of the integrated resilience framework (Fig. 2) which offers a structured way to analyze how systems respond, recover, or stagnate when facing abrupt shocks.

6. Discussion

6.1. Integrating findings through the proposed framework

The reviewed studies collectively show that FSS resilience depends on more than a singular trait or a one-time intervention. We align with Meuwissen et al. (2019, 2021) by designating redundancy, adaptability, diversity, flexibility as attributes inherent in a system irrespective of shocks. Anticipatory (pre-shock), responsive (during-shock), and transformative (post-shock) capacities harness these attributes. Our proposed integrated resilience framework presents attributes, capacities, actions, and outcomes as four interlinked pillars, each playing a distinct and essential role in shaping resilience to sudden shocks (Fig. 1). Crucially, unlike many prior models, our framework separates "attributes" from "capacities". Attributes, further categorized here into operational, relational, and structural, are enduring features of an FSS that cut across all phases of a shock; in contrast, capacities (pre-shock readiness, during-shock responsiveness, and post-shock transformation) and the actions they generate are temporal or phase-specific.

6.1.1. Attributes: universal foundations for resilience

Resilience attributes form the bedrock of an FSS. They exist irrespective of whether or not a shock is imminent, providing the overarching qualities that can be leveraged in capacities (i.e., "what the system can do") and manifested in actions (i.e., "what the system actually does in each shock phase"). In our framework, we distinguish three sets of attributes presented in Table 4.

- Operational Attributes - These encompass agility, flexibility, and velocity which are traits that define how quickly and efficiently a system can adjust its operational flows (e.g., production scheduling, logistics routing, market alignment). For instance, Bachman et al. (2021) describes how Maryland fruit and vegetable farmers were able to quickly set up contactless pickup points when COVID-19 disrupted traditional marketing channels. This agility did not materialize from thin air but rather stemmed from pre-existing operational strengths: small vehicle fleets, direct sales experience, or farm-scale autonomy.
- Relational Attributes – Connectivity, cohesion, visibility, alignment of goals, and social capital define how well FSS actors collaborate and share information. Stoll et al. (2021) highlights how alternative seafood networks in North America leveraged long-standing relationships to pivot rapidly to local direct-sales models. This relational cohesion was not a capacity triggered only in crisis; rather, it was an embedded attribute that spanned pre-crisis, crisis, and recovery phases, allowing for coordinated risk-sharing at each step.
- Structural Attributes - Diversity (multiple crops, suppliers, or distribution channels), redundancy (backup resources, extra inventory), embeddedness (strong local roots), and modularity (semi-independent chain segments) offer FSS the built-in architecture to sustain shocks. Smith et al. (2016), examining flood-affected Queensland, shows that short supply chains with inherently diverse distribution routes fared better than large, centralized chains. These structural designs exist continuously, shaping how a system can respond during disruptions.

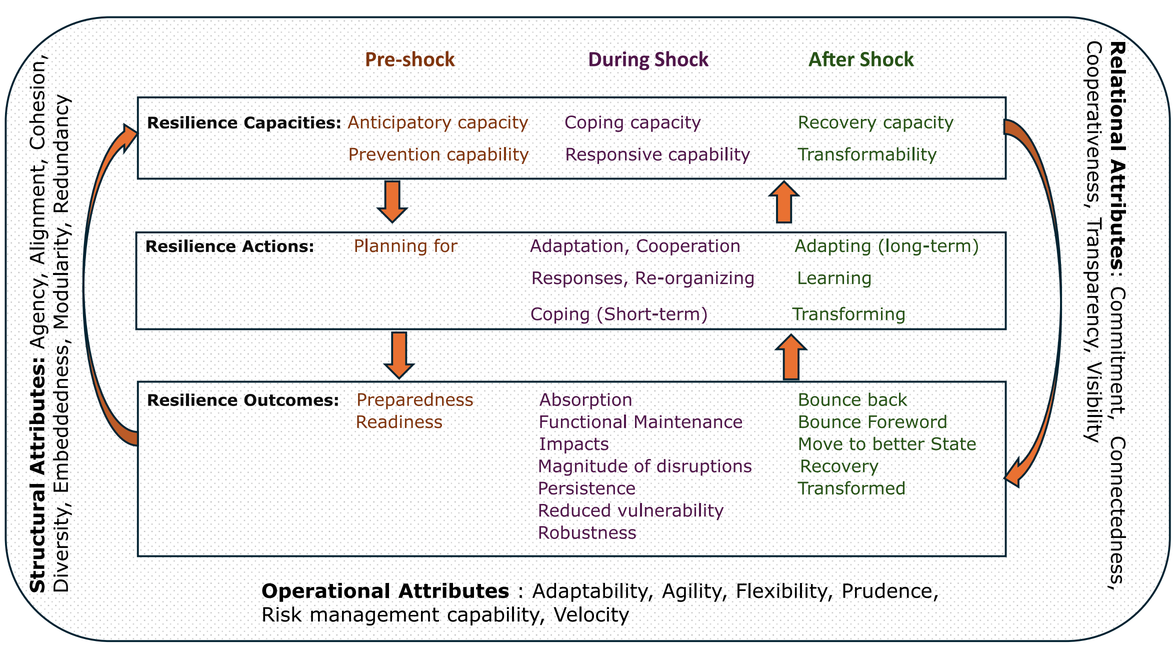

Fig. 2. PRISMA flow diagram of identification of studies (adapted from Page et al., 2021).

Such attributes are omnipresent: they do not switch on or off with a shock. Instead, they serve as universal qualities or "default toolkits" that can be drawn upon and activated through capacities—which, in turn, manifest as actions aligned with each shock phase.

6.1.2. Capacities: phase-specific abilities to mobilize attributes

Capacities in our framework are inherently temporal. They represent how the system leverages its attributes (operational, relational, or structural) to anticipate, cope with, and recover from or transform after a shock (Table 5).

- Pre-Shock (Anticipatory) Capacities - Systems with robust anticipatory capacities typically engage in scenario planning, stockpiling, or building emergency funds. For example, Zhan and Chen (2021) describe China's proactive investments in agriculture and communication technology, allowing early detection of pandemic-related supply chain bottlenecks. These anticipatory measures rely on pre-existing operational efficiency (smooth data collection) and strong relational links to policymakers. In other words, the attributes of trust and institutional collaboration feed into the capacity to plan for disruptions.
- During-Shock (Coping and Responsive) Capacities - Once a crisis unfolds, responsive capacities govern how swiftly and effectively a system can adapt. This might involve rerouting logistics (Mishra et al., 2021), launching digital marketplaces (Perrin and Martin, 2021), or rapidly forming new alliances (Jones et al., 2021). Here, operational agility is crucial, but so is relational trust (collaboration across multiple segments) and structural flexibility (redundant suppliers, smaller distribution footprints). Systems lacking these foundational attributes struggle to mount an effective real-time response. For instance, Mangano et al. (2022) highlights aquaculture supply chains failing to coordinate alternate transport routes, indicating a shortfall in both relational and structural underpinnings.
- Post-Shock (Transformative) Capacities - Arguably the most challenging dimension, post-shock capacities revolve around learning, reorganizing, and potentially transforming the FSS to become more robust. Bø et al. (2023) documents Norwegian agrifood enterprises that moved beyond emergency home-delivery solutions, embedding these "crisis fixes" into their long-term business model. Such an evolution to "bounce forward" hinges on the system's ability to critically evaluate what worked, invest in new resources, and institutionalize novel practices. A strong structural attribute may allow incremental reconfiguration, while relational trust fosters acceptance of deeper changes.

Importantly, the difference between an attribute and a capacity is that attributes are universal system features (they persist at all times), whereas capacities are time-bound abilities to deploy those attributes in specific, actionable ways.

6.1.3. Actions: translating capacities into practice

Resilience actions are the concrete responses or actions stakeholders take before, during, and after a shock (Table 5). They translate capacities into on-the-ground interventions. This can be broken down as follows.

- Pre-Shock Actions - Setting up contingency funds, procuring additional stock, establishing direct communication protocols among supply chain members, or scheduling training for potential crises. Ali et al. (2022a) contrasts how Australian SMEs, buoyed by government support, undertook robust pre-shock measures whereas their counterparts in Pakistan and Tanzania did not.
- During-Shock Actions – Adaptations like switching to online sales, engaging in collective transport solutions (Stoll et al., 2021), reorganizing supply chain governance structures or scaling down certain product lines while boosting others (Love et al., 2021). These actions do not emerge spontaneously but build on existing capacities which themselves arise from underlying attributes.
- Post-Shock Actions - Post-shock actions prioritize recovery, learning, and building long-term resilience by shifting from short-term coping to planned adaptations (Love et al., 2021), potentially transforming operational models (Ferguson et al., 2022). Learning and transforming are central for enhanced future resilience (Tittonell et al., 2021). Key post-shock activities include analyzing during-shock responses, synthesizing lessons learnt, developing future adaptation strategies, fostering cooperation and information sharing, and promoting open innovation (Fava et al., 2022; Tittonell et al., 2021).

In practice, actions are the "visible" dimension of resilience. However, whether these actions succeed depends on the interplay of attributes (the system's baseline conditions) and capacities (the system's phase-relevant capabilities).

6.1.4. Outcomes

Resilience outcomes reflect how well FSS maintain or improve essential functions following shocks. Some systems merely "bounce back", returning to normalcy after minimal adjustments. Others leverage disruptions to "bounce forward" and achieve transformative change.

- Bouncing Back - Sá et al. (2020) describes Brazilian processors returning to pre-drought levels by multi-sourcing sugarcane and oranges, whereas farmers remained vulnerable, failing to invest in new irrigation strategies. This partial outcome indicates that some sub-sectors rebound quickly, but others stay locked in a risk-prone state.
- Bouncing Forward - Stoll et al. (2021) shows alternative seafood networks sustaining new consumer relationships formed during COVID-19, leading to ongoing diversification and broader income streams. In these cases, post-shock actions lead to a fundamental reconfiguration of supply channels, upgrading system resilience for future crises.

In systems lacking the synergy among attributes, capacities, and actions, the outcome is typically suboptimal: limited or no recovery, ongoing fragmentation, or repeated vulnerability. Goti-Aralucea et al. (2021) reports how German brown shrimp fishers, with no scenario planning and little redundancy, struggled to exit a low-resilience cycle. Since their structural and relational attributes were weak, no robust capacity developed, and minimal actions could be taken during or after the shock.

6.1.5. Contribution to resilience studies

A key innovation in our framework is its separation of "attributes" from "capacities". Many existing approaches merge them under broad "system capabilities". However, we show that attributes are persistent features like agility and diversity, that do not disappear or appear solely when a shock is imminent. Capacities, on the other hand, describe how (and when) the system mobilizes these attributes in a phased manner (e.g. anticipation before the crisis, coping during, and transforming afterward). By clearly distinguishing these dimensions, practitioners can better diagnose which foundational attributes need strengthening (e.g., building social capital or diversifying local markets) versus which phase-specific capacities are underdeveloped (e.g., insufficient scenario planning or lack of knowledge-sharing protocols).

This lens also clarifies why some FSS appear more consistently resilient: they possess robust, well-balanced attributes that can be summoned for each shock phase. In contrast, systems may have high operational agility but fail to coordinate across actors if relational attributes (collaboration and visibility) are weak. Or they may have strong synergy in specific phases (like a well-organized response mid-crisis) yet falter afterward if post-shock transformation is never activated.

By mapping real-world examples onto the four pillars, researchers and policymakers can pinpoint where resilience falters. For instance.

- Mixed-resilience studies (e.g., Jones et al., 2021; Smith et al., 2016) often reveal partial operational strengths but weak structural or relational attributes, causing uneven responses within the same system.
- Consistently resilient cases (e.g., Ali et al., 2022; Snow et al., 2021) highlight how proactive investments in attributes such as robust local networks and digital infrastructure activate strong capacities, enabling effective pre-shock, during-shock, and post-shock actions.
- Low-resilience examples (e.g., Mangano et al., 2022; Goti-Aralucea et al., 2021) show attributes insufficient in nearly every domain, resulting in minimal or even counterproductive real-time measures.

Overall, the integrated resilience framework answers the call by Ujjwal et al. (2024) for "a comprehensive framework to assess and realize food systems resilience at multiple levels" (p. 8). It offers a structured yet flexible blueprint for understanding FSS responses to sudden shocks. By delineating attributes (always present) from capacities (activated at each stage), stakeholders can better strategize interventions, whether that entails building structural redundancy, fostering relational trust, or bolstering operational agility. Importantly, capacities translate into actions (planning, improvisation, consolidation), and the outcomes observed ranging from minimal recovery to thorough transformation, reflect the depth of this alignment.

This clarity is especially critical in an era where global pandemics, geopolitical conflicts, and extreme climate events converge to test FSS resilience. Systems that continuously invest in robust attributes, develop phase-specific capacities, and commit to learning from disruptions are more likely to thrive, not just bouncing back to prior states, but truly bouncing forward to stronger, more adaptive configurations over time.

7. Conclusion and implications

Our integrated framework shows FSS resilience depends on a synergy of attributes, capacities, and phased actions. In practice, crises such as floods, pandemics, or geopolitical conflicts can reveal weaknesses in system readiness, collaboration, or redundancy. Addressing these gaps requires multi-stakeholder engagement, consistent policy support, and learning from crises to stimulate meaningful transformations.

Future research should explore how short-term "coping" matures into deeper structural shifts under varying regulatory, socio-economic, and climatic conditions. As FSS become more interlinked, resilience strategies must balance local embeddedness with global risk management. By refining and expanding the framework's application, researchers and practitioners can build more adaptive, equitable, and transformative food systems.

The review's focus on resilience attributes, capacities, and acute shocks produced a relatively small set of studies, limiting the scope of generalisations. However, we believe this reflects an actual gap in the literature rather than inadequate search or screening strategies, as our methods were rigorous and reliable. This view is supported by Ujjwal et al. (2024), who also observed a shortage of primary studies on FSS resilience prior to 2015.

Resilience studies often tackle slower-moving stressors (e.g. climate change) without fully addressing how they might precipitate sudden shocks. Beyond COVID-19, few works examine short-term disruptions, typically focusing on agility, diversity, or adaptability. Future research could investigate how acute shocks trigger transformability, producing fundamental, long-term systemic change.

To improve resilience assessment and interventions, clarity is needed on whether resilience is viewed as an outcome or an emergent quality of complex systems. We hope that our integrated framework will help strengthen these discussions, guiding more robust, context-sensitive resilience strategies and fostering transformative change in FSS. Recognising power relations, vested interests, and local agency is also essential for determining whether shocks can prompt truly transformative change. Applying the dynamic framework in more case studies may standardise resilience evaluations, guide context-specific strategies, and encourage multi-scalar approaches hence strengthening socio-ecological resilience across the entire FSS.

CRediT authorship contribution statement

Iona Y. Huang: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Oscar A. Forero:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Conceptualization. **Erika V. Wagner-Medina:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Hernando Florez Diaz:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Ourania Tremma:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Xavier Fargetton:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **James Lowenberg-DeBoer:** Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Conceptualization.

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No data was used for the research described in the article.

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