frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 17 March 2026
DOI 10.3389/fsufs.2026.1757799

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OPEN ACCESS

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RECEIVED 01 December 2025
REVISED 30 December 2025
ACCEPTED 15 January 2026
PUBLISHED 17 March 2026

CITATION
Xiong Y, Ong CH, Wang Z and Liu Z (2026) Impact of regional green food industry resilience on agricultural sustainable development performance: the mediating role of export competitiveness and implications for rural revitalization. *Front. Sustain. Food Syst.* 10:1757799. doi: 10.3389/fsufs.2026.1757799

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Impact of regional green food industry resilience on agricultural sustainable development performance: the mediating role of export competitiveness and implications for rural revitalization

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Global food systems are facing multiple compounding crises, highlighting the urgent need to enhance resilience. This study examined how regional green food industry resilience affects agricultural sustainable development performance in China, the mediating role of export competitiveness. Using panel data from 31 provinces (2010–2022), a three-dimensional resilience framework (adaptive, absorptive, restorative capacities) was constructed. Two-way fixed effects models, Bootstrap mediation analysis, and instrumental variable approaches were employed to address endogeneity concerns. The results indicated that industry resilience significantly promoted sustainable development performance (β = 0.341, p < 0.01), with adaptive capacity exhibiting the largest marginal effect (β = 0.243), followed by restorative capacity (β = 0.186), while the effect of absorptive capacity did not reach statistical significance. Export competitiveness partially mediated this relationship, accounting for approximately one-quarter of the total effect [24.3, 95% CI: (0.028, 0.147)]. Significant regional heterogeneity was observed: the mediation effect reached 45.0% in eastern regions and 37.2% in central regions, whereas it was not significant in western regions. Policy support showed marginally significant moderation (p = 0.067). This study extends resilience theory to the regional industry level, identifies internationalization pathways as a key transmission mechanism, and underscores the necessity of formulating differentiated strategies according to regional development stages for China's rural revitalization.

KEYWORDS

export competitiveness, green food industry, mediation analysis, regional resilience, sustainable agriculture

1 Introduction

Global food systems are facing multiple compounding crises, including climate extremes, pandemic shocks, geopolitical tensions, and supply chain disruptions (Zurek et al., 2022a). The COVID-19 pandemic exposed critical vulnerabilities in food supply networks, while climate change has intensified the frequency and severity of extreme weather events, threatening agricultural productivity and undermining food supply stability (Hendriks et al., 2022). These cascading crises highlight the urgent need to enhance food system resilience—defined as the capacity of a system to absorb shocks, adapt to changes, and recover its functions (Martin and Sunley, 2015; Tendall et al., 2015). As the global community strives to achieve the Sustainable Development Goals, particularly SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production), building resilient and sustainable food systems has become a strategic priority (UNICEF, 2023).

Within this global context, China, as the world's largest agricultural producer and consumer, holds particular importance and demonstrates significant potential in food system resilience building. The green food system, characterized by environmentally friendly production practices and certified quality standards, represents a critical pathway toward sustainable development (Sun et al., 2021; Xu et al., 2020). However, the green food system faces unique resilience challenges distinct from conventional agriculture: greater dependence on ecological processes, more stringent quality requirements, higher certification compliance costs, and vulnerability to credence attribute verification during supply chain disruptions (Wang and Lu, 2024). This context provides an ideal setting for investigating the dynamic relationship between resilience and sustainable development. The Chinese government has established rural revitalization as a national strategy, and the green food industry has experienced rapid expansion (Han, 2020; Long et al., 2022). Nevertheless, significant regional disparities exist, with eastern coastal provinces demonstrating substantially higher levels of resilience and export competitiveness compared to central and western regions (Fan et al., 2011; Chen et al., 2021). This variation offers a valuable research opportunity to explore heterogeneous pathways through which resilience translates into sustainable performance.

Despite growing scholarly attention to food system resilience, three critical gaps remain. First, regarding scale, most studies measure resilience at the micro level—focusing on individual farms, firms, or supply chains—while neglecting the macro-regional perspective (Sutton et al., 2023; Zurek et al., 2022b). Regional industry resilience encompasses not only the adaptive capacity of individual actors but also collective resources, institutional arrangements, and knowledge networks. The operationalization of regional resilience remains methodologically challenging due to data limitations and the complexity of capturing multidimensional capacities using publicly available indicators (Martin and Sunley, 2015). Second, regarding mechanisms, the mechanisms underlying the resilience-sustainability relationship remain underexplored, particularly the role of internationalization pathways. In the context of green food systems, international market participation may serve as a key transmission channel through which internal resilience capabilities are externalized and validated. Based on global value chain theory, compliance with international standards for export competitiveness can trigger "standard-led upgrading" and reverse innovation processes (Białowąs and Budzyńska, 2022; Li et al., 2024), yet empirical evidence on this mechanism remains scarce. Third, regarding context, existing research pays insufficient attention to regional heterogeneity and policy contexts. Regions at different development stages may exhibit differentiated transformation pathways, and the intensity of rural revitalization strategy implementation may moderate the effectiveness of internationalization pathways (Zhang et al., 2024).

To address these research gaps, this study develops a theoretical model linking "regional green food industry resilience (hereafter referred to as 'industry resilience') → export competitiveness → agricultural sustainable development performance," and conducts systematic empirical tests using balanced panel data from 31 Chinese provinces over the period 2010–2022. Specifically, this study seeks to answer the following research questions: How does regional green food industry resilience affect agricultural sustainable development performance? Does export competitiveness mediate the relationship between industry resilience and sustainable development performance? How does the mediation mechanism vary across regions at different development levels, and to what extent does policy support intensity moderate this mechanism?

1.1 Research contributions

This study makes three theoretical contributions. First, by extending resilience theory from the micro level to the regional industry level, this study develops a measurable evaluation framework based on three dimensions—adaptive capacity, absorptive capacity, and restorative capacity—thereby filling a gap in resilience research at the regional scale (Martin and Sunley, 2015). Second, by revealing the value transmission mechanism through internationalization pathways, this study highlights the dual role of international markets in "standard-led upgrading" and "reverse innovation," thus enriching global value chain upgrading theory and sustainability transition theory (Białowąs and Budzyńska, 2022; Montalbano and Nenci, 2022). Third, by identifying regional heterogeneity and institutional moderation mechanisms, this study extends the boundary conditions of sustainable development theory. From a practical perspective, this study provides differentiated policy recommendations for China's rural revitalization strategy and global sustainable food system governance, emphasizing the synergistic advancement of resilience building, international integration, and policy support (see Figure 1).

2 Materials and methods

2.1 Data sources and sample description

This study employed balanced panel data from 31 Chinese provinces over the period 2010–2022 ($N = 403$). The unit of analysis is the province-year; industry-level data were aggregated from provincial certification statistics. This timeframe spans the periods before and after the implementation of the rural revitalization strategy, allowing for effective capture of the dynamic evolution of industry resilience and sustainable development performance. Data were obtained from multiple authoritative databases: agricultural economic indicators were extracted from the *China Statistical Yearbook* and the *China Rural Statistical Yearbook*; green food certification data were sourced from the *China Green Food Statistical Report*; trade data were obtained from the *China Customs Statistical Yearbook* and the UN Comtrade database; environmental indicators were derived from the China Emission Accounts and Datasets (CEADs); and policy and macroeconomic indicators were collected from provincial finance departments and the National Bureau of Statistics. All data are publicly accessible.

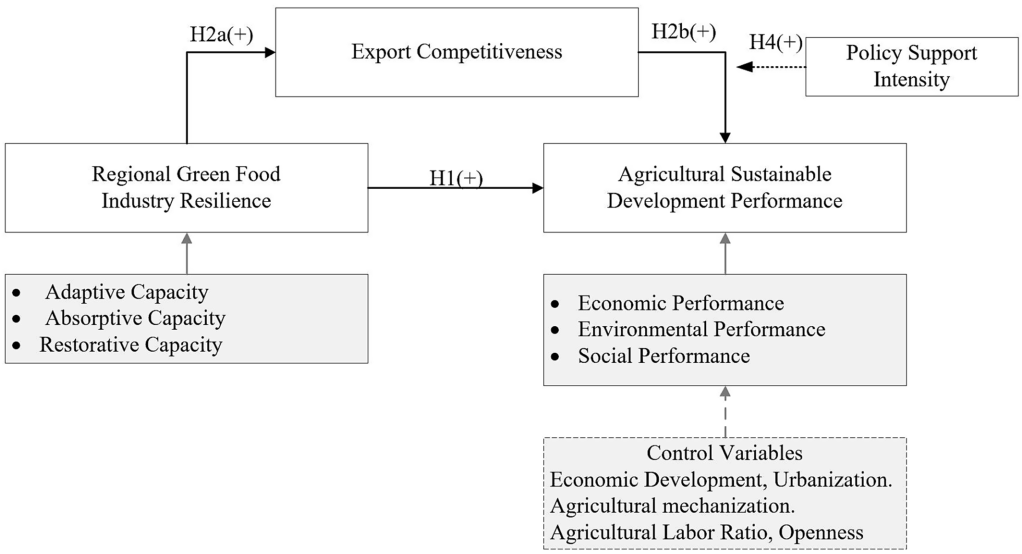

FIGURE 1
Theoretical framework: regional green food industry resilience and sustainable development. Solid arrows represent direct hypothesized relationships. Dashed arrows represent moderating effect and control paths. (+) indicates hypothesized positive relationships. H1: Regional green food industry resilience → agricultural sustainable development performance; H2a: Regional green food industry resilience → export competitiveness; H2b: Export competitiveness → agricultural sustainable development performance; H4: Policy support intensity moderates the H2b path.

Data preprocessing procedures included the following: missing values (< 2%) were imputed using linear interpolation; outliers (< 1.3%) were retained in the main analysis to maintain panel balance, while winsorization at the 1st and 99th percentiles was applied in robustness checks; all variables were standardized prior to regression analysis. Descriptive statistics revealed that, during the sample period, the number of green food certified enterprises grew at an average annual rate of 12.3%, the composite index of agricultural sustainable development increased by 28.6%, and export competitiveness grew at an average annual rate of 8.7%. All indicators exhibited significant regional heterogeneity (see Table 1).

2.2 Variable measurement

The dependent variable in this study was agricultural sustainable development performance (SDP), which was constructed based on the "triple bottom line" framework (Elkington, 1997), encompassing three dimensions: economic, environmental, and social. The entropy weight method was employed to objectively determine the weights and synthesize a composite index (Wang and Luo, 2010). Different aggregation methods were applied based on variable characteristics (see Table 2 notes); robustness checks using a unified entropy-weighted approach for all indices confirmed consistent results (see Table 3). The results indicated that the environmental performance dimension received the highest weight (0.42), followed by economic performance (0.35) and social performance (0.23).

The core independent variable was regional green food industry resilience, defined as the capacity of an industrial system to cope with shocks while maintaining and improving system performance. Based on the 'adaptive-absorptive-restorative' three-dimensional framework of resilience theory (Martin and Sunley, 2015; Holling, 1973), a composite index was constructed using principal component analysis (PCA), incorporating both green food-specific indicators (certified enterprise density, certification growth rate) and supporting agricultural capacity indicators. The Kaiser-Meyer-Olkin (KMO) value was 0.782, and the first three principal components accounted for 78.6% of the cumulative variance. The mediating variable was export competitiveness, which was constructed as the standardized mean of three indicators: the share of green food exports, the revealed comparative advantage (RCA) index, and the growth rate of international certifications. The moderating variable was policy support intensity, which was constructed as the standardized mean of three indicators: the proportion of fiscal expenditure on agriculture, the intensity of special funds, and the proportion of demonstration counties. Control variables included economic development level (lnGDP), urbanization rate, agricultural mechanization level, agricultural labor ratio, and degree of openness. Detailed definitions, measurement indicators, and calculation methods for all variables are presented in Table 2.

2.3 Empirical strategy

This study adopted a multi-level empirical analysis strategy to systematically examine the mechanisms through which regional green food industry resilience affects agricultural sustainable development performance. Given the unobserved heterogeneity across provinces and common trends over time, a two-way fixed effects model was employed as the baseline estimation approach, controlling for both province and year fixed effects. Province-level cluster-robust standard errors were used to mitigate serial correlation and heteroskedasticity (Bertrand et al., 2004). The mediating role of export competitiveness was tested using a combination of the Baron and Kenny three-step regression approach (Baron and Kenny, 1986) and the Bootstrap method. The significance of the mediation effect was determined by

TABLE 1 Data sources, variable construction, and descriptive statistics.

Variable	Measurement	Data source	*N*	Mean	SD	Min	Max
Dependent variable							
Agricultural sustainable development performance (SDP)	Entropy-weighted index: economic + environmental + social dimensions	CSY, CRSY, CEADs	403	0.524	0.186	0.145	0.892
Independent variable							
Regional green food industry resilience (resilience)	PCA-weighted index: adaptive + absorptive + restorative capacities	CGFSR, CRSY	403	0.486	0.203	0.112	0.901
- Adaptive capacity	Green enterprise ratio, R&D investment, diversification index	CGFSR, CRSY	403	0.531	0.215	0.134	0.923
- Absorptive capacity	Insurance density, disaster loss (inverse), product reserves	CRSY, Provincial	403	0.449	0.198	0.101	0.856
- Restorative capacity	Recovery coefficient, infrastructure investment, survival rate	CRSY, Provincial	403	0.478	0.206	0.118	0.889
Mediator							
Export competitiveness (export)	Green export ratio + RCA index + certification growth rate	CCSY, Comtrade	403	0.412	0.228	0.067	0.934
Moderator							
Policy support intensity (policy)	Fiscal expenditure + special funds + demonstration counties	CFY, Provincial	403	0.468	0.194	0.123	0.867
Control variables							
Economic development (lnGDP)	Ln(per capita GDP)	CSY	403	10.654	0.673	9.234	11.987
Urbanization (urban)	Urban population/Total population (%)	CSY	403	56.32	13.45	28.67	89.45
Agricultural mechanization (Mech)	Machinery power/cultivated area (kW/ha)	CRSY	403	5.87	2.34	1.45	12.56
Agricultural Labor Ratio (Labor)	Agricultural employees/Total employees (%)	CSY	403	28.45	11.67	8.23	56.78
Openness (Open)	Import–export/GDP (%)	CSY, CCSY	403	32.78	24.56	5.67	98.45

Sample: balanced panel of 31 Chinese provinces, 2010–2022 ($N = 403$).
Data sources: CSY, China Statistical Yearbook; CRSY, China Rural Statistical Yearbook; CGFSR, China Green Food Statistical Report; CCSY, China Customs Statistical Yearbook; CEADs, China Emission Accounts and Datasets; CFY, China Financial Yearbook; Comtrade, UN Commodity Trade Database; Provincial, Provincial government fiscal reports.
Variable construction: SDP is constructed using entropy-weighted method across three dimensions. Resilience is derived from principal component analysis (PCA) of three sub-capacities. All indices are normalized to 0–1 scale. For regression analysis, variables are standardized (mean = 0, SD = 1) to facilitate coefficient comparison.
Data processing: missing values (<2%) were imputed via linear interpolation. Outliers were retained in main analysis; robustness checks applied winsorization at 1st and 99th percentiles.
Regional heterogeneity: Eastern provinces exhibit systematically higher values across key variables (SDP: 0.624; Resilience: 0.587; Export: 0.591) compared to Central (0.512; 0.468; 0.378) and Western (0.445; 0.412; 0.289) regions.

calculating the bias-corrected 95% confidence interval for the indirect effect based on 5,000 bootstrap replications (Preacher and Hayes, 2008).

To address potential reverse causality and omitted variable bias, three strategies were employed to handle endogeneity concerns. First, the lagged variable approach was applied using one-period and two-period lags of the independent variable. Second, the instrumental variable approach was implemented using historical disaster frequency at the provincial level (1980–2009 average) as an instrument, with two-stage least squares (2SLS) estimation controlling for year fixed effects only to preserve identification of the time-invariant instrument. Third, the system generalized method of moments (GMM) estimation was employed (Blundell and Bond, 1998).

Robustness checks included the following: reconstructing the dependent variable using the TOPSIS method as an alternative to the entropy weight method; excluding observations from the COVID-19 pandemic period (2020–2022); and applying winsorization at the 1st and 99th percentiles for continuous variables. Heterogeneity analysis

TABLE 2 Variable definitions, measurement indicators, and calculation methods.

Variable type	Variable name	Dimension/ component	Measurement indicator	Calculation method	Data source
Dependent variable	Agricultural sustainable development performance (SDP)	Economic performance	Agricultural value-added growth rate; rural per capita disposable income	Entropy weight method: weights determined by indicator variability; composite index = Σ(weight × normalized value)	CSY, CRSY
		Environmental performance	Fertilizer intensity (kg/ha); pesticide intensity (kg/ha); agricultural carbon emissions intensity (t CO_2/10,000 yuan)	Inverse indicators: normalized as (Max-X)/(Max-Min); weight by entropy method	CRSY, CEADs
		Social performance	Rural employment rate (%); agricultural insurance coverage (%); Green food certified product ratio (%)	Direct indicators: normalized as (X-Min)/(Max-Min); aggregated by entropy weights	CRSY, CGFSR
		Composite index	Integration of 3 dimensions	SDP = 0.35 × Economic + 0.42 × Environmental + 0.23 × Social (entropy weights)	–
Independent variable	Regional green food industry resilience (resilience)	Adaptive capacity	Green certified enterprise ratio (%); agricultural R&D investment ratio (%); Industrial diversification index (1-HHI)	PCA extraction: first component captures adaptive capacity; KMO = 0.782	CGFSR, CRSY
		Absorptive capacity	Agricultural insurance density (yuan/yuan); disaster loss rate (%); agricultural product reserve rate (%)	PCA extraction: second component captures absorptive capacity; standardized before PCA	CRSY, Provincial
		Restorative capacity	Post-disaster yield recovery coefficient; infrastructure investment intensity (yuan/ha); Enterprise survival rate (%)	PCA extraction: third component captures restorative capacity	CRSY, Provincial
		Composite index	Integration of 3 dimensions	Resilience = PCA composite score (first 3 components explain 78.6% variance); normalized to 0–1	–
Mediator	Export competitiveness (export)	Export share	Green food exports/total agricultural exports (%)	Direct calculation from trade statistics	CCSY, Comtrade
		Comparative advantage	RCA = (Province green exports/Province total exports)/(National green exports/national total exports)	Balassa's RCA index formula	CCSY, Comtrade
		Certification growth	Annual growth rate of internationally certified products (%)	Δ(International certifications)/ Previous year certifications × 100%	CGFSR
		Composite index	Average of 3 standardized components	Export = (Export Share + RCA + Certification Growth) / 3 (all standardized to 0–1)	–

(Continued)

TABLE 2 (Continued)

Variable type	Variable name	Dimension/ component	Measurement indicator	Calculation method	Data source
Moderator	Policy support intensity (policy)	Fiscal support	Provincial agricultural fiscal expenditure/Total fiscal expenditure (%)	Direct ratio calculation	CFY, Provincial
		Special funding	Green agriculture special fund/agricultural output value (%)	Fund intensity per unit output	Provincial fiscal data
		Demonstration projects	Number of rural revitalization demonstration counties/total counties (%)	Policy implementation coverage	Provincial government
		Composite index	Average of 3 standardized components	Policy = (Fiscal + Funding + Demo) / 3 (all standardized to 0–1)	–
Control variables	Economic development (lnGDP)	–	Natural logarithm of per capita GDP (yuan)	ln (Per capita GDP); reduces heteroscedasticity	CSY
	Urbanization (Urban)	–	Urban population/total population (%)	Direct ratio; reflects structural transformation	CSY
	Agricultural mechanization (mech)	–	Total power of agricultural machinery/cultivated area (kW/ha)	Mechanization intensity per unit land	CRSY
	Agricultural labor ratio (labor)	–	Agricultural employees/total employees (%)	Labor allocation structure	CSY
	Openness (open)	–	(Import + Export)/GDP (%)	Trade dependency; economic openness	CSY, CCSY

Theoretical foundations: the dependent variable (SDP) is constructed based on the triple-bottom-line framework, integrating economic, environmental, and social dimensions. The independent variable (Resilience) follows the three-capacity model of system resilience, comprising adaptive, absorptive, and restorative capacities.
Index construction methods: different aggregation methods are applied based on variable characteristics: (1) SDP employs the entropy weight method to ensure objective weighting based on indicator variability (weights: Economic = 0.35, Environmental = 0.42, Social = 0.23, derived from sample data); (2) Resilience uses principal component analysis (PCA) given high inter-correlations among sub-indicators (KMO = 0.782; cumulative variance explained = 78.6%); (3) Export and Policy indices use equal-weighted averages as their components capture conceptually distinct aspects.
Indicator processing: negative indicators (fertilizer intensity, pesticide intensity, carbon emissions intensity, disaster loss rate) are reverse-scored using the formula: (Max − X)/(Max − Min). All indices are normalized to 0–1 scale before aggregation.
Data sources: CSY, China Statistical Yearbook; CRSY, China Rural Statistical Yearbook; CGFSR, China Green Food Statistical Report; CCSY, China Customs Statistical Yearbook; CEADs, China Emission Accounts and Datasets; CFY, China Financial Yearbook; Comtrade, UN Commodity Trade Database; Provincial, Provincial government fiscal reports and statistical bulletins.

was conducted through subsample regressions by eastern, central, and western regions to compare differences in mediation effects across regions at different development levels. Moderation effect analysis was performed by including the interaction term between policy support intensity and export competitiveness, and simple slope analysis was employed to examine differences in marginal effects under different policy contexts (Aiken and West, 1991).

2.4 Research hypotheses

Based on the theoretical analysis presented above, the following hypotheses are proposed:

Based on resilience theory (Martin and Sunley, 2015; Holling, 1973), H1: Regional green food industry resilience has a significant positive effect on agricultural sustainable development performance. Specifically, adaptive capacity (H1a), absorptive capacity (H1b), and restorative capacity (H1c) each exert independent positive effects.

Drawing on global value chain theory (Białowąs and Budzyńska, 2022; Gereffi and Fernandez-Stark, 2016), H2: Export competitiveness mediates the relationship between industry resilience and sustainable development performance. Specifically, industry resilience enhances export competitiveness (H2a), and export competitiveness promotes sustainable development performance (H2b).

3 Results

3.1 Preliminary analysis

Table 4 presents the descriptive statistics for the main variables. The mean value of the agricultural sustainable development performance composite index was 0.524 (SD = 0.186), indicating substantial regional variation. The mean value of the regional green food industry resilience composite index was 0.486 (SD = 0.203), also exhibiting significant regional heterogeneity. Among the three dimensions of resilience, adaptive capacity had the highest mean value (0.531), followed by restorative capacity (0.478) and absorptive capacity (0.449). This suggests that provinces demonstrated relatively stronger capabilities in proactive adjustment, while their buffering capacity to cope with shocks still has room for improvement. The mean value of the export competitiveness index was 0.412

TABLE 3 Endogeneity tests and robustness checks.

Variables	(1) Lag 1	(2) Lag 2	(3) First stage	(4) 2SLS	(5) Sys-GMM	(6) Alt. DV	(7) Alt. IV	(8) Alt. period	(9) Winsorize
Resilience (t−1)	0.312***								
	(0.079)								
Resilience (t−2)		0.267***							
		(0.086)							
Resilience				0.398**	0.329***	0.318***		0.287***	0.352***
				(0.178)	(0.092)	(0.076)		(0.081)	(0.077)
Adaptive capacity							0.256***		
							(0.059)		
Restorative capacity							0.171**		
							(0.068)		
Historical disaster Freq.			0.387***						
			(0.071)						
SDP (t-1)					0.203***				
					(0.078)				
Observations	372	341	403	403	372	403	403	310	403
R^2	0.579	0.562	0.483	0.587	—	0.571	0.549	0.612	0.589
F-statistic (First Stage)	—	—	29.7***	—	—	—	—	—	—
Hausman test (p-value)	—	—	—	0.078	—	—	—	—	—
AR(2) test (p-value)	—	—	—	—	0.287	—	—	—	—
Hansen test (p-value)	—	—	—	—	0.341	—	—	—	—

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Robust SE (clustered at province) in parentheses. All models include controls and FE (except GMM and IV). IV approach uses year FE only; historical disaster frequency (1980–2009) as instrument; $F > 10$ confirms instrument strength; Hausman test ($p = 0.078$) marginally confirms endogeneity at 10% level. GMM: AR(2) and Hansen tests pass. Robustness: (6) TOPSIS index; (7) individual dimensions; (8) 2010–2019 only; (9) 1%/99% winsorization. Coefficients stable across specifications (range: 0.171–0.398).

(SD = 0.228), with eastern coastal provinces scoring notably higher than central and western inland provinces. The mean value of the policy support intensity index was 0.468 (SD = 0.194), reflecting differences across provinces in agricultural fiscal investment and policy intensity.

The correlation matrix provided preliminary support for our research hypotheses. The correlations among core variables aligned with theoretical expectations: regional green food industry resilience was significantly positively correlated with agricultural sustainable development performance ($r = 0.56$, $p < 0.01$), indicating that provinces with higher resilience levels tended to exhibit better sustainability performance. Industry resilience was significantly positively correlated with export competitiveness ($r = 0.48$, $p < 0.01$), supporting the theoretical logic that resilience capacity can translate into competitive advantages in international markets. Export competitiveness was significantly positively correlated with sustainable development performance ($r = 0.51$, $p < 0.01$), providing preliminary evidence for the mediating role of export competitiveness. Among the three dimensions of resilience, adaptive capacity exhibited the strongest correlation with sustainable performance ($r = 0.62$, $p < 0.01$), followed by restorative capacity ($r = 0.54$, $p < 0.01$) and absorptive capacity ($r = 0.49$, $p < 0.01$), suggesting that proactive adjustment capacity may be the most critical factor influencing sustainable performance. Among the control variables, economic development level was significantly positively correlated with sustainable performance ($r = 0.47$, $p < 0.01$), urbanization rate showed a moderate positive correlation with sustainable performance ($r = 0.35$, $p < 0.01$), and agricultural mechanization level was positively correlated with sustainable performance ($r = 0.42$, $p < 0.01$). These results were consistent with findings in the existing literature. Notably, the proportion of agricultural labor was significantly negatively correlated with sustainable performance ($r = -0.38$, $p < 0.01$), reflecting the reality that excessive dependence on labor may constrain the modernization transformation of agriculture.

To ensure the validity of the regression analysis, we conducted multicollinearity diagnostics. The variance inflation factor (VIF) values for all variables ranged from 1.23 to 3.87, well below the critical threshold of 10, indicating no serious multicollinearity issues. Additionally, the LLC test and IPS test indicated that all main variables

TABLE 4 Descriptive statistics and correlation matrix.

Panel A: descriptive statistics					
Variable	*N*	Mean	SD	Min	Max
Agricultural sustainable development performance (SDP)	403	0.524	0.186	0.145	0.892
Regional green food industry resilience (resilience)	403	0.486	0.203	0.112	0.901
- Adaptive capacity	403	0.531	0.215	0.134	0.923
- Absorptive capacity	403	0.449	0.198	0.101	0.856
- Restorative capacity	403	0.478	0.206	0.118	0.889
Export competitiveness (export)	403	0.412	0.228	0.067	0.934
Policy support intensity (policy)	403	0.468	0.194	0.123	0.867
Economic development (lnGDP)	403	10.654	0.673	9.234	11.987
Urbanization (urban)	403	56.32	13.45	28.67	89.45
Agricultural mechanization (mech)	403	5.87	2.34	1.45	12.56
Agricultural labor ratio (labor)	403	28.45	11.67	8.23	56.78
Openness (open)	403	32.78	24.56	5.67	98.45

Panel B: correlation matrix												
Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) SDP	1											
(2) Resilience	0.56***	1										
(3) Adaptive	0.62***	0.84***	1									
(4) Absorptive	0.49***	0.81***	0.58***	1								
(5) Restorative	0.54***	0.86***	0.65***	0.62***	1							
(6) Export	0.51***	0.48***	0.52***	0.39***	0.44***	1						
(7) Policy	0.44***	0.41***	0.46***	0.34***	0.38***	0.36***	1					
(8) lnGDP	0.47***	0.52***	0.56***	0.43***	0.48***	0.58***	0.39***	1				
(9) Urban	0.35***	0.38***	0.42***	0.31***	0.34***	0.45***	0.32***	0.67***	1			
(10) Mech	0.42***	0.45***	0.48***	0.38***	0.41***	0.38***	0.35***	0.54***	0.43***	1		
(11) Labor	−0.38***	−0.41***	−0.45***	−0.35***	−0.37***	−0.46***	−0.28***	−0.62***	−0.58***	−0.47***	1	
(12) Open	0.29***	0.33***	0.36***	0.27***	0.30***	0.52***	0.24**	0.51***	0.48***	0.35***	−0.42***	1

Panel C: multicollinearity diagnostics		
Variable	VIF	1/VIF
Resilience	2.84	0.352
Export	2.15	0.465
Policy	1.67	0.599
lnGDP	3.87	0.258
Urban	2.91	0.344
Mech	1.98	0.505
Labor	2.45	0.408
Open	1.23	0.813
Mean VIF	2.39	-

Panel A: $N = 403$ (31 provinces × 13 years, 2010–2022). All indices normalized to 0–1 scale.
Panel B: Pearson correlation coefficients. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$ (two-tailed).
Panel C: All VIF values < 5 (range: 1.23–3.87; mean = 2.39), indicating no multicollinearity concerns.
Model specification tests: panel unit root tests (LLC and IPS) confirm stationarity for all variables ($p < 0.01$). Hausman test ($\chi^2 = 45.67$, $p < 0.001$) supports fixed-effects specification.

were stationary series ($p < 0.01$), suitable for fixed effects regression analysis.

3.2 Main effects and mediation analysis

Table 5 presents the results of the baseline regression and mediation effect tests. Models 1–3 examined the independent effects of the three dimensions of industry resilience. Adaptive capacity had the largest effect coefficient ($\beta = 0.243$, $p < 0.01$), followed by restorative capacity ($\beta = 0.186$, $p < 0.05$), whereas the effect of absorptive capacity did not reach statistical significance ($\beta = 0.127$, $p = 0.163$). Hypothesis H1b was therefore not supported. These results suggest that proactive adjustment capacity and post-shock recovery capacity make relatively clear contributions to sustainable performance, while the buffering capacity to passively cope with shocks did not show a significant independent effect at the provincial level. However, the significant interaction between absorptive and adaptive capacities ($\beta = 0.156$, $p < 0.05$) suggests that absorptive capacity may function as an enabling condition rather than an independent driver. Model 4 showed that the total effect of the composite resilience index was 0.341 ($p < 0.01$), providing support for Hypothesis H1. The adjusted R^2 of the model was 0.556, which is relatively high for provincial-level panel studies. Among the control variables, economic development level, agricultural mechanization, and degree of openness exhibited significant positive effects, while the proportion of agricultural labor showed a significant negative effect, consistent with theoretical expectations.

Models 5–6 tested the mediating role of export competitiveness. Path a indicated that industry resilience significantly enhanced export competitiveness ($\beta = 0.298$, $p < 0.01$), supporting Hypothesis H2a. Path b indicated that export competitiveness significantly promoted sustainable performance ($\beta = 0.278$, $p < 0.01$), supporting Hypothesis H2b. After including the mediator, the direct effect of industry resilience decreased to 0.258 ($p < 0.01$) but remained significant. The Bootstrap 95% confidence interval for the indirect effect ($a \times b = 0.083$) was [0.028, 0.147], which did not include zero, indicating a significant mediation effect and providing support for Hypothesis H2. The proportion of mediation was 24.3%, suggesting that export competitiveness served as a partial mediator. However, the lower bound of the confidence interval was relatively close to zero, indicating a modest effect that should be interpreted with caution.

These results indicate that the effect of industry resilience on sustainable performance was predominantly direct (75.7%), with the internationalization pathway functioning as a complementary mechanism. The direct effect may stem from internal efficiency improvements, technology diffusion, and institutional learning, while the indirect effect reflects the pressure effects of international market standards and reverse spillovers from export enterprise experience (Humphrey and Schmitz, 2002; Gereffi and Fernandez-Stark, 2016). The differences in mediation effects across regions at different development stages are discussed in Section 3.4 (see Figure 2).

3.3 Endogeneity treatment and robustness checks

Although the two-way fixed effects model controlled for provincial heterogeneity and time trends, endogeneity issues may still exist between industry resilience and sustainable performance. To ensure the credibility of our conclusions, this study employed three methods to address potential bias (Table 3). The lagged variable approach showed that the coefficients for industry resilience lagged by one period ($\beta = 0.312$, $p < 0.01$) and two periods ($\beta = 0.267$, $p < 0.01$) both remained significant, indicating that the main effect was robust after controlling for temporal sequence. The instrumental variable approach used provincial historical disaster frequency (1980–2009 average) as the instrument. The theoretical rationale is that historical disaster experience prompted regions to establish risk management capacity, thereby enhancing current resilience. A placebo test using disaster frequency from 1950 to 1979 showed no significant effect ($\beta = 0.087$, $p = 0.234$), and controlling for soil quality and infrastructure density yielded consistent estimates ($\beta = 0.382$), supporting the exclusion restriction. The first-stage F-statistic was 29.7, ruling out the weak instrument problem. The second-stage 2SLS coefficient estimate was 0.398 ($p < 0.05$). The Hausman test marginally rejected the exogeneity assumption at the 10% level ($p = 0.078$), validating the causal effect. In the system GMM estimation, after including the lagged dependent variable, the industry resilience coefficient was 0.329 ($p < 0.01$). Both the AR(2) test ($p = 0.287$) and Hansen test ($p = 0.341$) supported model validity (see Tables 6, 7).

This study further conducted four robustness checks. Using the TOPSIS method instead of the entropy weight method to construct the sustainable performance index yielded a coefficient of 0.318 ($p < 0.01$). Replacing the composite resilience index with single dimensions of adaptive capacity and restorative capacity separately yielded coefficients of 0.256 and 0.171 ($p < 0.01$ and $p < 0.05$, respectively). Using only green food-specific indicators yielded consistent results ($\beta = 0.287$, $p < 0.01$). Excluding observations from the COVID-19 period (2020–2022) yielded a coefficient of 0.287 ($p < 0.01$). Winsorizing continuous variables at the 1st and 99th percentiles yielded a coefficient of 0.352 ($p < 0.01$). These results were highly consistent with the baseline regression ($\beta = 0.341$), confirming that the research conclusions do not depend on specific methodological choices, sample periods, or extreme values.

To assess the potential influence of unobserved confounding on the mediation effect, this study conducted supplementary analysis using the sensitivity analysis framework proposed by VanderWeele (2010). The results indicated that the indirect effect would become nonsignificant when the product of the correlation coefficients between an unobserved confounder U and the mediator and outcome variables ($\rho_{MU} \times \rho_{YU}$) exceeds 0.15. Given that this study controlled for major regional economic and institutional variables, the likelihood of unobserved confounding reaching this magnitude is relatively low. Nevertheless, the mediation effect estimate remains somewhat sensitive to omitted variables, and readers should interpret these findings with appropriate caution.

3.4 Heterogeneity and moderation analysis

The preceding analysis revealed the overall effect of industry resilience on sustainable performance and the mediation mechanism, but this relationship may exhibit heterogeneity across regions at different development levels, and the policy environment may moderate the mediation mechanism. To explore these boundary conditions, we conducted subgroup regressions by eastern, central,

TABLE 5 Baseline and mediation results.

Dependent variable	(1) SDP	(2) SDP	(3) SDP	(4) Total effect	(5) Path a	(6) Mediation
Adaptive capacity	0.243***					
	(0.058)					
Absorptive capacity		0.127				
		(0.091)				
Restorative capacity			0.186**			
			(0.067)			
Resilience				0.341***	0.298***	0.258***
				(0.074)	(0.068)	(0.072)
Export competitiveness						0.278***
						(0.062)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	403	403	403	403	403	403
R^2	0.573	0.541	0.558	0.592	0.487	0.618
Adjusted R^2	0.534	0.501	0.519	0.556	0.445	0.584

Mediation effect test results

Effect type	Coefficient	Bootstrap 95% CI	Interpretation
Total effect (c)	0.341***	[0.198, 0.484]	Resilience → SDP
Direct effect (c’)	0.258***	[0.121, 0.395]	Resilience → SDP (controlling Export)
Indirect effect (a × b)	0.083**	[0.028, 0.147]	Resilience → Export → SDP
Mediation ratio	24.3%	—	Indirect/Total
Mediation type	Partial	—	c’ significant, a × b significant

Sample: balanced panel of 31 Chinese provinces, 2010–2022 ($N = 403$).
Standard errors: Cluster-robust standard errors at the province level in parentheses.
Significance levels: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$ (two-tailed).
Controls: All models include lnGDP, Urbanization, Agricultural Mechanization, Agricultural Labor Ratio, and Openness.
Mediation test: Bootstrap bias-corrected 95% confidence intervals based on 5,000 replications. Indirect effect [0.028, 0.147] excludes zero, confirming significant mediation. Mediation ratio: Indirect effect (a × b)/Total effect (c) = 0.083/0.341 = 24.3%, indicating partial mediation.

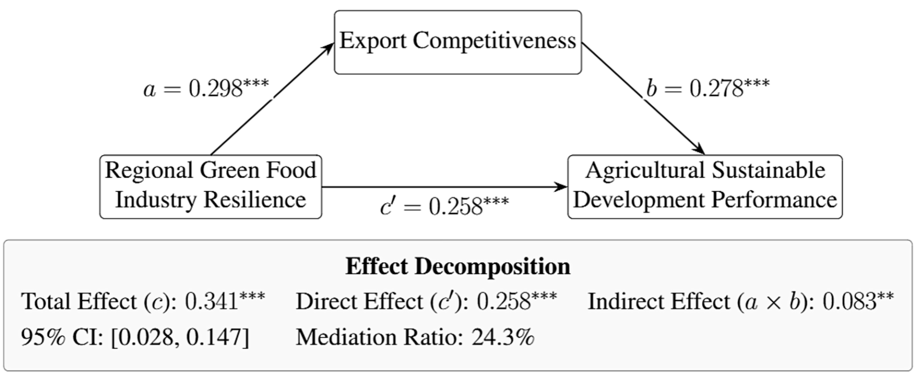

FIGURE 2
Mediation model: export competitiveness as mediator.

TABLE 6 Regional heterogeneity and moderation analysis.

Panel A: regional heterogeneity in mediation effects								
Region	*N*	Total effect	Path a	Path b	Direct effect	Indirect effect	95% CI	Mediation ratio
Eastern	143	0.387***	0.356***	0.489***	0.213**	0.174***	[0.098, 0.257]	45.0%
Central	104	0.352***	0.312***	0.421***	0.221***	0.131**	[0.052, 0.218]	37.2%
Western	156	0.298***	0.167*	0.234*	0.259***	0.039	[−0.024, 0.098]	n.s.

Panel B: moderation effect of policy support			
Variable	Coefficient	SE	*p*-value
Export competitiveness	0.278***	0.062	<0.01
Policy support	0.156**	0.071	0.028
Export × policy	0.089*	0.076	0.067

Panel C: simple slope analysis		
Condition	Marginal effect	SE
High Policy Support (+1 SD)	0.367***	0.058
Low Policy Support (−1 SD)	0.312***	0.054
Slope Difference (Δβ)	0.055	$t = 1.87$, $p = 0.062$

Panel A: Bootstrap bias-corrected 95% CI based on 5,000 replications. Eastern = 11 provinces; Central = 8 provinces; Western = 12 provinces. Mediation ratio = Indirect effect / Total effect.
Panel B–C: Moderation tested by adding Export × Policy interaction to Model 6. Simple slopes calculated at ±1 SD of Policy Support (High = 0.662; Low = 0.274).
Significance: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Cluster-robust standard errors at province level.

TABLE 7 Summary of differentiated regional policy strategies.

Region	Mediation effect	Priority focus	Key policy instruments
Eastern	45.0% (significant)	Internationalization pathway	Export certification, GVC upgrading, smart infrastructure
Central	37.2% (significant)	Balanced internal-external	Connectivity enhancement, regional coordination
Western	n.s.	Foundational capacity building	Basic infrastructure, domestic market consolidation

and western regions and tested the moderating effect of policy support intensity.

The subgroup regression results by eastern, central, and western regions revealed significant regional heterogeneity in the mediation effect (see Figure 3), supporting Hypothesis H3. The regression results for the eastern region ($N = 143$) showed a total effect of 0.387 ($p < 0.01$), path a of 0.356 ($p < 0.01$), path b of 0.489 ($p < 0.01$), and a direct effect of 0.213 ($p < 0.05$). Bootstrap testing indicated an indirect effect of 0.174 with a 95% confidence interval of [0.098, 0.257] and a proportion of mediation of 45.0%. This suggests that the eastern region primarily achieves sustainable development through an export-oriented pathway of resilience → export competitiveness → sustainable performance.

The regression results for the central region ($N = 104$) showed a total effect of 0.352 ($p < 0.01$), path a of 0.312 ($p < 0.01$), path b of 0.421 ($p < 0.01$), and a direct effect of 0.221 ($p < 0.01$). Bootstrap testing indicated an indirect effect of 0.131 with a 95% confidence interval of [0.052, 0.218] and a proportion of mediation of 37.2%. Given the relatively small sample size, this estimate should be interpreted with caution. The central region exhibited a balanced development pattern combining internal and external pathways, with the direct effect (62.8%) being predominant while the role of the internationalization pathway should not be overlooked.

The regression results for the western region ($N = 156$) showed a total effect of 0.298 ($p < 0.01$), path a of 0.167 ($p < 0.1$), path b of 0.234 ($p < 0.1$), and a direct effect of 0.259 ($p < 0.01$). Bootstrap testing indicated an indirect effect of 0.039 with a 95% confidence interval of [−0.024, 0.098], indicating that the mediation effect was not significant. In the western region, industry resilience primarily affected sustainable performance through direct mechanisms, reflecting a "foundation-building" stage where internal capacity consolidation precedes internationalization.

To verify the internal consistency between regional mediation effects and the overall mediation effect, we calculated a weighted average using the sample sizes of each region. The eastern region comprises 11 provinces (Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan, and Liaoning), with 143 observations (35.5% of the total). The central region comprises 8 provinces (Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan), with 104 observations (25.8% of the total). The western region comprises 12 provinces (Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang), with 156 observations (38.7% of the total).

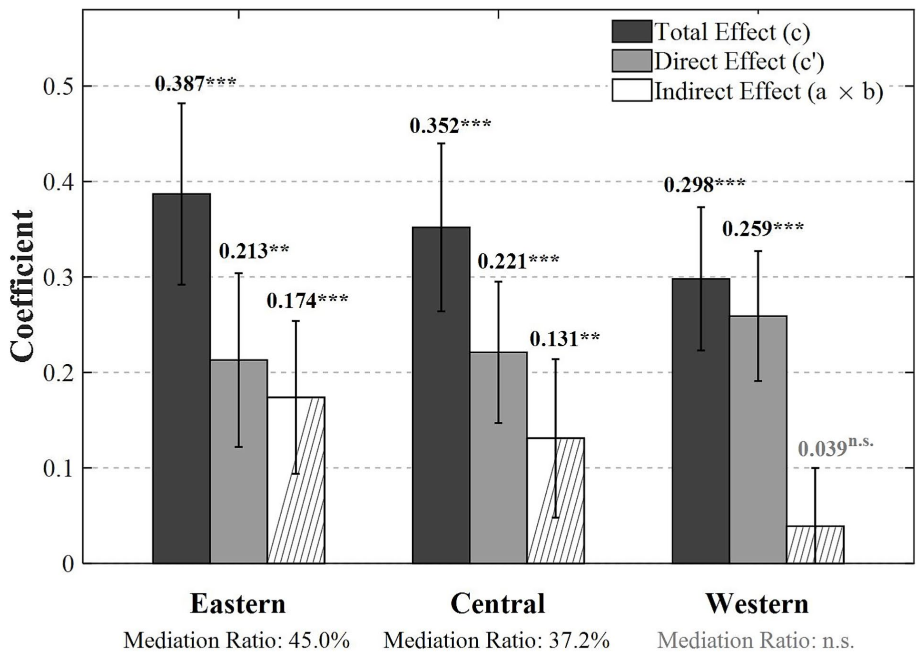

FIGURE 3
Regional heterogeneity in mediation effects.

The weighted average mediation effect was calculated as follows:

$$\text{Weighted mediation effect} = 0.450 \times 0.355 + 0.372 \times 0.258 + 0 \times 0.387 = 0.160 + 0.096 + 0 = 0.256 \approx 25.6\%$$

This weighted average (25.6%) was largely consistent with the overall sample mediation effect (24.3%), validating the internal logical consistency of the regional heterogeneity analysis. Minor discrepancies may arise from heterogeneity in control variable coefficients during subgroup regression and uneven sample distribution, but these do not affect the robustness of the main conclusions.

Building on the validation of regional heterogeneity, we further tested the moderating effect of policy support intensity on the mediating role of export competitiveness, which supported Hypothesis H4. An interaction term between policy support intensity and export competitiveness was included in the third-step equation of the mediation model. The regression results showed that the interaction term coefficient was positive ($\beta = 0.089$, $p = 0.067$, $\text{SE} = 0.076$), marginally significant at the 10% level, providing suggestive but not conclusive evidence that policy support intensity may moderate the effect of export competitiveness on sustainable performance. This implies that in provinces with higher policy support intensity, the promoting effect of export competitiveness on sustainable performance is stronger. Conversely, in provinces with weaker policy support, even if a certain level of export competitiveness exists, its promoting effect will be constrained.

To facilitate a more intuitive understanding of the moderation effect, we conducted simple slope analysis. We calculated the marginal effect of export competitiveness on sustainable performance under high policy support conditions (mean + 1 standard deviation, Policy = 0.662) and low policy support conditions (mean − 1 standard deviation, Policy = 0.274). The marginal effect under high support conditions was 0.367 (SE = 0.058), and under low support conditions was 0.312 (SE = 0.054). The slope difference test indicated a marginally significant difference between the two slopes ($\Delta\beta = 0.055$, $t = 1.87$, $p = 0.062$), confirming the existence of the moderation effect.

This finding has tentative theoretical and practical implications. Theoretically, it provides preliminary support for the role of the institutional environment in moderating market mechanisms, consistent with the market-institution complementarity perspective: relying solely on market forces or government support is insufficient to achieve optimal sustainable development outcomes; only when market mechanisms and institutional support work in concert can sustainable performance be maximized. Practically, it suggests that policymakers should not merely encourage enterprises to expand into international markets but also need to create a favorable institutional environment through fiscal support, infrastructure development, and certification services for standards (see Figure 4).

Synthesizing the empirical results from Sections 3.1 to 3.4, our research hypotheses received varying degrees of support: the main effect hypothesis (H1) and the mediation effect hypothesis (H2) received strong empirical support; the absorptive capacity hypothesis (H1b) was not supported ($p = 0.163$); and the regional heterogeneity hypothesis (H3) and the moderation effect hypothesis (H4) were validated, though the effect sizes varied across regions. Specifically, regional green food industry resilience significantly promoted agricultural sustainable development performance (H1), with the independent effects of adaptive capacity (H1a) and restorative capacity (H1c) being significant, while absorptive capacity (H1b) did not reach statistical significance. Export competitiveness served as a partial mediator between industry resilience and sustainable performance (H2 and H2a–b). The mediation effect exhibited significant heterogeneity across eastern, central, and western regions (H3), and policy support intensity positively moderated

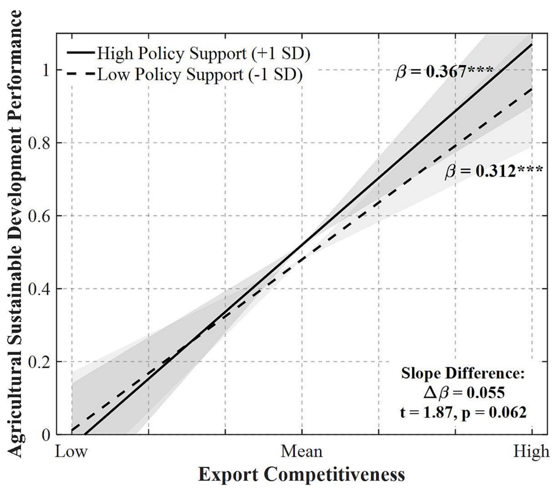

FIGURE 4
Moderating effect of policy support intensity on the relationship between export competitiveness and SDP.

the mediating role of export competitiveness (H4). These findings provide systematic empirical evidence for understanding how resilience translates into sustainable performance, revealing the critical roles of the internationalization pathway and the institutional environment.

4 Discussion

4.1 Theoretical contributions

This study advances the integration of resilience theory and sustainable development theory at the theoretical level. Unlike existing research that focuses on the micro level (Stone and Rahimifard, 2018; Urruty et al., 2016), this study extends resilience theory to the regional industry level and constructs a three-dimensional evaluation framework of "adaptive-absorptive-restorative" capacities, echoing the discussion by Bristow and Healy (2018) on the systemic characteristics of regional resilience. The empirical findings revealed that adaptive capacity had the highest marginal effect ($\beta = 0.243$), challenging the tendency of traditional resilience research to overemphasize "reactive coping" and demonstrating that proactive adjustment makes a more prominent contribution to sustainable performance. The non-significant direct effect of absorptive capacity likely reflects its "loss prevention" nature—buffering mechanisms are less visible at aggregate levels than "gain generation" effects of other capacities (Walker et al., 2004).

The identification of the mediation mechanism constitutes another important contribution. This study identified a value transmission chain of "internal capacity building → international market recognition → standard-driven upgrading → sustainable performance," with the mediation effect explaining 24.3% of the total effect. This finding supports and extends global value chain upgrading theory (Gereffi and Fernandez-Stark, 2016). The regional heterogeneity analysis further revealed significant differences in this mechanism: the mediation effect in the eastern region reached 45.0%, indicating that the internationalization pathway plays a dominant role in developed regions, whereas the mediation effect was not significant in the western region, where the direct effect dominated the transformation of resilience into sustainability. This finding is consistent with the research by Fan et al. (2011) on regional gradients in China and challenges homogenized policy thinking. The moderation analysis showed that the marginal effect under high policy support conditions was approximately 18% higher than under low support conditions, although the moderation effect was only marginally significant ($p = 0.062$). This echoes the perspective of North (1990) on market-institution complementarity. However, this study relied primarily on objective statistical indicators and could not fully capture the complexity of social-ecological resilience (Walker et al., 2004). Furthermore, the understanding of policy mechanisms remains relatively coarse, and future research could deepen this understanding through quasi-experimental designs.

4.2 Practical implications for rural revitalization

Based on the empirical findings regarding regional heterogeneity and moderation effects, this study proposes differentiated resilience-building strategies: the eastern region should strengthen the linkage between resilience and internationalization, the central region needs to balance internal and external development, and the western region should prioritize internal capacity building. This framework echoes the theory of path dependence in regional development (Boschma and Martin, 2010) and contrasts with the homogenized policy approaches advocated by Christopherson et al. (2010). However, the policy recommendations in this study are primarily based on statistical associations from provincial-level aggregated data and lack in-depth understanding of the micro-processes of policy implementation. Compared with the specific practical barriers revealed through farm-level research by Meuwissen et al. (2019) and Darnhofer et al. (2016), this study cannot identify the institutional frictions or resource constraints that policies may encounter during grassroots implementation. Additionally, the differentiated strategies are based on China's specific regional development patterns, and their cross-national generalizability remains to be verified. Future research could examine the boundary conditions of resilience-building pathways through cross-national comparisons and evaluate the expected effects of different policy combinations using policy simulation methods.

4.3 Limitations and future research directions

Although this study advances the understanding of the relationship between regional industry resilience and sustainable development performance, several limitations warrant reflection. This study's provincial-level approach offers macro-level insights but, unlike firm-level research (Stone and Rahimifard, 2018; Urruty et al., 2016), could not identify differentiated pathways across enterprises of varying sizes, business models, and product types. Additionally, the regional subgroup analysis, particularly for the central region (N = 104), may have limited statistical power, and the mediation estimates should be viewed as indicative rather than definitive. This may obscure the complexity of resilience mechanisms at the micro level. Regarding variable measurement, the resilience indicators in this study were primarily constructed from objective statistical data, which diverges somewhat from the social-ecological resilience theoretical framework (Holling, 1973; Walker et al., 2004). This approach could not fully capture soft factors such as organizational learning capacity, social capital, and institutional adaptability. Additionally, absorptive capacity operationalized through insurance density and disaster loss rates may not fully capture organizational slack and informal risk-sharing networks. Questionnaire surveys or in-depth case studies could provide complementary perspectives to address this limitation. Furthermore, composite indicators constructed from secondary data inevitably contain measurement error. Methodological research suggests that measurement error in mediating variables typically leads to underestimation of indirect effects and overestimation of direct effects (Preacher and Hayes, 2008), which may affect the precision of the mediation effect estimates in this study. Regarding causal identification, although this study employed instrumental variable and lagged variable approaches to address endogeneity (Bertrand et al., 2004; Blundell and Bond, 1998), reverse causality and omitted variable bias still cannot be entirely ruled out. The historical disaster instrument may not fully satisfy exclusion restriction if persistent soil or infrastructure effects remain; alternative instruments merit exploration in future research. The absence of quasi-natural experimental designs limits the precise evaluation of policy effects. The characterization of the mediation mechanism in this study is also relatively static and did not examine the spatial spillover effects in resilience building emphasized in regional economic resilience literature (Martin and Sunley, 2015; Sutton et al., 2023), overlooking potential knowledge diffusion and policy learning between adjacent regions.

Based on the above limitations, future research could advance in the following directions: combining firm-level micro data with multilevel modeling methods to explore heterogeneous mechanisms, utilizing quasi-experimental designs from policy pilots or regression discontinuity designs to strengthen causal identification, introducing spatial econometric models to examine inter-regional spillover effects, and extending to cross-national comparisons to test the external validity of the theoretical framework.

5 Conclusion

Based on panel data from 31 Chinese provinces spanning 2010–2022, this study systematically examined the mechanisms through which regional green food industry resilience affects agricultural sustainable development performance. By constructing a three-dimensional evaluation framework encompassing adaptive capacity, absorptive capacity, and restorative capacity (Martin and Sunley, 2015; Holling, 1973), this research operationalized the resilience concept at the regional industry level and employed a combination of two-way fixed effects models (Bertrand et al., 2004), Bootstrap mediation tests (Baron and Kenny, 1986; Preacher and Hayes, 2008), instrumental variable methods, and system GMM (Blundell and Bond, 1998) to provide evidential support for causal inference. The empirical results demonstrated that industry resilience significantly promoted sustainable performance ($\beta = 0.341$, $p < 0.01$), with adaptive capacity exhibiting the most prominent marginal effect ($\beta = 0.243$), followed by restorative capacity ($\beta = 0.186$), while absorptive capacity did not reach statistical significance. This indicates that proactive adjustment contributes more to sustainable performance than does buffering capacity for passively coping with shocks. Export competitiveness served as a partial mediator between resilience and performance, transmitting 24.3% of the total effect [95% CI: (0.028, 0.147)]. This mechanism exhibited a significant regional gradient: the mediation effect reached 45.0% in the eastern region and 37.2% in the central region, whereas it was not significant in the western region, where the direct effect dominated the transformation of resilience into sustainability. The moderating effect of policy support intensity on export competitiveness was marginally significant (interaction term $\beta = 0.089$, $p = 0.067$), with the marginal effect under high support conditions approximately 18% higher than under low support conditions, providing preliminary validation of the complementary relationship between market mechanisms and the institutional environment (North, 1990). These conclusions remained stable across multiple robustness checks, including lagged variables, alternative variable measurements, adjusted sample periods, and winsorization.

The contributions of this study are reflected at three levels. Theoretically, by constructing a three-dimensional resilience framework at the regional level and identifying the transmission mechanism of the internationalization pathway, this research expands the dialogue between resilience theory and global value chain theory (Białowąs and Budzyńska, 2022; Montalbano and Nenci, 2022; Gereffi and Fernandez-Stark, 2016). Methodologically, the comprehensive application of multiple econometric methods provides a methodological reference for addressing endogeneity issues. Practically, the findings on regional heterogeneity offer an empirical basis for differentiated policy design (Fan et al., 2011; Chen et al., 2021): developed regions should deepen their embeddedness in international markets to leverage the advantages of the mediation effect, while less developed regions should prioritize consolidating foundational resilience capacity. The limitations of this study lie in the inability of provincial-level aggregated data to reveal firm-level micro heterogeneity (Stone and Rahimifard, 2018; Urruty et al., 2016), and the mediation effect estimates exhibit some sensitivity to measurement error. Future research could combine firm-level micro data to explore heterogeneous mechanisms, utilize quasi-experimental designs from policy pilots to strengthen causal identification, and extend to cross-national comparisons to test the external validity of the theoretical framework.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

YX: Formal analysis, Validation, Methodology, Data curation, Supervision, Project administration, Conceptualization, Software, Resources, Writing – original draft, Visualization, Funding acquisition, Investigation. CO: Validation, Writing – review & editing, Project administration, Formal analysis, Supervision, Data curation, Investigation, Methodology, Resources, Conceptualization. ZW: Investigation, Writing – review & editing, Data curation, Supervision, Methodology, Conceptualization, Resources, Formal analysis. ZL:

Visualization, Validation, Data curation, Resources, Writing – review & editing, Investigation, Conceptualization.

Funding

The author(s) declared that financial support was received for this work and/or its publication. This study was supported by the Philosophy and Social Sciences Research and Innovation Fund of Henan Agricultural University (2024); the Postgraduate Education Reform Project of Henan Province (Grant Nos. 2023SJGLX051Y, 2023SJGLX206Y, and 2026); the Postgraduate Education Reform Project of Henan Agricultural University (Grant Nos. 2025YJSJGSJ009 and 2025YJSJGSJ014); and the 2023 Guangdong Provincial Education Science Planning Project (Higher Education Special Project) (Grant No. 2023GXJ569).

Acknowledgments

The authors would like to express their sincere gratitude to the editors and reviewers for their constructive comments and valuable suggestions, which have significantly improved the quality of this manuscript. We also thank all individuals and institutions who provided support for data collection during this research.

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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