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Beyond technology in building resilience for agrifood systems: a case study of Guangdong's lychee sector

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KEYWORDS

Agrifood system, resilience, value-chain governance, high-value perishable product, IST framework

HIGHLIGHTS

- Guangdong's lychee sector exhibits significant volatility and vulnerability.
- Vulnerability is driven by systemic issues, rather than farmer hesitance.
- Policy must focus on enhancing value chain efficiency and farmer claimancy.
- A comprehensive approach is required to support new technology adoption.

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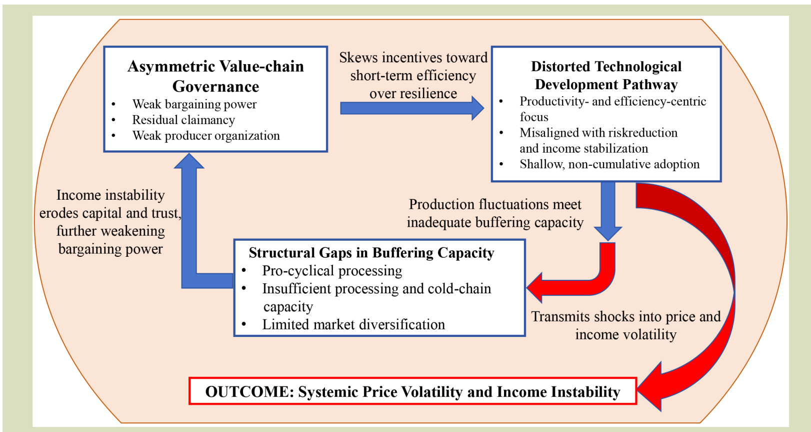
GRAPHICAL ABSTRACT



ABSTRACT

Building resilience in smallholder-dominated, high-value perishable product (HVPP) systems requires going beyond technology-first approaches, which raise outputs while leaving farm incomes volatile. Drawing on fieldwork in Guangdong's lychee sector (68 orchards and more than 20 processing and marketing entities from 2024 and 2025), this study demonstrates how pronounced supply swings and a compressed marketing window interact with fragmented producer organizations, asymmetric market access, and procyclical processing. These conditions form a self-reinforcing institutional–structural trap, where weak value chain governance and farmer residual claimancy distort technological upgrading toward short-term productivity, while inadequate buffering capacity prevents intertemporal adjustment. As a result, productivity-enhancing technologies may intensify market gluts, exacerbate price volatility, and worsen income instability, which is an outcome we refer to as the "technology amplification effect", consistent with a broader productivity–volatility paradox. We develop an institutional–structural–

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technological framework that conceptualizes resilience as a hierarchical alignment of institutional, structural, and technological capacities and argue for sequenced interventions, namely governance reforms that rebalance risks and rewards and strengthen producer organization, followed by investment in countercyclical buffering infrastructure (processing, cold chains, and market diversification), creating an enabling ecosystem for technology to act as a resilience catalyst. The proposed pathway provides a transferable blueprint for building inclusive resilience in HVPP value chains facing concentrated supply and coordination failures.

1 Introduction

Global agrifood systems are facing unprecedented stress due to climate change, market volatility, and extreme weather events[1–6]. This situation has promoted a strategic shift in policy priorities from a focus on productivity growth to an emphasis on resilience and inclusiveness[7,8]. Although technological innovations are often championed as primary solutions, their effectiveness is inconsistent across diverse contexts[9–13]. This inconsistency is particularly evident in high-value perishable product (HVPP) systems such as fruits, vegetables, and flowers, which exhibit heavy reliance on coordination, logistics, and rapid market access, rendering these systems acutely vulnerable to institutional and structural failures[14–17]. Despite their significant roles in supporting smallholder livelihoods and enhancing nutrition[18,19], HVPPs frequently suffer from severe price and income instability, highlighting the inherent limitations of technology-centric resilience pathways[20].

This study analyzes the systemic vulnerabilities in HVPPs through an in-depth study of the lychee sector in Guangdong, China. Contributing over half of the national output and supporting millions of smallholder farmers, this sector is characterized by concentrated production, pronounced alternate bearing, and high perishability, which are traits that exacerbate exposure to climate and market risks[21]. Drawing on fieldwork conducted across 68 orchards and 20 processing and marketing entities in Guangdong in 2024 and 2025, we analyze how farm-level outcomes interact with value chain organizations and institutional arrangements under volatile conditions.

We address three core questions: Why do technology-led strategies in HVPP systems often increase output but fail to stabilize income? How do institutional, structural, and technological factors interact to shape or undermine resilience? How should interventions be sequenced to develop robust and inclusive systemic resilience? These questions challenge the prevailing “technology-first” orthodoxy and call for a comprehensive reappraisal of resilience-building strategies.

To address these questions, we develop an institutional–structural–technological (IST) framework that conceptualizes resilience as an emergent property arising from three hierarchically related capacities. Our analysis reveals a self-reinforcing institutional–structural trap, where weak governance and distorted development priorities create critical gaps in buffering capacity, leading to situations where technological advancements amplify volatility, rather than mitigate it. We refer to this phenomenon as the “technology amplification effect”.

Although grounded in the lychee sector, our framework offers a transferable lens for analyzing HVPP systems globally, including mangoes in Southeast Asia to horticulture in Africa, where high value, perishability, and smallholder dominance intersect with institutional and structural constraints[22]. By shifting the focus from technology-first solutions to an institution-led systemic design, this study contributes to a coherent approach for developing agrifood systems that are both productive and resilient.

The remainder of this paper is organized as follows. Section 2 conceptualizes resilience from an economic perspective. Section 3 reviews the limitations of technology-centric pathways and establishes the institution-structural premise. Section 4 details the features and systemic vulnerabilities of

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Guangdong's lychee sector. Section 5 describes the IST framework used to diagnose institutional structural traps. Section 6 proposes a reordered resilience pathway prioritizing institutional reform and structural buffering. Section 7 discusses the integrated policy implications, and Section 8 concludes the paper.

2 Conceptualizing resilience in agrifood systems

The concept of resilience is crucial for navigating the climatic and economic uncertainties faced by agricultural food systems. While international definitions often emphasize maintaining core functions and absorbing shocks, approaches focused solely on ecological or production stability fail to explain critical economic phenomena such as price volatility, livelihood insecurity, and coordination failures along value chains[3,8,23].

From the agricultural economic perspective, resilience is a systemic economic property reflecting an agrifood system's capacity to allocate resources efficiently, manage risk, and maintain incentive-compatible behavior under uncertainty[19]. In contexts dominated by smallholders, where markets are often incomplete and producer organizations are relatively weak, poor resilience typically manifests not only in the form of production shortfalls but also in income instability and systemic risk spillovers[8,24].

This study advances the conceptualization of agrifood system resilience based on three interdependent capacities: institutional resilience, structural resilience, and technological resilience.

Institutional resilience refers to the ability of organizational arrangements, contractual forms, and governance mechanisms to reduce transaction costs, support coordinated actions, and strengthen producer participation in markets. Weak institutions may exacerbate individual risk exposure and hinder collective responses, making it difficult for systems to establish effective risk-sharing arrangements.

Structural resilience reflects the capacity of value chains to absorb and buffer shocks through processing, storage, and market diversification. Extensive evidence shows that systems with sufficient structural redundancy can moderate price fluctuations and protect producers and consumers when supply and demand are misaligned[25,26]. In contrast, value chains that rely heavily on fresh sales and lack intertemporal adjustment mechanisms are more likely to transform localized shocks into system-wide instability.

Technological resilience refers to the role of technological change in improving productivity, enhancing climate adaptability, and reducing risk exposure at the unit level. However, a substantial body of research has shown that without a stable institutional foundation and adequate structural buffering capacity, technologies with clear agronomic or engineering advantages may struggle to achieve sustained adoption. In some cases, technological improvements may even intensify market volatility by concentrating the supply over short periods[19,25].

Importantly, these three dimensions of resilience form a hierarchical relationship. Institutional and structural conditions determine whether technological advances translate into stable economic outcomes. When institutions fail to support coordination and value chains lack sufficient buffering capacity, technology alone is unlikely to generate durable resilience[20,27]. Conversely, when institutional and structural foundations are robust, technology can effectively amplify resilience.

This hierarchy is particularly relevant for HVPPs, which are characterized by short marketing windows, high demand elasticity, and strong asset specificity. In this context, risk often arises from coordination failures within the value chain, rather than from production variability alone[24]. Consequently, understanding resilience in these systems requires paying close attention to institutional arrangements and structural conditions, rather than adopting a narrow focus on technology.

3 Institutional-structural premise: why technology-centric pathways fall short

Policy and research debates have positioned technological innovation as the primary mechanism for building resilience. Concepts such as climate-smart agriculture and digital farming emphasize technologies that boost productivity, optimize inputs, and enhance climate adaptation[12,28]. However, a growing consensus among scholars highlights the context-

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dependent effectiveness of these technology-centric pathways, particularly in market-oriented smallholder systems[20,25,27,29].

The technology-focused approach has two major limitations. First, the adoption of new technologies is often constrained. Smallholders frequently face incomplete markets, high price volatility, and weak bargaining power, which are characteristics commonly observed in HVPP chains. Under these conditions, the decision-making calculus shifts, as investing in new technologies is a high-risk endeavor if potential income gains are likely to be eroded by sudden price collapses or exploitative intermediaries[28,30]. Therefore, what may appear as “conservatism” or “low adoption” is often a rational risk-avoidance strategy in unstable institutional and market environments.

Second, even when technologies are adopted, they may have systemic consequences. In HVPP systems, productivity-enhancing technologies (e.g., improved varieties and irrigation) may successfully raise yields but fail to extend marketing windows or enhance coordination. This effect can lead to more severe gluts in the market. Without corresponding improvements in structural buffering capacity (e.g., processing and storage), the increased output is funneled into a narrow timeframe, thereby exacerbating price crashes and income instability. This phenomenon is referred to as the “productivity–volatility paradox.”

Therefore, the central argument emerging from the literature is clear. Technology alone is not an adequate substitute for absent institutions or structural buffers, which fundamentally mediate and amplify the effects of technology. Specifically, technology can significantly enhance system performance only when institutional arrangements provide stable incentives and structural mechanisms offering protection against downside risks. This “institutional–structural premise” is especially critical for HVPPs, where the economic necessity of rapid product realization makes effective coordination and buffering essential for survival.

The case of Guangdong lychee provides a suitable empirical context for examining this premise, enabling us to go beyond the general theoretical understanding of institutional–structural primacy to the concrete analysis of how specific governance failures and structural gaps interact to entrap producers in a cycle of volatility. Furthermore, we can explore what an alternative resilience-oriented pathway may entail.

4 Guangdong’s lychee sector: structural features and systemic vulnerabilities

China’s lychee sector, which is concentrated in Guangdong, exemplifies the opportunities and challenges of HVPP systems. Our analysis draws on fieldwork conducted in 2024 and 2025. Although our research spanned several core producing regions, Huizhou served as the focal study area for our in-depth analysis. We selected Huizhou for its analytical pertinence, rather than focusing on aggregate production volume, because Huizhou perfectly encapsulates the sector’s structural and organizational heterogeneities. Specifically, our primary field sites, including Boluo County (e.g., the Yashiyuan Orchard) and the adjacent towns of Zhenlong and Lilin, encompass a spectrum of farming models, contrasting levels of producer organization, and diverse processing enterprises.

To capture these dynamics, we employed a qualitative data collection protocol. Semi-structured interviews were conducted with 68 smallholder farmers and orchard managers to assess yield fluctuations, cost structures, and technology adoption. Additionally, key informant interviews with over 20 processing and marketing entities, along with on-site observations, were used to evaluate value chain capacities. Interview data and field observations were documented via detailed field notes, which were subsequently systematically coded and analyzed. This empirical knowledge base reveals how the sector’s biological traits, fragmented organization, and market structure interact to generate pronounced volatility and fragile farmer income.

4.1 Inherent production volatility: biological traits and concentrated supply

The vulnerability of Guangdong’s lychee sector is rooted in the biological and economic traits of the lychee. First, this species exhibits a pronounced alternate-bearing cycle, leading to significant interannual output fluctuations. For example, Guangdong’s production plummeted by over 40%, dropping to approximately 876,000 tons in 2024, as a result of poor flowering, only to rebound sharply to an estimated 1.6 to 2.0 million tons in 2025. Second, production is geographically and varietally concentrated. Guangdong alone accounts for roughly 56% of the national output, relying heavily on a few mid-to-late-season varieties (e.g., Feizixiao and Guiwei). This concentration synchronizes the harvest and compresses marketing windows. In 2025, delayed maturity funneled over one million tons into the market within a short period in June. These characteristics of inherent yield instability and concentrated supply create a baseline for the supply-side shocks that the downstream system must absorb.

It is critical to note that this varietal concentration is not a biological necessity but a structural outcome. Our fieldwork identified cases in which strategic adjustments at the farm level could mitigate this risk. A notable example is the Yashiyuan orchard in Boluo County, which introduced early and late-maturing varieties (e.g., Xiantao and Jinfeng) to desynchronize its harvest from peak glut periods. During the widespread production downturn in 2024, this orchard maintained a stable output, achieving a relatively steady income. This case illustrates that temporal diversification is technically feasible and enhances individual resilience. However, such successful microlevel adjustments remain an exception, rather than the norm across the sector. The persistent dominance of concentrated varieties raises an important question: If diversification is beneficial, then why has it not been widely adopted? The answer lies not in agronomic constraints but in the deeper institutional and structural factors shaping farmers' incentives and capacities. These factors will be detailed in the following subsections.

4.2 Fragmented production and asymmetric market access

Downstream, the sector's capacity to manage supply shocks is constrained by fragmented production bases. As it is dominated by smallholders with low levels of organization, the sector struggles with coordination and economies of scale. This fragmentation has led to significant disparities in market access costs. Our fieldwork in the adjacent towns of Zhenlong and Lilin in Huizhou clearly illustrates this disparity, as shipping a 5 kg box to Shanghai costs approximately 110 yuan for individual farmers in Zhenlong Town, compared with 90 yuan for organized farmers in Lilin Town. Such cost asymmetries mean that during price downturns, unorganized farmers face higher break-even points, often forcing them to abandon harvests or sell at a loss earlier than their organized counterparts, which amplifies overall financial distress.

4.3 Limited buffering capacity: the failure of processing and price collapse

The system's inability to buffer supply shocks is most evident in its failure to stabilize prices. With an extremely short shelf life and immediate precooling requirements, lychees cannot be stored to achieve better prices. As a result, supply gluts trigger immediate and severe price collapses. For example, the farm gate price of Guiwei crashed from 94 yuan·kg^{-1} in the low-output year of 2024 to 10.8 yuan·kg^{-1} in the high-output year of 2025.

The processing sector, which theoretically acts as a buffer, operates cyclically. With a fresh fruit processing rate of only approximately 10% (well below international benchmarks), processors typically enter the market only after farm gate prices collapse to rock-bottom levels (e.g., 3–5 yuan·kg^{-1}). Evidence from our interviews with processors and farmers in Boluo County indicates that these prices often fall below harvesting costs (approximately 4 yuan·kg^{-1} for many farmers). Therefore, rather than mitigating price declines, processing actually exacerbates the issue, creating a buyer's market at the farmer's expense and offering minimal income support.

5 Institutional–structural trap: explaining systemic vulnerability

Evidence from the lychee sector reveals that the vulnerability in HVPP systems is not merely a result of natural perishability or technological gaps. Instead, it arises from a self-reinforcing institutional–structural trap. This trap explains why beneficial adjustments such as varietal diversification remain exceptions and why the documented structural gaps persist. In this section, we develop a framework to illustrate the formation of this trap. Asymmetric value chain governance confines smallholder farmers to weak bargaining power and residual claimancy, distorting the pathway of technological development. Rather than promoting resilience, these dynamics skew advancements toward short-term efficiency. Ultimately, this pattern results in significant structural gaps in buffering capacity, exacerbating all shocks and leading to heightened prices and income volatility.

5.1 Core constraint: asymmetric governance and residual claimancy

The fundamental vulnerability of HVPP systems such as the lychee sector lies in their governance structure. Despite being the primary risk bearers of production shocks (e.g., alternate bearing and weather), smallholder producers are typically

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positioned at the upstream end of buyer-driven chains. Their participation is often limited to the supply of raw materials for informal or incomplete contracts. This configuration creates a severe issue of residual claimancy, which refers to the right (or obligation) to absorb the net profit and loss after all other contractual obligations are met. In this setting, residual claimancy implies that smallholders bear the residual risk and profit-and-loss volatility, capturing only a small, unstable fraction of the final product's value, while other value chain actors operate with more protected or fixed margins. This dynamic weakens the incentives and capacity for long-term investment in quality-, diversification-, and resilience-enhancing technologies. Additionally, the frequent absence of stable producer organizations further exacerbates this power asymmetry, leaving farmers vulnerable to bargaining risks and unable to coordinate collective responses to shocks. The institutional foundation of this vulnerability is a governance model that misaligns risks, rewards, and decision-making authority.

5.2 Distorted development pathway: technology supply misaligned with systemic needs

Considering the governance context described above, the technological development trajectory in the lychee sector becomes systematically biased. Policy and development programs often promote advanced technologies (e.g., precision irrigation and digital tools) with a primary focus on boosting productivity and efficiency. However, when farmers operate under weak residual claimancy, their primary needs are not higher output but risk reduction and income stabilization. Technologies that increase output without addressing the core concern of price collapse during glut seasons may exacerbate farmers' losses.

Field evidence indicates that technologies requiring significant upfront investments or ongoing maintenance costs are frequently abandoned, and not as a result of farmer conservatism, but based on a rational calculation. Under conditions of volatile prices and weak bargaining power, the returns on such investments are highly uncertain. Consequently, technology adoption tends to be shallow and noncumulative. Therefore, the development pathway is distorted, prioritizing isolated productivity gains over integrated risk management and value-capture capacities that would genuinely enhance systemic resilience.

5.3 Manifestation: structural gaps in buffering and intertemporal adjustment

The interaction between asymmetric governance and distorted technological development manifests as tangible structural gaps within the value chain. The most critical gap is the lack of buffering capacity for intertemporal adjustments. For HVPPs, developing such capacity requires sufficient and strategically utilized processing, cold chain storage, and diversified market channels.

In the lychee sector, the procyclical behavior of the processing sector (buying only at rock-bottom prices) is not an isolated failure but a symptom of a structure that lacks incentives to invest in countercyclical capacity. When farmers are price takers, they feel no pressure to offer stable procurement contracts. The result is a two-sided failure. In high-output years, limited absorption capacity leads to price collapse and waste, whereas in low-output years, processing lines sit idle as a result of raw material shortages. The absence of a "shock absorber" is a direct structural manifestation of prior institutional and developmental failures, which ensures that production fluctuations are transmitted directly and violently into the economic space.

5.4 Reinforcing cycle: how the trap sustains systemic vulnerability

The three elements outlined above, namely asymmetric governance, distorted development, and structural gaps, do not simply coexist; rather, they interact in a vicious, self-reinforcing cycle that constitutes the institutional–structural trap (Fig. 1).

Weak governance leads to unstable farmer income, reducing both capital and trust in long-term investments (in technology or diversification). This effect stifles the demand for resilience-oriented technologies and leads to a development pathway focused on external productivity-centric solutions that ignore the underlying risk context. The resulting structural gaps, including a lack of buffering capacity, amplify price volatility, which further undermines farmer income and bargaining power, reinforcing weak governance.

This cycle explains why single-point interventions (e.g., introducing new technology or building a processing plant) often fail. The trap ensures that the gains achieved in one dimension are eroded by the constraints in another. Therefore,

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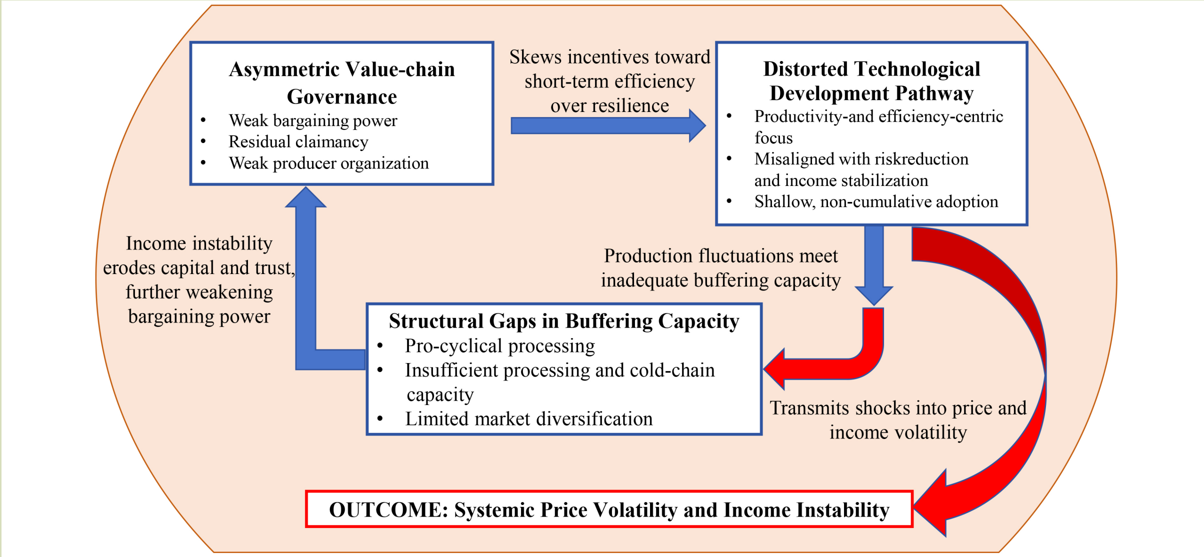

Fig. 1 The institutional–structural trap in the lychee value chain.

building resilience requires integrated strategies that simultaneously address governance imbalances, reorient technological development toward risk management, and incentivize investment in structural buffering capacity to break the cycle.

6 Building systemic resilience: a pathway to escape the institutional–structural trap

The preceding analysis identifies a self-reinforcing trap in which asymmetric governance, distorted development, and structural gaps perpetuate vulnerability. Escaping this trap requires more than isolated improvements, necessitating a reordered and integrated pathway that simultaneously addresses multiple core components. This section proposes a systemic intervention logic that prioritizes institutional redesign and structural buffering to create the necessary conditions for technology to function as a true resilience accelerator, thereby shifting the system from a vicious cycle to a virtuous cycle.

6.1 Foundational step: reforming governance to align risks and rewards

Escaping the trap must begin with reforming the misaligned distribution of risks and rewards. The first and most critical intervention is institutional reform to rebuild the governance foundation of the value chain. This process will involve substantively enhancing smallholders' residual claimancy and collective agency through concrete measures such as fostering stable producer organizations, promoting equitable contract farming models with risk-sharing clauses, and developing effective institutions for collective bargaining or joint ownership of downstream assets (e.g., brands and processing facilities). The fundamental objective of such reforms is to stabilize producers' income expectations and ensure that they secure a fairer and more stable share of the value they create. By transforming farmers from passive price-takers into active stakeholders with incentives for long-term investment, this new institutional foundation will directly dismantle the "asymmetric governance" pillar of the trap, creating a credible commitment and stable incentive environment for all subsequent interventions.

6.2 Enabling step: investing in structural buffering capacity

Once governance is improved and incentives are clarified, the focus of system building can shift to the construction of the physical and economic infrastructure required to absorb shocks. This step addresses the "structural gaps" manifested in the lychee sector's procyclical processing and lack of temporal

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flexibility. Developing the necessary infrastructure will require strategic public and private investment in countercyclical processing capacity, integrated cold chain networks, and market infrastructure that supports product diversification (e.g., for early and late-maturing varieties). Concurrently, policies should incentivize processors to offer forward procurement contracts to guarantee baseline demand. The ultimate goal of these investments is to create redundancy and temporal flexibility for the entire system. This “buffer” will decouple production volatility from price collapses, protect farmers’ incomes during gluts, and ensure raw material supply during shortages, thereby making the entire value chain more predictable. In turn, the enhancement of structural buffering capacity reinforces the systemic stability pursued through institutional reform.

6.3 Catalytic step: embedding technology within a supportive ecosystem

Technology can only realize its full potential as a resilience catalyst when institutional and structural conditions are improved synergistically, freeing technology from the cycle of isolated promotion and subsequent abandonment. At this stage, technology promotion must be repositioned to serve new institutional and structural priorities explicitly. This process involves prioritizing technologies that enhance risk management (e.g., stress-resistant varieties and precision irrigation for stable quality), align with new structural pathways (e.g., varieties suited for premium markets or processing, along with sorting technologies), and reduce coordination costs (e.g., digital platforms for collective logistics or market information). In such a supportive ecosystem, technology adoption becomes a rational response to better incentives and reduced market uncertainty, amplifying the benefits derived from institutional coordination and structural buffering. These benefits lead to sustained cumulative improvements in productivity, quality, and climate adaptation, which endure because they are economically viable within the reformed system.

6.4 Toward a virtuous cycle: integrating pathways for inclusive resilience

The proposed pathway is explicitly designed to reverse the logic of the vulnerability trap. By first stabilizing expectations and then building shock-absorption capacity, it creates an environment in which investment in technology and diversification (as exemplified by the Yashiyuan orchard model) becomes a low-risk, high-reward strategy for the majority of producers, rather than being limited to a fortunate few. This integrated approach fundamentally shifts the guiding logic of the system from a narrow focus on production efficiency to the pursuit of income resilience and inclusive value capture. Resilience and inclusion are not separate goals but mutually reinforce the outcomes of a system in which primary producers possess the agency, security, and tools to manage risk collectively. Therefore, escaping the institutional–structural trap depends on a sequenced, synergistic intervention aimed at the heart of the agrifood system.

7 Policy implications: operationalizing the escape from the trap

Our analysis revealed that vulnerability in HVPP systems such as Guangdong’s lychee sector is entrenched in a self-reinforcing institutional–structural trap. Therefore, effective policy must be designed explicitly to disrupt this trap and enable the transition toward a more resilient and inclusive pathway. The following recommendations translate the proposed analytical framework into concrete and prioritized policy actions.

7.1 Prioritize institutional foundations: from facilitation to active co-design

Current policies often treat farmer organizations and equitable market linkages as secondary “soft” components, focusing primarily on technological hardware and physical infrastructure. To dismantle the core of the trap, this sequence must be decisively inverted. Policies should primarily act as catalysts for governance reform by actively co-designing and legally underpinning equitable contract models that explicitly share risks and rewards. This reform will require moving beyond voluntary guidelines to provide targeted grants, technical assistance, and fiscal incentives specifically designed to build the business and negotiation capacities of producer organizations. Furthermore, public support should be extended to establish producer-led branding or geographical indication schemes, where governance and benefit-sharing rules are legally defined to ensure smallholder inclusion. The overarching objective is to use public action to recalibrate bargaining power and residual claimancy deliberately, thereby

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creating stable income expectations that form an essential foundation for long-term resilience-oriented investments.

7.2 De-risking and Co-investing in structural buffering capacity

Market failures in building critical shock-absorbing infrastructure, including countercyclical processing, integrated cold chains, and diversified market channels, are direct symptoms of a systemic trap. Therefore, public policy must intervene strategically to de-risk and crowd-in private investments, which are highly significant for systemic resilience. Concrete measures include establishing dedicated “Resilience Infrastructure Funds” or public–private partnerships aimed at financing countercyclical processing and storage facilities, with public support conditional on commitments to minimum off-take volumes or price floors during supply gluts. Additionally, policies can stimulate the crucial diversification of harvest timing by implementing differentiated subsidies or public procurement policies that create early market demand for early and late-maturing varieties. Concurrently, public investment in shared logistics and digital information platforms can reduce pervasive coordination costs and market access disparities, particularly for unorganized smallholders. These actions collectively transform structural buffering from a high-risk private cost into a stability-enhancing public good.

7.3 Reform evaluation frameworks to incentivize systemic resilience

Policies and investments are inevitably shaped by what factors are being measured and rewarded. Prevailing metrics have narrowly focused on yield, planted area, and short-term productivity gains, inadvertently reinforcing the efficiency-centric logic that sustains the vulnerability trap. Therefore, a fundamental shift in the evaluation paradigm is required to align incentives with resilience outcomes. Such realignment involves adopting and mandating “Income Resilience Metrics” in agricultural program evaluations, which track the stability of farm gate prices and producer incomes over time, rather than focusing solely on their peak levels. Likewise, sectoral assessments must incorporate structural indicators such as processing capacity utilization across seasons, cold chain penetration rates, and the market share of producer organizations. Ultimately, public support and subsidies should be linked to the performance of these resilience and inclusion indicators, ensuring that the incentives for all system actors, ranging from farmers and processors to local governments, are coherently aligned with the goal of long-term systemic stability.

7.4 Foster integrated, problem-driven research and policy pilots

The complexity of the institutional–structural trap, which spans the economic, technological, and social domains, demands a decisive break from siloed research and top-down blueprint policies. Advancing effective solutions requires fostering deeply interdisciplinary research consortia integrating agronomy, economics, food engineering, and social science to co-design context-specific innovations such as viable processing technologies for smallholder clusters or financial instruments for collective risk management. Furthermore, the public funding agenda must shift toward “policy innovation labs” or living labs that test integrated intervention packages combining governance, finance, and technology in real-world settings, such as a specific lychee-producing county. Such initiatives must focus on learning how to sequence and combine interventions effectively to generate actionable, systemic evidence for scaling approaches that truly work to enhance resilience[19,31,32].

8 Conclusions

As global agrifood systems face mounting climatic and market uncertainties, building resilience has become an urgent priority in both the policy and research domains. This study demonstrates that resilience in smallholder-dominated HVPP systems such as the Guangdong lychee is fundamentally an institutional and structural challenge. The sector’s acute vulnerability, which is expressed through extreme price volatility and fragile farm incomes, stems not solely from biological perishability or farmer practices but also from a self-reinforcing institutional–structural trap. Asymmetric governance undermines farmers’ bargaining power and residual claimancy, distorts technological development toward prioritizing short-term efficiency over risk management, and results in critical gaps in buffering capacity that amplify shocks into systemic instability.

The analytical framework developed in this study diagnoses this trap and points toward an escape route. Our findings suggest that resilience in HVPP systems depends on the

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hierarchical and synergistic alignment of three capacities. Institutional resilience, forged through governance reform and stronger producer organizations, must provide a foundation to establish the stable expectations required to foster structural resilience and physical and market infrastructures that can absorb shocks across time and space. Only when built upon such a foundation can technological resilience act as a true catalyst for sustained productivity and adaptation, rather than a source of further volatility. Reordering priorities in this manner offers a systemic blueprint for transforming the vicious cycle of vulnerability into a virtuous cycle of inclusive resilience.

In contributing to broader debates on agricultural development and food system governance, this study goes beyond merely critiquing "technology-centric" approaches by detailing the mechanisms of their failure in HVPP contexts, including the productivity–volatility paradox and the problem of residual claimancy. Furthermore, this study provides a generalizable diagnostic and interventional framework. Although we focused on the lychee sector in China, the dynamics of concentrated supply, fragmented production, procyclical processing, and distorted incentives are common across HVPP systems worldwide. Such characteristics are frequently observed in mango value chains in Southeast Asia and avocado export chains in Latin America. Smallholder productivity gains are undermined by price volatility and weak bargaining power[33,34]. Therefore, the presented framework provides a lens for systematic analysis and context-sensitive intervention design.

However, translating insights into practice requires a decisive shift from isolated projects to an integrated systemic redesign. Policymakers should prioritize co-designing equitable institutions, de-risking investments in countercyclical infrastructures, and reforming evaluation metrics to incentivize income stability and structural robustness. Such efforts will yield not only efficiency gains, but also a reorientation of agrifood policy toward equity and risk management as core objectives. Ultimately, the resilience of modern agrifood systems will depend less on the sophistication of any single technology than on the deliberate sequencing and integration of social, economic, and technical innovations. For smallholders worldwide, future prosperity hinges on transforming HVPP systems into coordinated, buffered, and dynamic value chains, where farmers are not merely vulnerable suppliers but empowered stakeholders. The path forward begins by dismantling the institutional–structural traps that perpetuate instability and consciously constructing foundations for shared and sustainable growth.

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Compliance with ethics guidelines

Taian Deng, Baizhan Lei, Xiaojing Liu, Guangjiang Xiao, and Fuli Tan declare that they have no conflicts of interest or financial conflicts to disclose. This article does not contain any studies with human or animal subjects performed by any of the authors.

REFERENCES

1. Tilman D, Clark M. Food, agriculture & the environment: can we feed the world & save the earth? *Daedalus*, 2015, **144**(4): 8–23
2. Caron P, de Loma-Osorio G F Y, Nabarro D, Hainzelin E, Guillou M, Andersen I, Arnold T, Astralaga M, Beukeboom M, Bickersteth S, Bwalya M, Caballero P, Campbell B M, Divine N, Fan S G, Frick M, Friis A, Gallagher M, Halkin J P, Hanson C, Lasbennes F, Ribera T, Rockstrom J, Schuepbach M, Steer A, Tutwiler A, Verburg G. Food systems for sustainable development: proposals for a profound four-part transformation. *Agronomy for Sustainable Development*, 2018, **38**(4): 41
3. Fan S G, Cho E E, Meng T, Rue C. How to prevent and cope with coincidence of risks to the global food system. *Annual*

EA-26698-DTA 2026-04-29 16:37:47

Review of Environment and Resources, 2021, **46**: 601–623
4. The Intergovernmental Panel on Climate Change (IPCC). Summary for policymakers. In: Climate Change and Land: IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems. Cambridge, UK: *Cambridge University Press*, 2022, 1–36
5. De Camillis C, McAllister T. Agrifood systems transformation for climate action and environmental improvements, with co-benefits for food security and nutrition. *The International Journal of Life Cycle Assessment*, 2024, **29**(12): 2165–2168
6. Juri S, Terry N, Pereira L M. Demystifying food systems transformation: a review of the state of the field. *Ecology and Society*, 2024, **29**(2): 5
7. FAO, IFAD, UNICEF, WFP, WHO. The State of Food Security and Nutrition in the World 2024: Financing to End Hunger, Food Insecurity and Malnutrition in All Its Forms. Rome: *FAO*, 2024
8. Zurek M, Ingram J, Sanderson Bellamy A, Goold C, Lyon C, Alexander P, Barnes A, Bebber D P, Breeze T D, Bruce A, Collins L M, Davies J, Doherty B, Ensor J, Franco S C, Gatto A, Hess T, Lamprinopoulou C, Liu L X, Merkle M, Norton L, Oliver T, Ollerton J, Potts S, Reed M S, Sutcliffe C, Withers P J A. Food system resilience: concepts, issues, and challenges. *Annual Review of Environment and Resources*, 2022, **47**: 511–534
9. Komarek A M, De Pinto A, Smith V H. A review of types of risks in agriculture: what we know and what we need to know. *Agricultural Systems*, 2020, **178**: 102738
10. Liu Y P, Wood L C, Venkatesh V G, Zhang A, Farooque M. Barriers to sustainable food consumption and production in China: a fuzzy DEMATEL analysis from a circular economy perspective. *Sustainable Production and Consumption*, 2021, **28**: 1114–1129
11. Li J H, Leeuwis C, Heerink N, Zhang W F. The science and technology backyard as a local level innovation intermediary in rural China. *Frontiers of Agricultural Science and Engineering*, 2022, **9**(4): 558–576
12. Lipper L, Thornton P, Campbell B M, Baedeker T, Braimoh A, Bwalya M, Caron P, Cattaneo A, Garrity D, Henry K, Hottle R, Jackson L, Jarvis A, Kossam F, Mann W, McCarthy N, Meybeck A, Neufeldt H, Remington T, Sen P T, Sessa R, Shula R, Tibu A, Torquebiau E F. Climate-smart agriculture for food security. *Nature Climate Change*, 2014, **4**(12): 1068–1072
13. Rojas-Reyes J J, Rivera-Cadavid L, Peña-Orozco D L. Disruptions in the food supply chain: a literature review. *Heliyon*, 2024, **10**(14): e34730
14. Perdana T, Tjahjono B, Kusnandar K, Sanjaya S, Wardhana D, Hermiatin F R. Fresh agricultural product logistics network governance: insights from small-holder farms in a developing country. *International Journal of Logistics Research and Applications*, 2023, **26**(12): 1761–1784
15. UNEP, FAO. Sustainable Food Cold Chains: Opportunities, Challenges and the Way Forward. Nairobi: *UNEP*, 2022
16. Zhu H L, Liu C C, Wu G H, Gao Y J. Cold chain logistics network design for fresh agricultural products with government subsidy. *Sustainability*, 2023, **15**(13): 10021
17. Webb P, Sonnino R, Fraser E, Arnold T. Everyone at the Table: Transforming Food Systems by Connecting Science, Policy and Society. Luxembourg: *Publications Office of the European Union*, 2022
18. Scott P. Global panel on agriculture and food systems for nutrition: food systems and diets: facing the challenges of the 21st century. *Food Security*, 2017, **9**(3): 653–654
19. Fan S G. Economics in food systems transformation. *Nature Food*, 2021, **2**(4): 218–219
20. Singh B K, Fraser E D G, Arnold T, Biermayr-Jenzano P, Broerse J E W, Brunori G, Caron P, De Schutter O, Fabbri K, Fan S G, Fanzo J, Gajdzinska M, Gurinovic M, Hugas M, McGlade J, Nellemann C, Njuki J, Tuomisto H L, Tutundjian S, Wesseler J, Sonnino R, Webb P. Food systems transformation requires science–policy–society interfaces that integrate existing global networks and new knowledge hubs. *Nature Food*, 2023, **4**(1): 1–3
21. Qi W E, Tang W Z, Yan F F. How environmental conditions, phenological periods, and production endowment affect lychee yield. *Agronomy Journal*, 2023, **115**(6): 2778–2790
22. Fan S G. Sustainable intensification of agriculture is key to feeding Africa in the 21st century. *Frontiers of Agricultural Science and Engineering*, 2020, **7**(4): 366–370
23. International Food Policy Research Institute (IFPRI). 2016 Global Food Policy Report. Washington: *IFPRI*, 2016
24. Reardon T, Echeverria R, Berdegué J, Minten B, Liverpool-Tasie S, Tschirley D, Zilberman D. Rapid transformation of food systems in developing regions: highlighting the role of agricultural research & innovations. *Agricultural Systems*, 2019, **172**: 47–59
25. Davis K F, Downs S, Gephart J A. Towards food supply chain resilience to environmental shocks. *Nature Food*, 2021, **2**(1): 54–65
26. Xue L, Liu X J, Lu S J, Cheng G Y, Hu Y C, Liu J G, Dou Z X, Cheng S K, Liu G. China's food loss and waste embodies increasing environmental impacts. *Nature Food*, 2021, **2**(7): 519–528
27. Rad M, Sonesson U. Drivers of a more sustainable future food system–lessons from Sweden. *Journal of Cleaner Production*, 2024, **462**: 142639
28. FAO, IFAD, UNICEF, WFP, WHO. The State of Food Security and Nutrition in the World 2018: Building Climate Resilience for Food Security and Nutrition. Rome: *FAO*, 2018
29. Reardon T, Zilberman D. Climate smart food supply chains in developing countries in an era of rapid dual change in agrifood

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systems and the climate. In: Lipper L, McCarthy N, Zilberman D, Asfaw S, Branca G, eds. Climate Smart Agriculture: Building Resilience to Climate Change. Cham: *Springer*, 2018, 335–351

30. Assefa T T, Meuwissen M P M, Gardebroek C, Oude Lansink A G J M. Price and volatility transmission and market power in the German fresh pork supply chain. *Journal of Agricultural Economics*, 2017, **68**(3): 861–880
31. Davies W J, Shen J B. Promoting green transformation by ensuring food security while reducing the environmental footprint of food and farming with agriculture green development. *Frontiers of Agricultural Science and Engineering*, 2024, **11**(1): 1–4
32. Shen J B, Zhu Q C, Hou Y, Cong W F, Xu W, Xu J L, An Z C, Jiao X Q, Zhang K, Yu T X, Ma L, Oenema O, Davies W J, Zhang F S. Agriculture green development in China: insights and advances. *Frontiers of Agricultural Science and Engineering*, 2024, **11**(1): 5–19
33. Wulandari E, Meuwissen M P M, Karmana M H, Lansink A G J M O. The role of access to finance from different finance providers in production risks of horticulture in Indonesia. *PLoS One*, 2021, **16**(9): e0257812
34. Taramuel-Taramuel J P, Montoya-Restrepo I A, Barrios D. Challenges in the avocado production chain in Latin America: a descriptive analysis. *Agronomía Colombiana*, 2024, **42**(2): e113982