Asia Pacific Science Press

Asia Pacific Economic and Management Review
ISSN(O):3005-9275
ISSN(P):3005-9267
Vol. 3 No.4 (2026)

Technological, Organizational, and Environmental Drivers of Supply Chain Resilience in a Regional Brown Sugar Industry: Evidence from Qiaojia, China

Xin Yang, Xue Zhang*

College of Economics and Management, Southwest Forestry University, Kunming, Yunnan, 650224, China

Corresponding author: Xue Zhang, zhangx@swfu.edu.cn

Abstract: Regional specialty agri-food supply chains face growing risks from production shocks, logistics disruptions, market volatility, and institutional uncertainty, yet evidence on resilience in traditional smallholder-based systems remains limited. Drawing on the technology-organization-environment framework, this study investigates resilience drivers in the Qiaojia brown sugar industry in Yunnan, China. A questionnaire survey of sugarcane growers, processors, distributors, retailers, government-related stakeholders, and other stakeholders yielded 230 valid responses from 248 returns, with an effective response rate of 92.74%. Structural equation modeling examined the effects of digital technology, information sharing, collaboration capability, risk control capability, response capability, and policy and institutional support. The results show acceptable internal consistency, convergent validity, and model fit, with Cronbach's alpha values ranging from 0.696 to 0.803 and the main fit indices meeting conventional thresholds. All six hypothesized paths were positive and statistically significant. Policy and institutional support had the strongest standardized effect on supply chain resilience (β = 0.303), followed by response capability (β = 0.287), risk control capability (β = 0.266), collaboration capability (β = 0.262), digital technology (β = 0.230), and information sharing (β = 0.187). The findings suggest that resilience depends on the combined development of digital tools, organizational capabilities, and stable institutional support.

Keywords: Supply Chain Resilience; Agri-food Supply Chain; Brown Sugar Industry; Technology-Organization-Environment Framework; Digital Technology; Structural Equation Modeling; Qiaojia; China

Published: Jul 31, 2026

DOI: https://doi.org/10.62177/apemr.v3i4.1549

1. Introduction

Supply chain resilience has become a central concern in operations and agri-food management because disruptions rarely remain confined to a single firm. They tend to cascade through procurement, production, processing, logistics, distribution, and demand. Early resilience research emphasized the need to reduce vulnerability and build supply chain designs capable of withstanding disruption[1]. Later studies refined the concept as a supply chain's adaptive capability to prepare for unexpected events, respond to them, and recover while maintaining operational continuity[2]. This interpretation is particularly relevant to food systems, where resilience is closely connected not only to business performance but also to food availability, rural livelihoods, and regional industrial stability[3].

Agri-food supply chains face risks that differ from many manufacturing supply chains. They are exposed to seasonal production cycles, weather variability, perishable or quality-sensitive raw materials, price fluctuations, logistics constraints, and strict quality governance. Stone and Rahimifard argued that agri-food supply chain resilience requires a systemic view that integrates vulnerability, capability, and adaptive response across multiple actors[4]. Tendall and colleagues also defined food system resilience as the capacity of a food system and its units at multiple levels to provide sufficient, appropriate, and accessible food in the face of disturbances[5]. These theoretical developments suggest that resilience in agri-food contexts should be assessed at the network level rather than reduced to isolated firm-level efficiency.

Regional specialty agri-food industries provide a useful setting for examining this issue. They often rely on local ecological conditions, traditional techniques, family-based farms, small processing workshops, public brands, and government support. Such industries can generate distinctive rural value, but they may also suffer from fragmented production, weak digital integration, unstable raw material supply, uneven quality standards, and limited risk absorption capacity. Environmental shocks and market disruptions can therefore produce effects that are magnified by local dependence on a narrow set of products and channels[6].

The Qiaojia brown sugar industry in Yunnan Province represents this type of regional specialty agri-food supply chain. Qiaojia small-bowl brown sugar is associated with traditional sugarcane processing, a local geographical identity, and a public brand supported by intangible cultural heritage and geographical indication governance. Recent public reports indicate that the industry has expanded from more than 10,000 mu of sugarcane planting and more than 5,000 tonnes of brown sugar output in 2024 to about 12,000 mu and 7,200 tonnes of output in 2025; by 2026, planting area had reportedly increased to about 14,000 mu[7][8]. This expansion has strengthened the economic relevance of the industry, but it has not removed structural weaknesses such as dispersed growers, uneven standardization, dependence on traditional channels, emerging but incomplete digitalization, and continuing needs for quality control and brand protection.

The technology-organization-environment framework provides a suitable theoretical lens for this study because it explains how technological conditions, organizational resources, and external environmental factors jointly shape adoption and performance outcomes [9][10]. In this paper, the framework is extended from technology adoption to resilience formation. The technological context is represented by digital technology and information sharing. The organizational context is represented by collaboration capability, risk control capability, and response capability. The environmental context is represented by policy and institutional support. This structure fits the Qiaojia brown sugar supply chain because resilience is unlikely to be produced by a single intervention. Digital tools may improve visibility, but their value depends on reliable information exchange and coordinated action. Organizational capabilities may improve continuity, but their effectiveness depends on institutional support, quality standards, brand governance, and local infrastructure.

This study makes three contributions. First, it extends supply chain resilience research to a regional specialty agri-food industry that combines traditional production, smallholder participation, and gradual digitalization. Second, it integrates technological, organizational, and institutional drivers into a single structural equation model, allowing their relative strengths to be compared empirically. Third, it shows that policy and institutional support, response capability, and risk control capability are especially influential in a traditional agri-food industry where digitalization is developing but has not yet become fully integrated across the entire supply chain.

2. Literature Review

2.1 Supply Chain Resilience in Agri-food Systems

Supply chain resilience has developed from a concern with vulnerability reduction into a broader explanation of how supply networks prepare for, respond to, and recover from disruption. Christopher and Peck described resilience as a design and management problem that requires visibility, collaboration, flexibility, and a deliberate reduction of structural vulnerability[1]. Ponomarov and Holcomb later conceptualized supply chain resilience as an adaptive capability through which firms and networks prepare for unexpected events, respond to disruption, and recover to a desired operational state[2]. Subsequent reviews emphasized that resilience should not be reduced to recovery speed alone, because resilient supply chains also depend on anticipation, risk awareness, resource reconfiguration, and learning after disruption[3]. In agri-food settings, this network-based interpretation is especially important because production, processing, distribution, and consumption are connected through biological cycles, quality constraints, and regional livelihood systems.

The agri-food literature further suggests that resilience is shaped by both vulnerability and capability. Stone and Rahimifard argued that agri-food supply chains require a systemic resilience framework because disturbances may originate in production, logistics, market demand, food safety governance, or consumer access[4]. Tendall and colleagues similarly defined food system resilience as the capacity of food systems and their units to provide sufficient, appropriate, and accessible food despite disturbances[5]. More recent research on food supply chain exposure to environmental shocks shows that climatic and ecological disruptions can affect production volumes, transportation reliability, commodity flows, and regional food access[6]. These findings indicate that an agri-food resilience model should examine both operational capabilities and external institutional conditions, particularly in regional specialty industries where the supply base and brand identity are geographically concentrated.

2.2 Technological Drivers: Digitalization and Information Sharing

The technological stream of the literature identifies digital tools, information visibility, and traceability systems as important enablers of supply chain resilience. The technology, organization, and environment framework originally explained technology adoption as a function of technological characteristics, organizational conditions, and the external environment[9]. Later empirical research extended this logic by showing that innovation assimilation varies across firms and institutional settings, implying that digital technologies generate value only when they are absorbed into organizational routines and supported by environmental conditions[10]. For agricultural and food supply chains, blockchain-enabled traceability and related digital systems can improve provenance verification, data reliability, and auditability, but their benefits depend on clear business requirements, governance structures, and participation across supply chain actors[11][12].

Information sharing is closely connected to digitalization, but it is not identical to technology adoption. A supply chain may possess digital tools without achieving timely, accurate, and actionable information exchange. Li and Lin found that information sharing and information quality are associated with trust, coordination, and supply chain performance, suggesting that information becomes valuable only when it is reliable and usable for joint decision-making[13]. This distinction is relevant to the Qiaojia brown sugar supply chain because e-commerce platforms, inventory software, and production equipment may improve operational visibility, while resilience still depends on whether growers, processors, distributors, retailers, and public agencies can exchange price signals, inventory status, demand changes, quality information, and risk warnings in a coordinated manner.

2.3 Organizational Capabilities: Collaboration, Risk Control, and Response

Organizational capability research indicates that resilience is built through relationships and routines rather than through isolated resources. Cao and Zhang showed that supply chain collaboration creates collaborative advantage by supporting joint planning, resource sharing, decision synchronization, and incentive alignment[14]. This perspective is consistent with multi-actor agri-food systems, where a disruption in upstream planting or processing can rapidly affect downstream delivery, product quality, and market reputation. In a regional specialty product chain, collaboration also has a brand governance function because inconsistent quality, weak coordination, or fragmented market behavior can damage collective reputation.

Risk control and response capability represent two additional organizational foundations of resilience. Pettit, Croxton, and Fiksel developed a resilience assessment view in which vulnerability factors must be balanced with capabilities such as flexibility, visibility, capacity, recovery, and risk awareness[15]. Tang also argued that robust supply chain strategies should enable firms to manage ordinary variability while remaining prepared for more severe disruptions[16]. Applied to the Qiaojia brown sugar industry, these findings suggest that risk control should include monitoring of sugarcane supply, raw material price changes, processing quality, logistics bottlenecks, and brand misuse, whereas response capability should refer to the speed with which actors adjust procurement, production schedules, inventory allocation, and market channels after disruption.

2.4 Research Gap and Theoretical Positioning

The reviewed literature provides strong theoretical foundations, but three gaps remain. First, most supply chain resilience studies focus on manufacturing, large firms, global logistics, or broad food systems, while smallholder-based regional specialty agri-food industries remain less frequently examined. Second, digitalization studies often emphasize traceability and information systems, but they do not always compare technological factors with organizational and institutional drivers in the same empirical model. Third, research on agri-food resilience recognizes vulnerability and adaptive capability, but fewer studies quantify the relative effects of digital technology, information sharing, collaboration, risk control, response capability, and policy support in a geographically bounded traditional industry. This study addresses these gaps by applying the technology, organization, and environment framework to the Qiaojia brown sugar supply chain and by testing the relative strength of six resilience drivers through structural equation modeling.

Table 1 shows how the core literature streams are integrated into the empirical model. The table also clarifies why this study treats supply chain resilience as a multi-dimensional outcome shaped by technological enablers, organizational capabilities, and institutional conditions rather than as a purely technological or firm-level construct.

Table 1. Literature Review and Theoretical Integration

Research stream	Core theoretical finding	Gap or limitation in prior work	Operational role in this study
Supply chain resilience	Resilience involves preparation, response, recovery, adaptation, and learning rather than simple post-disruption restoration [1][2][3].	General resilience studies often emphasize firm-level or manufacturing contexts.	Defines supply chain resilience as the dependent construct measured through risk identification, preparedness, and adaptive adjustment.
Agri-food system resilience	Agri-food resilience requires a systemic view because food chains are exposed to biological cycles, environmental shocks, quality risks, and access constraints [4][5][6].	Regional specialty agri-food industries with smallholder participation remain underexamined.	Justifies the focus on the Qiaojia brown sugar supply chain as a geographically bounded agri-food network.
Technology and digitalization	Digital tools and traceability systems can improve visibility, provenance, auditability, and data reliability when supported by governance and participation [9][10][11][12].	Digital adoption alone does not explain whether supply chain actors convert data into coordinated resilience actions.	Supports digital technology and information sharing as technological drivers.
Information sharing and collaboration	Information quality, interorganizational trust, and collaborative advantage improve coordination and performance across supply chain partners [13][14].	Prior studies seldom compare information sharing with other organizational capabilities in traditional agri-food chains.	Supports information sharing and collaboration capability as predictors of resilience.
Risk control and response capability	Resilience requires capability portfolios, risk awareness, flexibility, and robust disruption mitigation strategies [15][16].	Empirical evidence is limited on how risk control and rapid response operate in local specialty product chains.	Supports risk control capability and response capability as organizational drivers.
Institutional support	The technology, organization, and environment framework indicates that environmental conditions shape technology use and performance outcomes [9][10].	Institutional support is rarely compared directly with technological and organizational factors in regional agri-food resilience models.	Supports policy and institutional support as the environmental driver.

The literature review therefore leads to a model in which resilience is expected to increase when supply chain actors possess stronger digital technology, higher-quality information sharing, closer collaboration, more systematic risk control, faster response capability, and stronger policy and institutional support. The following section explains the research context, questionnaire design, sampling procedure, and statistical methods used to test this model.

3. Materials and Methods

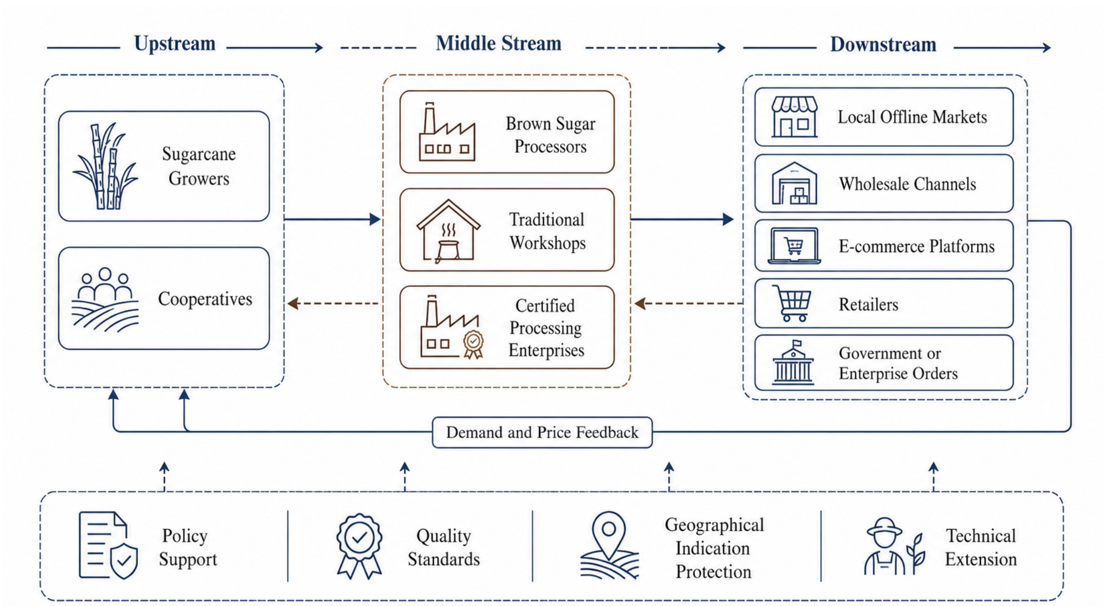
3.1 Research Context and Design

This study used a quantitative, cross-sectional survey design to examine how technological, organizational, and environmental factors influence the resilience of the Qiaojia brown sugar supply chain. The focal supply chain includes upstream sugarcane growers and cooperatives, middle-stream brown sugar processing enterprises and workshops, and downstream distributors, retailers, e-commerce sellers, and order-based buyers. Local government agencies, industry service centers, and regulatory bodies also shape the supply chain through infrastructure support, technical services, quality standards, market supervision, and geographical indication protection.

The research context was selected because it combines practical relevance with theoretical value. The industry has expanded in scale, but it still depends on a multi-actor production and distribution system in which no single participant can independently secure raw materials, stabilize quality, maintain brand identity, and respond to market or logistics disruptions. Public reports describe a supply chain that includes licensed enterprises, small workshops, cooperatives, growers, and sales channels that span offline markets, wholesale, e-commerce, and institutional orders [7][8]. This structure makes resilience a network-level outcome rather than a simple expression of one firm's operational capacity.

The structure of the Qiaojia brown sugar supply chain is illustrated in Figure 1. The figure shows that resilience in this industry is generated not by a single core firm, but by the coordination of upstream growers, processing actors, downstream channels, and institutional support systems.

Figure 1. Structure of the Qiaojia brown sugar supply chain



3.2 Conceptual Framework and Hypotheses

The conceptual framework adapts the technology, organization, and environment perspective to supply chain resilience. The technological dimension captures whether digital tools and information exchange can improve visibility and reduce decision delays. Digital technology refers to the use of e-commerce platforms, production equipment, inventory software, and other tools in brown sugar related operations. Research on blockchain and traceability has shown that digital technologies can improve provenance, auditability, and data reliability in agricultural and food supply chains[11][12]. Information sharing refers to the timely and reliable exchange of raw material prices, inventory levels, demand changes, and risk signals. Previous empirical work has shown that information sharing and information quality are closely associated with interorganizational trust and supply chain performance[13].

The organizational dimension includes collaboration capability, risk control capability, and response capability. Collaboration capability refers to stable relationships and coordinated action across planting, processing, logistics, and sales. Prior research indicates that supply chain collaboration can create collaborative advantage and improve performance by enabling joint planning, decision synchronization, and resource complementarity[14]. Risk control capability refers to the identification, monitoring, prevention, and mitigation of risks related to raw materials, product quality, market volatility, logistics interruptions, and compliance. Resilience assessment research emphasizes that continuity planning, visibility, flexibility, and risk awareness are core conditions for resilience improvement[15]. Response capability refers to the speed and consistency with which actors adjust production, inventory, logistics, and business strategies after a disruption. Robust disruption management research similarly highlights flexible strategies and rapid operational adjustment as necessary for mitigating supply chain interruptions[16].

The environmental dimension is represented by policy and institutional support. In a regional specialty industry, public institutions influence resilience through infrastructure, standards, quality regulation, technology extension, financial support, market promotion, and geographical indication protection. This factor was included because Qiaojia brown sugar depends on a public brand and a geographically bounded production identity that require collective governance rather than isolated firm-level management. Accordingly, six hypotheses were proposed: digital technology, information sharing, collaboration capability, risk control capability, response capability, and policy and institutional support were each expected to exert a positive effect on supply chain resilience. The conceptual structure is presented in Figure 2. The figure shows how technological, organizational, and environmental factors are expected to influence supply chain resilience through six hypothesized positive paths. The measurement design is then summarized in Table 2.

Figure 2. Conceptual framework of the study.

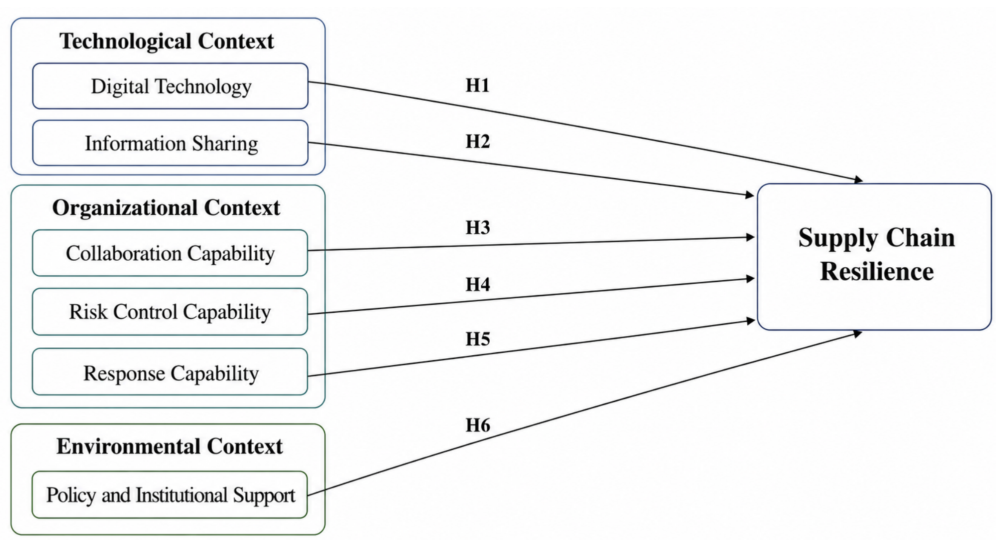


Table 2. Constructs and Measurement Design

Dimension	Construct	Items	Operational Meaning and Example Item	Hypothesis
Technology	Digital technology	4	Use of digital tools such as e-commerce platforms, production equipment, and inventory software. Example: The actor uses digital tools in Qiaojia brown sugar operations.	H1: Positive effect
Technology	Information sharing	4	Timely and reliable exchange of raw material prices, inventory, demand, and risk information. Example: The actor shares key information with upstream and downstream partners.	H2: Positive effect
Organization	Collaboration capability	4	Stable cooperation and coordinated action across planting, processing, logistics, and sales. Example: Supply chain actors coordinate efficiently in supply, production, and sales.	H3: Positive effect
Organization	Risk control capability	3	Ability to identify, monitor, and mitigate supply chain risks. Example: The actor can track changes in supply chain risk conditions.	H4: Positive effect
Organization	Response capability	3	Ability to adjust operations quickly when raw material shortages, demand shifts, or logistics disruptions occur. Example: The actor can respond rapidly to supply chain disturbances.	H5: Positive effect
Environment	Policy and institutional support	3	Support from agricultural policy, industrial development measures, quality standards, and market promotion. Example: Local policies provide support for raw material security, processing upgrades, and market development.	H6: Positive effect
Outcome	Supply chain resilience	3	Ability to identify risks, prepare countermeasures, and adjust production or business strategies after disruption. Example: The actor can adjust operations within a short time to adapt to supply chain changes.	Dependent variable

3.3 Questionnaire Development and Measurement

The questionnaire consisted of two parts. The first part collected demographic and supply chain role information, including gender, age, actor type, and main sales channel. The second part measured the seven latent constructs listed in Table 2. In total, 24 measurement items were retained. These included four items for digital technology, four for information sharing, four for collaboration capability, three for risk control capability, three for response capability, three for policy and institutional support, and three for supply chain resilience. All items were measured using a five-point Likert scale, where 1 indicated very low agreement and 5 indicated very high agreement.

The items were designed to reflect practical supply chain behaviors rather than abstract managerial attitudes. For example, the digital technology items asked whether respondents had used e-commerce platforms, production equipment, or inventory software in brown sugar related operations. The information sharing items asked whether raw material prices, inventory levels, and demand signals could be exchanged in a timely and reliable manner. The resilience items measured risk identification, preparedness, and the ability to adjust strategies within a short period. This wording was intended to make the questionnaire understandable to different respondent groups, including growers, enterprise managers, distributors, retailers, and government-related stakeholders.

3.4 Data Collection and Sample

Data were collected in Qiaojia County from February to March 2026. A purposive and stratified approach was used to reach the main actor groups in the brown sugar supply chain. Paper questionnaires containing QR codes were posted in Dongping Town, and the same questionnaire was distributed electronically through WeChat to increase coverage and response convenience. The survey was limited to participants who had knowledge of, or direct involvement in, the Qiaojia brown sugar supply chain. Participation was voluntary and anonymous, and the data were used only for academic analysis.

A total of 248 questionnaires were returned. After incomplete and invalid responses had been removed, 230 valid questionnaires remained, giving an effective response rate of 92.74%. The final sample included growers, processing enterprise employees and managers, distributors and retailers, government-related respondents, and other participants. This composition was appropriate because resilience is a multi-actor property and cannot be assessed only from the perspective of one firm or one production stage.

3.5 Statistical Analysis

The data were analyzed through reliability testing, validity testing, confirmatory factor analysis, and structural equation modeling. The measurement model was examined before the structural model, following the two-step logic recommended for structural equation modeling[17]. Internal consistency was assessed using Cronbach's alpha and corrected item-total correlation. Convergent validity was evaluated using standardized factor loadings, average variance extracted, and composite reliability, following established criteria for latent-variable measurement[18]. Because the data were collected through a self-reported questionnaire at one point in time, procedural remedies were used to reduce common method bias, including anonymity, neutral wording, and separation of demographic and construct items[19].

The structural model estimated the direct effects of six exogenous latent variables on supply chain resilience. Equation (1) represents the measurement model by linking observed indicators with latent variables and measurement errors. Equation (2) represents the structural relationship between supply chain resilience and its six antecedents. In the equations, SCR denotes supply chain resilience, DT denotes digital technology, IS denotes information sharing, CC denotes collaboration capability, RC denotes risk control capability, RP denotes response capability, PS denotes policy and institutional support, and ζ denotes the structural error term.

Equation (1). Measurement model for observed indicators

$$x = \Lambda_x \xi + \delta; \qquad y = \Lambda_y \eta + \varepsilon$$

Equation (2). Structural model for supply chain resilience

$$SCR = \beta_1 DT + \beta_2 IS + \beta_3 CC + \beta_4 RC + \beta_5 RP + \beta_6 PS + \zeta$$

4. Results

4.1 Sample Profile

The sample profile is reported in Table 3. The gender distribution was relatively balanced, with female respondents accounting for 53.48% and male respondents accounting for 46.52%. Respondents aged 30 to 40 formed the largest age group, accounting for 39.57% of the sample. The largest supply chain role group was distributors and retailers, followed by individual sugarcane growers and processing enterprise employees or managers. Together, these three groups accounted for 78.26% of the sample, indicating that the survey covered the main operational nodes of the supply chain. Traditional wholesale and local offline markets remained the dominant sales channels, while online e-commerce accounted for 18.26%, suggesting that digital channels had entered the industry but had not yet replaced conventional channels.

Table 3. Sample Profile of Respondents (N = 230)

Variable	Category	Frequency	Percentage (%)	Cumulative Percentage (%)
Gender	Male	107	46.52	46.52
Gender	Female	123	53.48	100.00
Age	Under 20	20	8.70	8.70
Age	20 to 30	56	24.35	33.05
Age	30 to 40	91	39.57	72.62
Age	40 to 50	43	18.70	91.32
Age	Over 50	20	8.70	100.00
Supply chain role	Individual sugarcane grower	61	26.52	26.52
Supply chain role	Government-related department	16	6.96	33.48
Supply chain role	Processing enterprise employee or manager	44	19.13	52.61
Supply chain role	Distributor or retailer	75	32.61	85.22
Supply chain role	Other	34	14.78	100.00
Main sales channel	Local offline market	66	28.70	28.70
Main sales channel	Traditional wholesale	76	33.04	61.74
Main sales channel	Online e-commerce platform	42	18.26	80.00
Main sales channel	Government or enterprise order	29	12.61	92.61
Main sales channel	Other	17	7.39	100.00

4.2 Reliability and Validity

Table 4 shows the reliability and convergent validity results. Cronbach's alpha values ranged from 0.696 to 0.803. Although the response capability scale was slightly below the conventional 0.700 threshold, the difference was marginal, and the construct was retained because it contained only three items and remained theoretically necessary. The total scale showed a high alpha value of 0.955, suggesting strong internal consistency for the overall instrument. Corrected item-total correlations ranged from 0.469 to 0.594, indicating that the retained items contributed meaningfully to their intended constructs.

The validity results also supported the measurement model. The Kaiser-Meyer-Olkin values ranged from 0.643 to 0.813, and Bartlett's tests were significant at $p < 0.001$ for all dimensions. These results indicated that the data were suitable for factor analysis. Average variance extracted values ranged from 0.619 to 0.662, and composite reliability values ranged from 0.832 to 0.872. Standardized factor loadings were all above 0.750 in the confirmatory factor analysis, and all non-reference items were significant at $p < 0.001$. The measurement model therefore provided a sufficient basis for testing the hypothesized structural relationships.

Table 4. Reliability and Convergent Validity Results

Construct	Items	Cronbach's Alpha	Minimum CITC	KMO	AVE	CR
Digital technology	4	0.793	0.527	0.759	0.619	0.866
Information sharing	4	0.794	0.580	0.756	0.619	0.867
Collaboration capability	4	0.803	0.594	0.813	0.630	0.872
Risk control capability	3	0.702	0.493	0.643	0.627	0.834
Response capability	3	0.696	0.469	0.664	0.622	0.832
Policy and institutional support	3	0.704	0.505	0.695	0.628	0.835
Supply chain resilience	3	0.744	0.544	0.698	0.662	0.854

Note. CITC = corrected item-total correlation; KMO = Kaiser-Meyer-Olkin measure; AVE = average variance extracted; CR = composite reliability.

4.3 Structural Model Fit

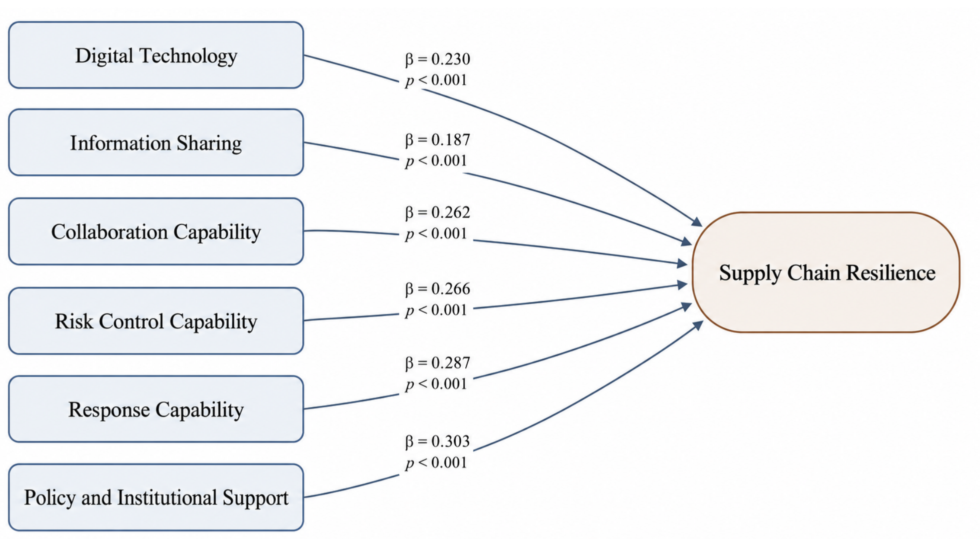
As shown in Table 5, the structural model demonstrated strong overall fit. The CMIN/DF value was 1.155, indicating an appropriate relationship between model complexity and covariance reproduction. The RMSEA value was 0.026, which was below the conventional 0.05 threshold for close fit. Incremental and absolute fit indices also supported the model, with NFI = 0.922, TLI = 0.986, GFI = 0.913, and CFI = 0.989. These statistics suggest that the specified model adequately represented the relationships among the latent variables.

Table 5. Structural Model Fit Indices

Index	Recommended Standard	Observed Value	Interpretation
CMIN/DF	1 to 3 indicates good fit	1.155	Good
RMSEA	< 0.05 indicates close fit; < 0.08 acceptable	0.026	Close fit
NFI	> 0.90 indicates good fit	0.922	Good
TLI	> 0.90 indicates good fit	0.986	Good
GFI	> 0.90 indicates good fit	0.913	Good
CFI	> 0.90 indicates good fit	0.989	Good

Figure 3 presents the structural equation model estimated from the survey data. The diagram should be inserted close to the path estimates because it visually links the validated measurement model with the six structural paths reported in Table 6.

Figure 3. Structural equation model for the Qiaojia brown sugar supply chain



4.4 Hypothesis Testing

Table 6 reports the structural path estimates and hypothesis testing results. All six paths were positive and statistically significant at $p < 0.001$. Policy and institutional support had the strongest standardized effect on supply chain resilience, followed by response capability, risk control capability, collaboration capability, digital technology, and information sharing. This ordering indicates that institutional and organizational capabilities were more influential than technological factors alone in explaining resilience in the Qiaojia brown sugar supply chain.

Table 6. Structural Path Estimates and Hypothesis Testing Results

Hypothesis	Path	Estimate	S.E.	C.R.	p	std.Estimate	Result
H1	Supply chain resilience - Digital technology	0.222	0.028	7.992	< 0.001	0.230	Supported
H2	Supply chain resilience - Information sharing	0.167	0.023	7.243	< 0.001	0.187	Supported
H3	Supply chain resilience - Collaboration capability	0.253	0.026	9.587	< 0.001	0.262	Supported
H4	Supply chain resilience - Risk control capability	0.255	0.030	8.618	< 0.001	0.266	Supported
H5	Supply chain resilience - Response capability	0.268	0.029	9.276	< 0.001	0.287	Supported
H6	Supply chain resilience - Policy and institutional support	0.281	0.030	9.460	< 0.001	0.303	Supported

5. Discussion

The empirical results show that supply chain resilience in the Qiaojia brown sugar industry is shaped by a combination of institutional support, organizational capabilities, and technological enablers. This finding is consistent with the broader resilience literature, which emphasizes that resilience is not a single operational attribute but a system-level capability involving preparedness, response, recovery, and adaptation[2][3]. In the present case, the strongest effect came from policy and institutional support. This result is theoretically plausible because regional specialty agri-food supply chains depend heavily on collective goods such as quality standards, geographical indication protection, technical extension, infrastructure, and public brand governance. Individual growers or processing firms can improve their own practices, but they cannot independently protect the public brand, coordinate all market actors, or establish region-wide rules for quality and traceability. Response capability and risk control capability also showed strong effects. This suggests that resilience in the Qiaojia brown sugar supply chain is closely related to operational readiness. The industry faces raw material seasonality, price movement, logistics constraints, and quality risks. When actors can respond rapidly to raw material shortages, demand shifts, or transportation delays, the supply chain becomes less vulnerable to disruption. Similarly, risk control capability helps actors identify emerging problems before they become systemic failures. These findings align with disruption mitigation research, which argues that robust strategies should help supply chains operate efficiently during normal fluctuation and remain resilient when major disruptions occur [16].

Collaboration capability had a significant positive effect, confirming that resilience in a multi-actor agri-food supply chain depends on coordinated relationships. The Qiaojia brown sugar industry includes growers, cooperatives, processors, distributors, retailers, online channels, and government-related institutions. If these actors behave independently, information asymmetry and fragmented decision-making can weaken the entire chain. Collaboration allows the chain to coordinate procurement, production scheduling, quality control, inventory management, and market feedback. This interpretation is consistent with evidence that supply chain collaboration can create collaborative advantage and improve performance through joint resource use and decision synchronization [14].

Digital technology and information sharing were also significant, but their standardized coefficients were smaller than those of institutional and organizational factors. This does not imply that digitalization is unimportant. Rather, it indicates that digital tools are still functioning mainly as enabling mechanisms in the Qiaojia context. E-commerce platforms, inventory software, and production equipment can improve efficiency and visibility, but they do not automatically produce resilience unless the data are trusted, shared, interpreted, and translated into coordinated action. This finding is consistent with traceability research showing that digital technologies require collaboration, governance, and organizational capability to produce practical value [11][12]. It also suggests that information sharing should be improved not only in frequency but also in reliability, standardization, timeliness, and actionability.

The practical implications of these findings are summarized in Table 7. The table translates the empirical path results into governance and management priorities. For policy makers, the central task is to build stable institutional conditions for quality standards, geographical indication protection, technology extension, and logistics infrastructure. For processing firms and cooperatives, the priority is to strengthen risk monitoring, joint planning, supplier coordination, and contingency routines. For growers and downstream channels, better information feedback and standardized communication can reduce delays and improve adaptive response. These actions should be developed as an integrated resilience system rather than as separate projects.

Table 7. Evidence-Based Implications for Resilience Enhancement

Empirical Priority	Evidence	Interpretation	Recommended Action
Policy and institutional support	Strongest standardized effect, β = 0.303	Public governance is central in a geographical indication industry with a public brand.	Strengthen quality standards, brand protection, technical extension, logistics infrastructure, and coordinated market promotion.
Response capability	Second strongest effect, β = 0.287	Rapid adjustment is critical when raw material shortages, logistics delays, or demand changes occur.	Develop emergency plans, flexible production scheduling, dynamic inventory allocation, and fast communication channels.
Risk control capability	β = 0.266	Early identification and mitigation prevent localized risks from becoming chain-wide disruptions.	Build risk monitoring routines for raw material supply, quality, logistics, prices, and regulatory compliance.
Collaboration capability	β = 0.262	Coordination converts fragmented resources into collective resilience.	Improve contract farming, cooperative coordination, joint planning, shared standards, and problem-solving routines.
Digital technology	β = 0.230	Digital tools improve visibility but require integration with management routines.	Use e-commerce, inventory systems, traceability tools, and production data platforms in a coordinated manner.
Information sharing	β = 0.187	Information exchange is significant but depends on quality, trust, and practical use.	Establish shared data standards, regular communication mechanisms, and market feedback loops across actors.

Several limitations should be acknowledged:

First, the empirical data were collected from one regional industry in one county, so the findings may not be directly generalizable to other agri-food sectors or regions. Second, the study used a cross-sectional questionnaire, which limits causal inference. Third, all variables were measured through self-reported perceptions, so common method bias cannot be fully excluded even though anonymity and neutral wording were used during data collection. Fourth, the study focused on direct effects and did not test mediating or moderating mechanisms, such as whether collaboration mediates the effect of digital technology on resilience or whether enterprise size changes the importance of policy support.

Future research could use longitudinal data, cross-regional samples, objective operational indicators, and multi-group structural models to examine whether the same pattern appears in other specialty agri-food supply chains.

6.Conclusion

This study examined the drivers of supply chain resilience in the Qiaojia brown sugar industry by applying the technology, organization, and environment framework and testing a structural equation model based on 230 valid survey responses. The results showed that digital technology, information sharing, collaboration capability, risk control capability, response capability, and policy and institutional support all had significant positive effects on supply chain resilience. Among these factors, policy and institutional support had the strongest effect, followed by response capability, risk control capability, collaboration capability, digital technology, and information sharing.

The findings indicate that resilience in a regional specialty agri-food supply chain cannot be built through digitalization alone. Digital tools and information exchange provide necessary enabling conditions, but their contribution becomes stronger when they are embedded in coordinated relationships, risk management routines, rapid response mechanisms, and supportive institutions. For Qiaojia brown sugar, this means that public brand protection, quality standardization, supply coordination, digital traceability, and market feedback should be developed as a connected resilience system. The study therefore contributes to supply chain resilience research by showing how technological, organizational, and environmental factors jointly shape resilience in a traditional agri-food industry undergoing modernization.

Funding

This research was funded by the Humanities and Social Sciences Foundation of Southwest Forestry University (Grant NO. WKYB25011)

Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

Reference

[1] Christopher, M., & Peck, H. (2004). Building the resilient supply chain. The International Journal of Logistics Management, 15(2), 1-14. https://doi.org/10.1108/09574090410700275

[2] Ponomarov, S. Y., & Holcomb, M. C. (2009). Understanding the concept of supply chain resilience. The International Journal of Logistics Management, 20(1), 124-143. https://doi.org/10.1108/09574090910954873

[3] Tukamuhabwa, B. R., Stevenson, M., Busby, J., & Zorzini, M. (2015). Supply chain resilience: Definition, review and theoretical foundations for further study. International Journal of Production Research, 53(18), 5592-5623. https://doi.org/10.1080/00207543.2015.1037934

[4] Stone, J., & Rahimifard, S. (2018). Resilience in agri-food supply chains: A critical analysis of the literature and synthesis of a novel framework. Supply Chain Management: An International Journal, 23(3), 207-238. https://doi.org/10.1108/SCM-06-2017-0201

[5] Tendall, D. M., Joerin, J., Kopainsky, B., Edwards, P., Shreck, A., Le, Q. B., Kruetli, P., Grant, M., & Six, J. (2015). Food system resilience: Defining the concept. Global Food Security, 6, 17-23. https://doi.org/10.1016/j.gfs.2015.08.001

[6] Davis, K. F., Downs, S., & Gephart, J. A. (2021). Towards food supply chain resilience to environmental shocks. Nature Food, 2(1), 54-65. https://doi.org/10.1038/s43016-020-00196-3

[7] Xinhua News Agency. (2025, January 23). Qiaojia brown sugar and the making of a sweet industry. Xinhua Net. https://www.yn.xinhua.org/20250123/a724f98b32df423889e71e4305f56ff1/c.html

[8] Zhang, S. (2026, April 22). Qiaojia's 14,000 mu of sugarcane paves a sweet road for rural revitalization. Zhaotong News. https://www.ztnews.net/article/show-485545.html

[9] Tornatzky, L. G., & Fleischer, M. (1990). The processes of technological innovation. Lexington Books.

[10] Zhu, K., Kraemer, K. L., & Xu, S. (2006). The process of innovation assimilation by firms in different countries: A technology diffusion perspective on e-business. Management Science, 52(10), 1557-1576. https://doi.org/10.1287/mnsc.1050.0487

[11] Hastig, G. M., & Sodhi, M. S. (2020). Blockchain for supply chain traceability: Business requirements and critical success factors. Production and Operations Management, 29(4), 935-954. https://doi.org/10.1111/poms.13147

[12] Kamble, S. S., Gunasekaran, A., & Sharma, R. (2020). Modeling the blockchain enabled traceability in agriculture supply chain. International Journal of Information Management, 52, Article 101967. https://doi.org/10.1016/

j.ijinfomgt.2019.05.023

[13] Li, S., & Lin, B. (2006). Accessing information sharing and information quality in supply chain management. Decision Support Systems, 42(3), 1641-1656. https://doi.org/10.1016/j.dss.2006.02.011

[14] Cao, M., & Zhang, Q. (2011). Supply chain collaboration: Impact on collaborative advantage and firm performance. Journal of Operations Management, 29(3), 163-180. https://doi.org/10.1016/j.jom.2010.12.008

[15] Pettit, T. J., Croxton, K. L., & Fiksel, J. (2013). Ensuring supply chain resilience: Development and implementation of an assessment tool. Journal of Business Logistics, 34(1), 46-76. https://doi.org/10.1111/jbl.12009

[16] Tang, C. S. (2006). Robust strategies for mitigating supply chain disruptions. International Journal of Logistics Research and Applications, 9(1), 33-45. https://doi.org/10.1080/13675560500405584

[17] Anderson, J. C., & Gerbing, D. W. (1988). Structural equation modeling in practice: A review and recommended two-step approach. Psychological Bulletin, 103(3), 411-423. https://doi.org/10.1037/0033-2909.103.3.411

[18] Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. Journal of Marketing Research, 18(1), 39-50. https://doi.org/10.1177/002224378101800104

[19] Podsakoff, P. M., MacKenzie, S. B., Lee, J.-Y., & Podsakoff, N. P. (2003). Common method biases in behavioral research: A critical review of the literature and recommended remedies. Journal of Applied Psychology, 88(5), 879-903. https://doi.org/10.1037/0021-9010.88.5.879