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Enhancing sustainable agricultural performance in selected Chinese region: the role of food supply chain management, resource utilization, and government support

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Introduction: As global food security and environmental sustainability become increasingly critical, understanding the factors that enhance sustainable agricultural performance is paramount. In this context, This study investigates the relationship between food supply chain management, resource utilization, sustainable agricultural practices, and sustainable agricultural performance within the Chinese market, focusing on the moderating role of government support.

Methods: Data were collected through 480 structured questionnaires distributed across Changsha, Wuhan, and Guangzhou and analyzed using a two-stage SEM-ANN approach.

Results and discussion: The findings reveal that sustainable agricultural practices significantly mediate the relationship between food supply chain management and sustainable agricultural performance. Moreover, sustainable agricultural practices also mediate the relationship between resource utilization and sustainable agricultural performance. Resource utilization was found to sequentially mediate the relationships between food supply chain management, sustainable agricultural practices, and sustainable agricultural performance. Additionally, government support was identified as a crucial moderator in strengthening the relationship between sustainable agricultural practices and performance. The findings have significant implications for policymakers, agricultural managers, and researchers, offering insights into strategies for improving agricultural sustainability in China and potentially other similar contexts.

KEYWORDS

food supply chain management, resource utilization, sustainable agricultural practices, sustainable agricultural performance, government support and incentives

1 Introduction

In the face of global challenges such as climate change, population growth, and resource depletion, the imperative for sustainable food systems has never been more pressing. By 2050, the world's population is projected to reach 9.7 billion (Putterill, 2023), necessitating a 70% increase in food production (Ivanovich et al., 2023). This demand must be met while contending that agriculture already accounts for 70% of global freshwater withdrawals and 23% of greenhouse gas emissions (Shi et al., 2024). This rising demand for food necessitates efficient supply chain management and resource utilization to ensure that agricultural practices are productive and sustainable. The transition towards sustainable farming practices is vital for meeting future food demands and mitigating traditional agriculture's negative environmental impacts, such as soil degradation, water depletion, and greenhouse gas emissions. Food supply chain management is pivotal in this transition as it influences how resources are allocated and utilized across the agricultural sector. Effective food supply chain management can lead to improved resource efficiency, reduced waste, and enhanced productivity, thereby fostering sustainable agricultural practices. These practices, in turn, are critical for achieving sustainable agricultural performance, which encompasses economic viability, environmental stewardship, and social responsibility. However, the adoption and effectiveness of sustainable agricultural practices are contingent on various factors, including government policies.

Government policies can significantly influence adopting sustainable practices by providing incentives, setting regulations, and fostering an enabling environment. Thus, understanding the role of government policies in moderating the relationship between sustainable agricultural practices and sustainable agricultural performance is essential for designing effective interventions and policies aimed at promoting sustainability in agriculture. China's agricultural sector is crucial in global food security, feeding approximately 20% of the world's population with only 9% of its arable land (Duan et al., 2021). The sector contributed 7.3% to China's GDP in 2021, underscoring its economic significance (Hu et al., 2024). China's food supply chain, valued at $1.5 trillion in 2020, is one of the world's largest and most complex. However, it faces significant challenges, including resource constraints and environmental concerns. The government has responded with ambitious policies, such as the 14th Five-Year Plan (2021–2025), which emphasizes green development and ecological protection in agriculture. These efforts have yielded positive results: organic farming increased from 1.9 million to 3.1 million hectares between 2011 and 2019, while water use efficiency in agriculture improved by 24% from 2010 to 2019 (Houkai, 2022). Despite these advances, challenges persist. Approximately 19% of China's arable land is contaminated, and food loss in the supply chain reaches approximately 35% of total production (Zhang and Drury, 2024). These issues highlight the critical need for sustainable agricultural practices and efficient resource utilization within China's food supply chain, which this study aims to address. As a result, local forming bodies have adopted their agri practices to sustainable agricultural practices supported by sustainable food supply chain management.

Recent literature has also shown their interest in the area, and several researchers such as (Chopra et al., 2022; Kamble et al., 2020; Trivellas et al., 2020) have explored the impact of supply chain management, resource utilization, and sustainable agri performance. Similarly, a few scholars also discussed the implications of sustainable agricultural practices on sustainable agrarian performance (Chopra et al., 2022; Sarkar et al., 2020). Even though sustainable practices have a significant role in resource optimization, food supply chain management, and agri performance, little attention to the mediating role of sustainable agricultural practices between food supply chain management, resource utilization, and sustainable agri performance has been received in the existing literature. In addition, government policy plays a supporting role in enhancing sustainable practices in the agricultural field, which further improves performance. However, the existing literature does not discuss the moderating role of government policies between sustainable agricultural practices and sustainable agricultural performance. Thus, the gap of the current study can be addressed twofold; first, it explores the mediating influence of sustainable agricultural practices between food supply chain management, resource utilization, and sustainable agri performance, an area not explored in the previous literature. Secondly, the study also investigates an uncovered literature gap of moderating impact of government between sustainable agri practices and sustainable agri performance. Through this research gap, the study's operational objective is to examine the effect of Food supply chain management and Resource utilization on sustainable agricultural performance. Secondly, it investigates the mediating effects of sustainable farming practices on food supply chain management, resource utilization, and sustainable agricultural performance.

The study also examines the moderating influence of government support and incentives on the relationship between sustainable agri-practices and sustainable agri-performance. The study significantly enhances the current literature and offers implications to stakeholders such as the government, agricultural organizations, agri firms, and local farmers. The study makes a theoretical contribution in terms of the uncovered literature gap on the following aspects: food supply chain management, resource utilization, sustainable agri practices, government policies, and sustainable agri performance. On the practical front, the study contributes important insights to the government in designing and refining policies to promote sustainable agricultural practices that enhance agrarian performance and formulate effective regulatory mechanisms. Local farming bodies can use the study to integrate sustainable farming practices into their strategic planning, improving overall sustainability and performance. The insights into resource utilization can help these bodies develop more efficient resource management strategies, while the study emphasizes the importance of collaboration with government agencies to ensure that sustainable practices are effectively supported. Similarly, the study offers practical guidance on adopting best practices to improve productivity and sustainability. It also facilitates knowledge transfer through training programs and workshops, helping farmers understand efficient resource utilization and food supply chain management. The study can also benefit other stakeholders, such as agricultural suppliers, NGOs, research institutions, and consumers. Suppliers can develop products and services that align with sustainable farming practices, while NGOs can design targeted programs to promote these practices.

2 Theoretical framework

2.1 Theoretical background

The resource-based view (RBV) is a strategic management perspective that posits that a business firm must possess specific internal resources and capabilities to sustain competitive advantage and superior organizational performance. Initially developed by (Barney and Arikan, 2005; Wernerfelt, 1989), the resources-based view postulates that a firm's competitive advantage lies in the capability to utilize and exploit resources that are valuable, rare, difficult to imitate, and have no substitutes. Resources of this nature may be things, individuals, processes, and the technical know-how of the firm. The resource-based view has argued that managing these resources to achieve a competitive advantage creates long-term sustainable competitive and environmental change. In the context of this study, which focuses on food supply chain management, resource utilization, sustainable agriculture practices, and sustainable agriculture performance, the RBV offers the framework for how resources and capabilities determine the ability to achieve sustainable performance. Food supply chain management is one of the vital resources through which firms can effectively manage food flow and coordinate material, information, and resources in the food supply chain. In the RBV theory, food supply chain management is a crucial resource for operational performance. Supply chain management, hence, can be used as an essential tool for achieving low cost and better product quality and an important avenue through which firms can improve their ability to respond to changes in the market. This competence is unique and hard to imitate because supply chain coordination requires advanced technologies and skills.

Food supply chain management is the principal strategic resource for enhancing resource efficiency and establishing sustainable agriculture practices. Resource, as it turns out, partially mediates the relationship between food supply chain management and sustainable agriculture. The resource-based view argues that water, energy, and labour are crucial in achieving organizational goals and efficiency. Effective resource management is one of the critical success factors that help firms optimize their resources and, hence, cut down their expenditure rate. It is also a variable that is very hard to imitate because it needs specific knowledge, skills, and equipment. In resource utilization, the tangible enactment of several aspects of food supply chain management is determined depending on resource consciousness, whereby resource stewardship and inputs are used to enhance the positive implementation of sustainable agriculture. Firm resources can be classified as tangible and intangible, and sustainable agricultural practices are tangible resources that help firms achieve sustainable and competitive advantage. Some practices include site management involving crop rotation, organic farming, and precision agriculture, among other practices that make soils healthier, reduce the impacts of farming on the environment, and boost yields. Based on a resources-based view, sustainable activities are considered valuable within firms because they meet the increasing societal and regulatory call for sustainability, thus creating a niche market for firms. This is the case because they are expertise- and technology-intensive, and their implementation is akin to such unique skills.

This study found a sequential mediated relationship between sustainable agricultural practices and resource utilization, which implied that firms that enhanced the use of resources were in a better place to adopt sustainable farming practices, forming the basis for enhanced sustainable agrarian performance. In the RBV framework, it becomes evident that internal resources and capabilities are critical determinants of organizational performance. As the dependent variable, agricultural performance results from well-implemented food supply chain management, resources, and sustainable practices. When firms are effective in acquiring valuable, rare, inimitable, and unsustainable resources, they can increase the yield of agriculture, decrease the negative impacts, and raise profitability. This is consistent with the RBV reasoning that only firms with control and better usage of resources and capabilities can manage and sustain competitive advantage. Even though RBV mainly concentrates on resources within the firm, it accepts external conditions as adding value to resources. Political support moderates sustainability initiatives by supplementing the competencies and significance of sustainable farming practices. It is supported by policies, subsidies, and incentives from the government, which institutionalize the practice and will make sustainable practices adopted and bear the intended positive impacts. This is consistent with RBV as it also shows that support from outside the firm can affect the value of the resources and capabilities of a firm, thus affecting its performance results. Mandatory commitments are that the funding, technology, and training, which are essential for implementing sustainable measures, may be provided under the support of the governments.

2.2 Hypothesis development

Recent research shows that managing the food supply chain remains important in enhancing sustainable performance in agriculture. For instance, food supply chain management includes inventory, transport, and food waste management, significantly affecting resource utilization and food production sustainability (Joshi et al., 2023). Implementing the best food supply chain management practices enhances sustainable agriculture performance by minimizing resource consumption wastage and improving the productivity of food production and delivery (Li et al., 2014). Improved supply chain and transportation can decrease food waste, improving the food chain in agriculture by becoming more sustainable (Kamble et al., 2020). Furthermore, implementing sustainable practices in food supply chain management entails using practices with low environmental footprints, including a reduction in emissions of greenhouse gases, excessive use of water, and detrimental impacts on soil fertility (Ozlu et al., 2022). This integration can improve the sustainability of the food supply chain, which would enhance long-term agriculture productivity and the environment's well-being (Hoang, 2021). In this context, sustainable agricultural practice could mediate between food supply chain management and sustainable agricultural performance. Efficient management of food supply chains can help drive the demand for sustainable agriculture by offering requisite support structures, innovation, and incentives (Kumar et al., 2022; Rahman et al., 2023). For example, an exemplary structure of the food chain can help source organic inputs, encourage the adoption of eco-friendly technologies, and help farmers adopt sustainable practices (Sapbamrer and Thammachai, 2021). That is why sustainable agricultural practices result in multiple advantages, such as the improvement of the condition of the soil, the increase in the number of species of plants and animals, and the increase in the utility of ecological systems (Hoang, 2021). Moreover, sustainable farming contributes to generating sustainable economic returns on farms by lowering the costs of inputs and producing more yields (Balafoutis et al., 2017). Consequently, there is a need to adopt sustainable agricultural practices if sustainable agricultural performance has to be realized since sustainable agriculture improves the sustainability of the farming system (Sharma et al., 2020). Hence, it is postulated that:

> *H1: Sustainable agricultural practices mediate the relationship between food supply chain management and sustainable agricultural performance.*

Recent studies support resource optimization's critical role in improving agri-food systems' sustainability. For instance, precision agriculture technologies that are used to control the consumption of water and fertilizers have been found to have positive impacts on yields and, at the same time, diminish the adverse effects on the environment (Anggono et al., 2023). Likewise, using renewable energy resources in farming reduces energy emissions and improves energy adequacy (Tian et al., 2018). It also includes the efficient usage of natural resources like soil and water so that they can remain productive in the long run. Techniques such as crop rotation pest management with legume cover crops and minimum tillage preserve the fertility of the soils, reduce land degradation, and improve water conservation in crop production (Calegari, 2020). This is because efficient resource management would provide inputs and technologies for sustainable agriculture.

Information technologies that enhance the appropriate application of resources in agricultural production are likely to strengthen the practice of sustainable processes and improve the productivity of agricultural activities (Yadav and Dagar, 2016). Besides, sustainable utilization of agricultural practices can also enhance the productivity of limited resources such as water holding capacity of the soil, water Availability, and Availability and cycling of nutrients at faster rates (Chopra et al., 2022). Another study by Mwalupaso et al. (2019) examined the energy use efficiency of rice production and reported that improving energy efficiency through renewable energy technology and energy-efficient machinery was positively associated with energy productivity. Similarly, Cao et al. (2018) show that efficient resource use for adopting such practices as crop rotation and conservation agriculture increased the resilience impacts on sustainability. Also, Hariram et al. (2023) revealed that while embracing sustainable practices, farmers' productivity and environmental health improved, and the efficiency of the resources used made them sustainable and equitable. Thus, we assume that:

> *H2: Sustainable agricultural practices mediate the relationship between resource utilization and sustainable agricultural performance.*

While a dearth of literature might explicitly reveal the combined relationship between food supply chain management, resource utilization, practices for sustainable agriculture, and sustainable agricultural performance, available evidence remains to give preliminary support. In this regard, the studies show that the adoption of sound food supply chain management practices greatly improves the use of resources through the efficient procurement, acquisition, and management of the products required from raw materials, water, energy, and fertilizers, among others. For instance, Tan et al. (2022) affirmed that using an advanced logistics system and information system in food supply chain management efficiently uses available resources in a business and minimizes wastage. Consequently, optimal resource use enhances the likelihood of adopting sustainable agriculture practices. Saikanth et al. (2023) have established that efficient use of resources facilitates practices like crop rotation, precision agriculture, and organic farming, which define environmental and economic sustainability. In addition, the literature supports the notion that sustainable agricultural practices affect sustainable agricultural performance through soil quality, species diversity, and climate change trends. For example, Kumar et al. (2022) noted that sustainable practices improve crop yields and decrease the adverse effects of agriculture on the environment, contributing to better agricultural performance. Therefore, through the analysis of the empirical literature, the authors stressed the relevance of food supply chain management in supporting resource efficiency and sustainability in the agriculture domain and, thus, underlined a sequential mediation effect of resource utilization and sustainable practice for the development of sustainable agricultural results; therefore, we proposed our following hypothesis;

> *H3: Sustainable agricultural practices sequentially mediate the relationship between Food supply chain management, Resource utilization, and Sustainable agri performance.*

Since government policies define the food supply chain processes and sustainable agriculture, they also significantly impact the subject. Incentives that include financial support, technical assistance, and legislation that govern farming practices can promote sustainable farming practices. For instance, support for sustainable farming inputs, training, and laws or policies promoting sustainable farming can greatly enhance sustainable agricultural standards. Evidence has indicated that policy support enhances the impact of sustainable agricultural interventions on agricultural productivity. For instance, Bopp et al. (2019) established a more positive effect of sustainable agricultural practices on environmental and economic returns when provoked by government policies on sustainable agriculture. This implies that for better and improved sustainable agricultural performance, there is a need to develop and adopt stable policies that support sustainable agricultural practices, offer monetary rewards and incentives, and support research activities (Ur Rahman and Amjad, 2024). Kamaluddin (2023) also noted that incentives towards organic farming, support for sustainable technologies, and pump-in laws to support sustainable farming increase the efficiency of sustainable practices in farming. A study comparing government-supported plant breeding programs (Ullah et al., 2023) showed that farmers who accessed financial incentives produced higher yields and farm-level returns to management and could better buffer against abiotic stresses. Some strategies limit the weak links between financial and technical factors and increase access to subsidies, technical training, or funding for research and development, making the practice convenient and efficient for farmers. Additionally, the governments help open markets for climate-friendly production, and the farmers get better prices and other incentives (Xiang and Gao, 2021). While issues, for instance, with policy gaps, gaps in policy execution, and restricted access to subsidies, particularly in rural areas, remain, enhancement of public-private collaboration and inclusion of sustainable development goals into government's policy agendas can deepen the correlation between such incentives to the green and broader policy goals (Sikandar et al., 2022). Given this, government intervention is instrumental in increasing the use and efficiency of efficient, sustainable agriculture practices to support sustainable agriculture and consistent performance. Therefore, it is proposed that:

> *H4: Government support moderates the relationship between sustainable agricultural practices and sustainable agricultural performance, so the relationship is stronger when government support is high.*

2.3 Research model

As mentioned, the RBV theory provides a solid theoretical framework for work by positing that firms' internal resources and capabilities are central to achieving superior production. Focusing on valuable, rare, inimitable, non-substitutable resources, RBV reveals the factors of successful food supply chain management and resource utilization that contribute to adopting sustainable agriculture and improving performance. Based on the moderation of government support, these practices have an even more favorable effect on business performance by acquiring the appropriate sanctioning support. This combined theoretical framework emphasizes resource management and capability enhancement of sustained efficiency and competitiveness in agriculture. Therefore, the graphical presentation of the study's research model is presented in Figure 1.

3 Methodology

A quantitative research design is employed in this study to determine the relationships between food supply chain management, resource utilization, sustainable agricultural practices, and sustainable agricultural performance while considering government support as the moderator. Recognizing China's commitment to implementing sustainable operations across various sectors, particularly agriculture, which significantly contribute to the country's economy, the study targeted collecting data from three major cities, including Changsha, Wuhan, and Guangzhou, due to time and resource limitations. Using a purposive sampling technique, the study aimed to collect data from executives and owners of firms engaged in sustainable agriculture practices, ensuring that only relevant farming bodies were included. The data was collected through a structured questionnaire administered to the local farming bodies in these cities. All ethical considerations were used in the data collected to ensure that the respondents' responses would remain confidential and solely be used for research purposes. For this purpose, a sample size of 600 questionnaires was circulated, reserving 200 sample sizes for each city. Out of 600 participants, 384 valid responses were obtained after removing cases with incomplete responses, reflecting an overall 64% response rate of the study. The sample size 384 exceeds the G*Power-suggested sample size of 111, considering an effect size of 0.3 and a 95% confidence interval (Rahman et al., 2024). Furthermore, the sample size is justified by the '50 times rule of thumb' recommended for artificial neural networks. Given that the study uses five parameters in the ANN, the sample size exceeds the required 250 (5 * 50; Alwosheel et al., 2018), further validating the chosen sample size.

3.1 Questionnaire design

This study questionnaire is divided into two main parts. The first section entails demographic variables from the respondents, including age, gender, and qualification. The second part concentrates on questions connected to the critical variables of the work. Food supply chain management is assessed using 10 items adapted from the scale by Zhao et al. (2021). Resource utilization is measured using a four-item scale adopted from Waiyawuththanapoom and Jermsittiparsert (2022), whereas sustainable agricultural practices are measured using the seven-item scale from Puntsagdorj et al. (2021). Sustainable agricultural performance is developed using eight Hayat et al. (2020) constructs. Government policies regarding financial and non-financial incentivization are evaluated based on eight items developed by Anwar et al. (2020). All these variables are measured with the help of five Likert scales ranging from 1 = Strongly Disagree to 5 = Strongly Agree. Furthermore, control variables like farming experience and family size are used in the analysis to boost the validity of the outcome and avoid a biased result.

3.2 Statistical methods

The study used two two-stage SEM-ANN approaches, using two software programs, SPSS and SmartPLS. In our initial analysis stage, we used SmartPLS to conduct the structure model (assessing our scale

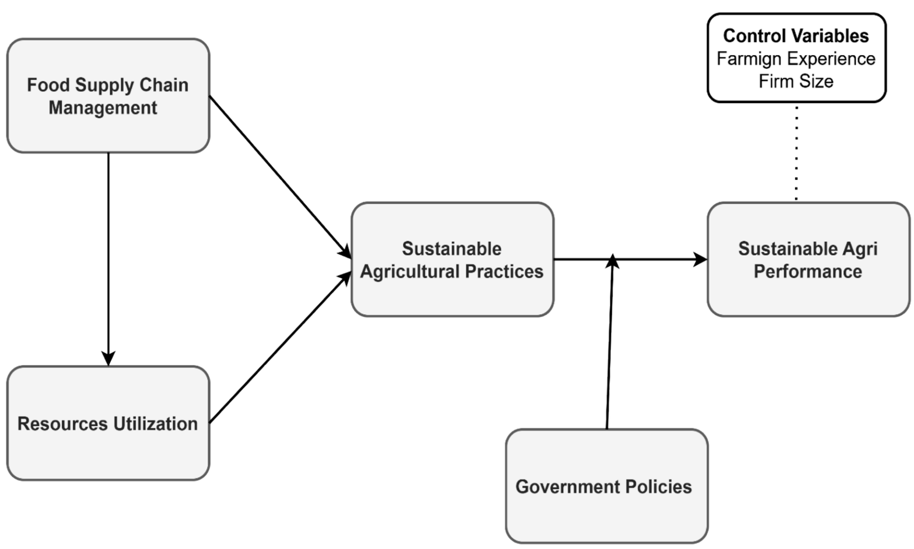

FIGURE 1
Research model.

reliability and validity) and measurement model (assessing our hypotheses). In the next step, we extended our analysis to artificial neural networking (ANN) using SPSS to estimate the relative importance of each predictor in the contribution of our core dependent variable.

4 Results

4.1 Descriptive analysis

Table 1 presents the sample's descriptive statistics, detailing the frequency and percentage of various demographic characteristics. Table 1 presents the sample's descriptive statistics, detailing the frequency and percentage of various demographic characteristics. Regarding gender, most respondents were male (67.45%), while females constituted 32.55%. Regarding educational qualifications, the largest group was graduates (43.75%), followed by undergraduates (38.80%) and postgraduates (17.45%). When examining farming experience, nearly half of the participants (47.92%) had over 20 years of experience, with 36.46% having 10 to 20 years and 15.63% reporting less than 10 years. Firm size showed that over half of the respondents worked in firms with fewer than 50 employees (54.95%), while 29.69% worked in firms with 50 to 150 employees, and another 29.69% were in firms with more than 150 employees. Lastly, regarding location, Changsha had the highest representation at 45.31%, followed by Wuhan (31.25%) and Guangzhou (23.44%). Overall, the sample consisted of 384 respondents, providing a well-rounded view of the demographics relevant to the study.

TABLE 1 Descriptive statistics.

	Frequency	Percentage
Gender		
Male	259	67.448
Female	125	32.552
Qualification		
Undergraduates	149	38.802
Graduate	168	43.750
Postgraduate	67	17.448
Farming experience		
Less than 10 years	60	15.625
10 to 20 years	140	36.458
20 and above	184	47.917
Firm size		
less than 50 employees	211	54.948
50 to 150	114	29.688
above 150	114	29.688
Location		
Changsha	174	45.313
Wuhan	120	31.250
Guangzhou	90	23.438
$N = 384$		

4.2 Multivariate assumptions and common methods biased

Before formally investigating our hypothesis, we investigate core assumptions such as collinearity, linearity, normality, and heteroskedasticity. Multicollinearity is assessed with the help of variance inflation factor (VIF) and tolerance values, as VIF values are found below the maximum range of 10, whereas the tolerance values are observed above the required limit of 0.1, confirming no potential multicollinearity. The linearity test and scatter plot suggested data linearity as p-value <0.05. We further conducted the Breusch-Pagan test, which confirm heteroskedasticity of data as p-value > 0.05; however, the Kolmogorov–Smirnov one-sample test revealed non-normal distribution of the data as p-value <0.05. Due to the non-normal distribution of the data, we conducted a variance-based structure equation model, a practical approach in non-normal data, whereas, in the next phase of data analysis, we performed ANN, which is efficient in handling linear and nonlinear relationships.

We further investigated common bias as the data was collected from a single source, so we expect potential common bias. In this study, we used two tests to examine potential common biases, one of which was Harmans' single factor, and the other was the marker variable approach. The Harman single factor test suggested that single factor variance is 24%, below the maximum limit of 50%, confirming no potential common bias. We introduce respondent qualifications (1 = undergraduate, 2 = graduate, 3 = postgraduate) as marker variables and investigate their impact on sustainable agricultural performance. We found an insignificant effect, confirming the evidence of no potential common bias.

4.3 Instruments internal consistency, reliability, and convergence validity

We have used a partial least square (PLS) algorithm to assess our proposed variables' reliability and validity, as depicted in Table 2 and Figure 2. The findings suggested that all Cronbach's alpha and composite reliability (CR) values are above the specified limit of 0.7, thus implying that all the constructs are highly reliable (Hair Jr et al., 2017). Furthermore, the average variance extracted (AVE) is above the benchmark of 0.5, confirming the successful convergent of all items to their respective constructs and thus affirming construct validity (Hair Jr et al., 2017). In addition, we noticed that all items are strongly loaded to their respective items except FSCM 10, FSCM 11, FSCM12, and SP3, which were removed due to their low loadings.

4.4 Discriminant validity of measurement model

After confirming the reliability and validity of constructs, we further investigated the discriminant validity of the constructs by conducting the Heterotrait-Monotrait Ratio (HTMT) and Fornell and Larcker criterion, presented below in Table 3. The findings suggested that All the values in the HTMT ratio table fall below the benchmark of 0.9, indicating that discriminant validity is fulfilled (Ab Hamid

TABLE 2 Measurement model (Algorithem).

Variable	Loadings	CR	Rho	AVE
Food supply chain management				
FSCM1	0.765	0.891	0.894	0.539
FSCM2	0.728			
FSCM3	0.765			
FSCM4	0.732			
FSCM5	0.781			
FSCM6	0.812			
FSCM7	0.752			
FSCM8	0.71			
FSCM9	0.527			
Government support and incentives				
GS1	0.804	0.874	0.881	0.533
GS2	0.809			
GS3	0.647			
GS4	0.617			
GS5	0.68			
GS6	0.734			
GS7	0.752			
GS8	0.774			
Resources utilization				
RU1	0.774	0.757	0.76	0.579
RU2	0.749			
RU3	0.718			
RU4	0.799			
Sustainable agricultural practices				
SAP1	0.786	0.891	0.893	0.607
SAP2	0.776			
SAP3	0.68			
SAP4	0.807			
SAP5	0.833			
SAP6	0.797			
SAP7	0.765			
Sustainable Agricultural Performance				
SP1	0.774	0.8	0.802	0.502
SP2	0.736			
SP4	0.678			
SP5	0.669			
SP6	0.708			
SP8	0.678			

et al., 2017). The Fornell and Larcker criterion shows that the square root of the AVE is higher than the inter-correlation coefficients, further validating discriminant validity (Fornell and Larcker, 1981). In addition, the Fornell and Larcker criterion also provides details of the correlations between the proposed variables, suggesting positive relationships and providing initial support for our hypotheses.

4.5 Results of structural model

To test the hypothesis, we further performed bootstrapping using SmartPLS. We initially checked the direct relationship between our variables (presented in Table 4 and Figure 3). Then, in the next step, we assessed our mediation and moderation analysis, which is given in Table 5. Table 4 shows that Our control variable (Family size and Farming experience) has an insignificant impact on sustainable agricultural practices as a p-value > 0.05. We further observed that food supply chain management significantly influences sustainable agricultural performance as the p-value <0.05 and $\beta = 0.528$. Similarly, resource utilization significantly influences sustainable agricultural performance with p-value < 0.05 and $\beta = 0.191$. sustainable agricultural practices have a significant positive impact on sustainable agricultural practices as p-value < 0.05 and $\beta = 0.22$. In addition, we found that Food supply chain management and resource utilization significantly positively influence sustainable agricultural practices as $\beta = 0.557$ between food supply chain management and sustainable agricultural practices, and $\beta = 0.18$ between resources utilization and sustainable agricultural practices, whereas p-value < 0.05 in both cases. We also noticed that food supply chain management significantly impacts resource utilization as $\beta = 0.552$ and p-value < 0.05.

After validating the direct relationship, we further investigated the mediation and moderation relationship, as presented in Table 5. The findings suggested that sustainable agricultural practices partially mediate the relationship between food supply chain management and sustainable performance ($\beta = 0.103$, p-value < 0.05), whereas their direct relationship remains significant, supporting our H1. The finding further suggested that sustainable agricultural practices also partially mediate the relationship between resource utilization and sustainable agricultural performance ($\beta = 0.041$, p-value < 0.05), with their direct relationship remaining significant, confirming our H2. Similarly, the findings revealed that resource utilization sequentially mediates the relationship between food supply chain management, sustainable agricultural practices, and sustainable performance ($\beta = 0.023$, p-value < 0.05). Once again, the direct relationship between these variables is significant and thus confirms our H3. We also examined the moderation impact of government support and incentives in the relationship between sustainable agricultural practices and performance. Table 5 suggested that Government support moderates the relationship between sustainable agricultural practices and sustainable performance as $\beta = 147$ and p-value < 0.05, suggesting that with the moderation of government support, the relationship between sustainable agricultural practices and sustainable agricultural performance further becomes stronger. We further validate the moderation analysis through the graphical presentation presented in Figure 4. The figure revealed that the line corresponding to higher government shows a steeper trajectory, indicating that higher government support significantly improves sustainable agricultural practices, further enhancing sustainable agricultural performance, confirming H4.

4.6 Implementing the artificial neural network

We further conducted an artificial neural network to examine the relative importance of each indicator in contributing to sustainable agricultural performance. The reason for using ANN in this study is

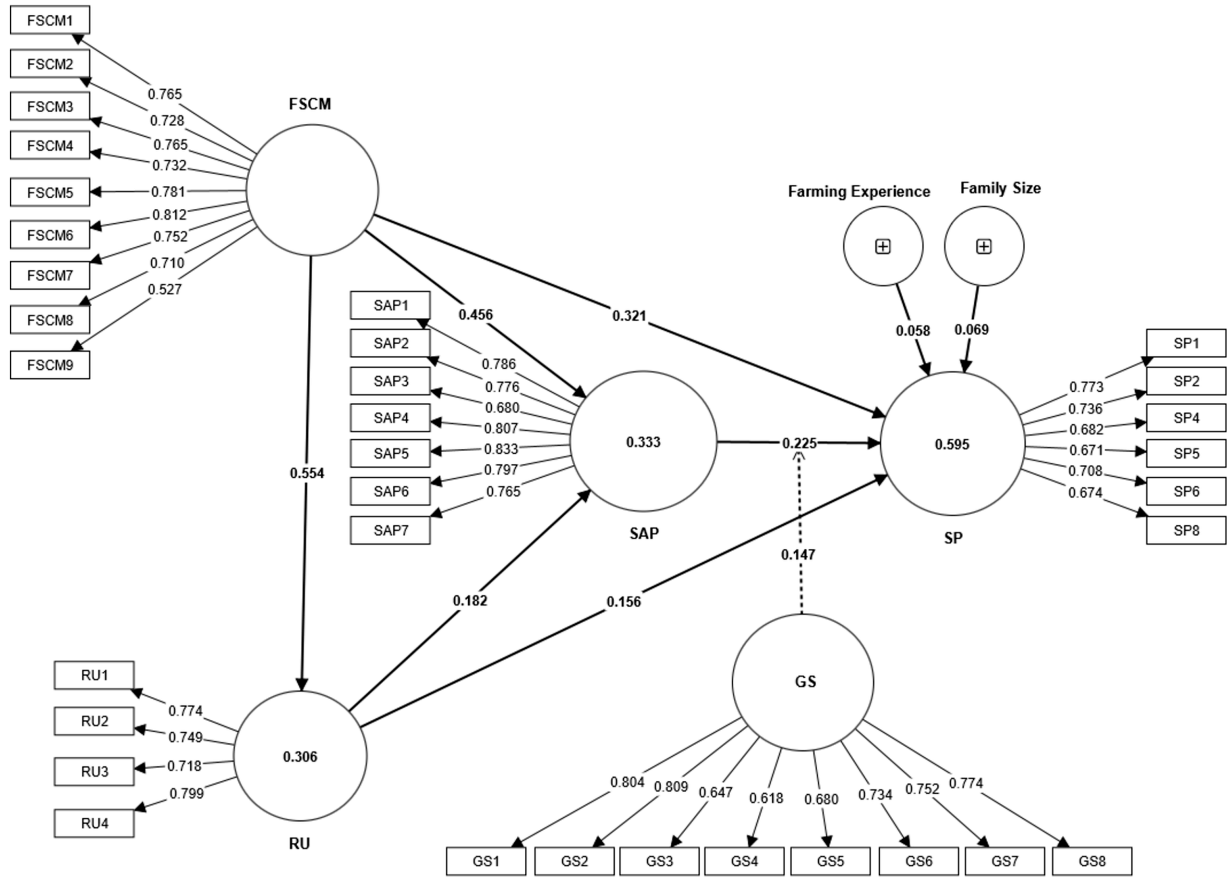

FIGURE 2
Measurement model (Algorithem).

justified by several reasons, such as its efficiency in handling non-normal and non-linear relationships and its ability to effectively manage the challenges associated with data outliers and low sample size (Alhumaid et al., 2021). In this study, we have conducted an artificial neural network using SPSS where we have used food supply chain management, resources utilization, supply agricultural practices, government support, and the interaction term (Supply agricultural practices × Government support) as input neurons for ANN to predict their contribution in sustainable agrarian performance. The approach contains two phases: the training phase and the testing phase. The training process involves using a feed-forward-backward-propagation (FFBP) algorithm, which allows the algorithm to predict analysis outcomes. This approach processes inputs through the network while the estimated errors are iteratively adjusted and refined backward (Rahman et al., 2024). In this analysis, we have employed multilayer perceptrons with sigmoid activation functions, which allow the model to minimize errors while improving predictive accuracy. 90% of the sample size was assigned during the training process, while the remaining 10% was reserved for testing the model. A tenfold cross-validation process calculates the RMSE values to ensure low overfitting. RMSE values for training and testing, as given in Table 6, indicated a high level of model accuracy as these values fall in the range of the required limit of 0.051 to 0.989 (Rahman et al., 2024), whereas $R2 = 0.685$ suggested that all the input neurons collectively contribute 68.5% sustainable agricultural performance.

Sensitivity analysis is further conducted to calculate the normalized importance of predictors in the contribution of sustainable agricultural performance. The normalized importance is calculated by dividing the relative importance of each neuron by the highest relative importance and then expressing it as a percentage. The findings presented in Table 7 show that Government support contributes the highest normalized importance, followed by food supply chain management with 92.37% normalized importance. The interaction term (Sustainable agricultural practices × Government support) shows a normalized importance of 71.44%, sustainable agricultural practices with a normalized importance of 40.89%, whereas resource utilization shows the lowest normalized importance of 40.43% in the contribution of sustainable agricultural performance. Concluding this part, the ANN analysis shows that Government support and food supply chain management are important predictors of enhancing sustainable agricultural performance.

5 Discussion and conclusion

5.1 Discussion

Sustainable agriculture has become increasingly crucial in addressing global food security and environmental challenges. As the world faces climate change, resource depletion, and population

TABLE 3 Discriminant validity.

	1	2	3	4	5
Heterotrait-Monotrait (HTMT) matrix					
Food Supply Chain Management					
Government Support and incentives	0.382				
Resources Utilization	0.674	0.247			
Sustainable Agricultural Practices	0.62	0.542	0.527		
Sustainable Agricultural Performance	0.748	0.642	0.592	0.669	
Fornell and Larcker criterion					
Food Supply Chain Management	0.734				
Government Support and incentives	0.336	0.73			
Resources Utilization	0.554	0.202	0.761		
Sustainable Agricultural Practices	0.556	0.472	0.434	0.779	
Sustainable Agricultural Performance	0.633	0.553	0.462	0.57	0.708

TABLE 4 Structural model 1 (Bootstrapping).

Direct relationship	β	*T* statistics	*p* values	2.50%	97.50%
Family size -> SP	0.07	1.896	0.058	0	0.144
Farming experience -> SP	0.057	1.799	0.072	−0.006	0.123
FSCM -> SP	0.528	8.728	0	0.4	0.636
RU -> SP	0.191	3.044	0.002	0.066	0.32
SAP -> SP	0.22	3.494	0	0.091	0.347
FSCM -> SAP	0.557	8.901	0	0.427	0.672
RU -> SAP	0.18	2.83	0.005	0.056	0.305
FSCM -> RU	0.552	9.21	0	0.429	0.661

FSCM, Food supply chain management; SP, Sustainable agricultural performance; RU, Resources utilization; SAP, Sustainable agricultural practices.

growth, optimizing food supply chains and adopting sustainable practices are essential for enhancing agricultural performance and ensuring long-term sustainability. In the context of China, a major agricultural and economic powerhouse, understanding how food supply chain management impacts sustainable agricultural performance is vital for achieving national and global sustainability goals. This study investigates these relationships, examining the roles of food supply chain management, resource utilization, and sustainable agricultural practices on sustainable agricultural performance with the moderating influence of government support. Using structured questionnaire, the data is collected from 480 farming firms, and data analysis is conducted in two staged SEM-ANN approaches.

The findings demonstrated that sustainable agricultural practices significantly mediate the relationship between food supply chain management and sustainable agricultural performance, validating our H1. The findings highlight that the benefits of food supply chain management are not fully realized unless sustainable practices are adopted. In line with prior findings, this suggests that the efficient management of the food supply chain needs to be coordinated with sustainable practices to enhance agricultural productivity(Ardekani et al., 2023; Martínez-Falcó et al., 2023; Nayal et al., 2023). Additionally, Kamble et al. (2020) emphasized the critical role of sustainable practices in improving productivity and environmental outcomes, reinforcing the importance of this mediation. The mediation effect of sustainable agricultural practices underscores agricultural firms' need to integrate sustainability into their supply chain strategies to achieve better performance outcomes. Similarly, we observed that sustainable farming practices mediate the relationship between resource utilization and sustainable agricultural performance, confirming our H2. By adopting practices that enhance soil health, optimize water usage, and reduce chemical inputs, the utilization of resources becomes more effective, directly contributing to improved agricultural performance (Sarkar et al., 2020). These finding is aligned with past studies and highlights the importance of integrating sustainable practices at every stage of resource management, ensuring that the benefits of resource optimization are fully realized in achieving long-term agricultural sustainability (Lykogianni et al., 2021; Patel et al., 2020). The findings also validate H3 that resource utilization sequentially mediates the relationship between food supply chain management, sustainable agriculture practices, and sustainable agriculture performance. This sequential mediation implies that food supply chain management can affect sustainable agricultural performance by focusing on resources utilized and thus fostering sustainable agriculture. Although this area is unexplored in the existing literature, minimal studies, such as (Kumar et al., 2022; Yontar and Ersöz, 2021), offer primary support. Mastos and Gotzamani (2022) highlighted that

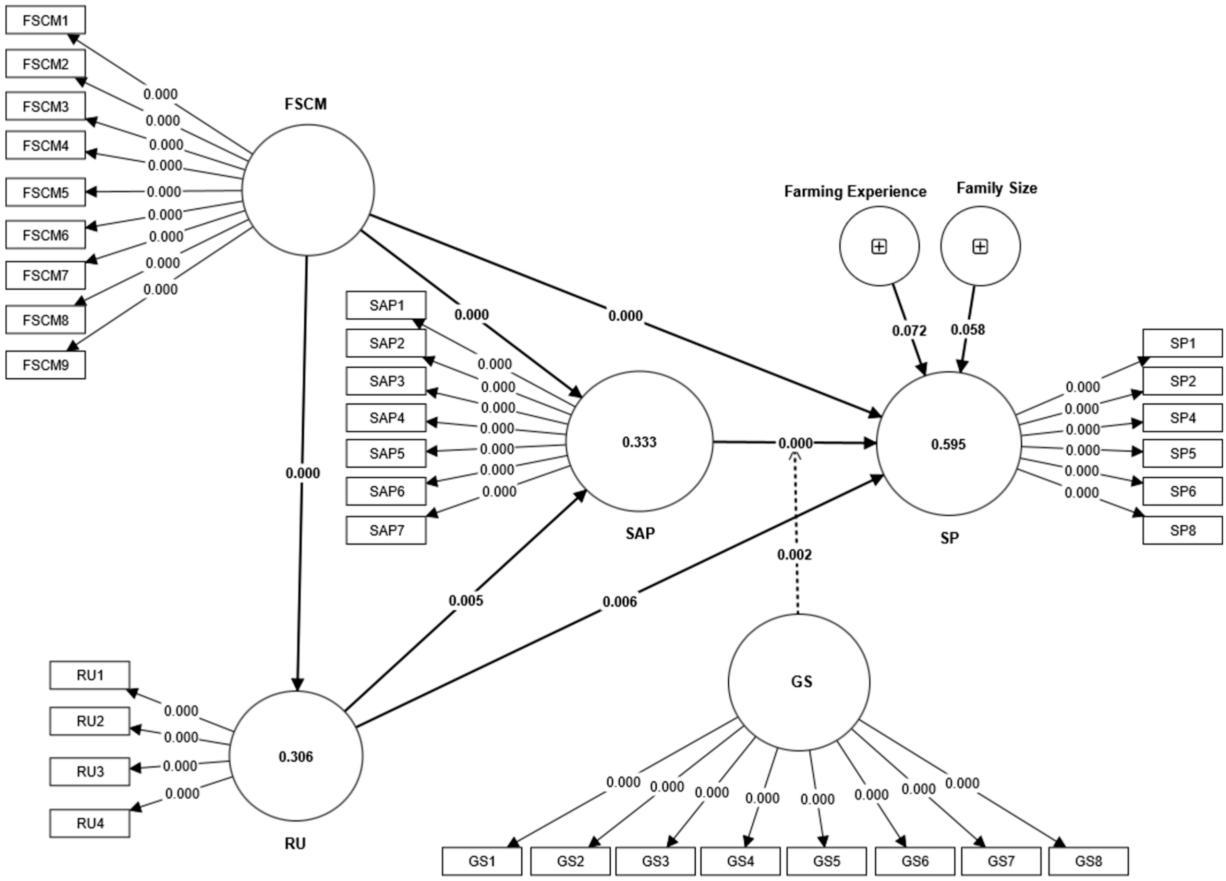

FIGURE 3
Structural model (Bootstrapping).

TABLE 5 Structural model 2 (Bootstrapping).

	β	*T* statistics	*p* values	2.50%	97.50%
Mediation analysis					
FSCM -> SAP -> SP	0.103	3.365	0.001	0.042	0.163
RU -> SAP -> SP	0.041	1.942	0.05	0.007	0.089
FSCM -> RU -> SAP -> SP	0.023	1.918	0.05	0.004	0.05
Moderation Analysis					
GS -> SP	0.133	6.88	0	0.286	0.51
GS × -> SAP -> SP	0.147	3.069	0.002	0.054	0.243

FSCM, Food supply chain management; SP, Sustainable agricultural performance; RU, Resources utilization; SAP, Sustainable agricultural practices; GS, Government support.

better supply chain management improves resource utilization, improving the effectiveness of sustainable agricultural practices on performance. Through resource leverage, the food supply chain and sustainable practices can further contribute to improving agriculture (Agbelusi et al., 2024). Presumably, this insight shows how Sustainable Agriculture can be optimized by effective management of resources and the consequent enhancement of the general performance of agriculture. The analysis also shows that government support and incentives moderate the relationship between sustainable agricultural practices and performance, confirming our final H4. These findings suggested that supportive policies and incentives from the government can enhance sustainable agricultural practices, further improving sustainable agricultural performance (Chaudhuri et al., 2024). Ullah et al. (2023) argued firm performance can be boosted through supportive policies and incentives, highlighting the significance of targeted policies and incentives to enhance agricultural performance. This finding supports prior literature emphasizing the importance of government incentives to promote sustainable agriculture (Chaudhuri et al., 2024; Hoque, 2018; Liang et al., 2022). The government's role as a moderator underscores the relevance of a policy environment conducive to achieving sustainable agricultural outcomes.

TABLE 6 Artificial neural network implementation.

Dependent variable: sustainable agricultural performance					
N	RMSE (Training)	N	RMSE (Testing)	R^2 SEM	R^2 ANN
346	0.397	38	0.358	0.595	0.685
345	0.371	39	0.263		
339	0.397	45	0.308		
335	0.355	49	0.517		
348	0.388	36	0.387		
341	0.346	43	0.329		
347	0.320	37	0.276		
337	0.309	47	0.247		
346	0.388	38	0.393		
343	0.383	41	0.206		
Mean	0.365	Mean	0.328		
Std Dev	0.032	Std Dev	0.090		

TABLE 7 Sensitivity analysis.

Neural network (NN)	FSCM	GS	RU	SAP	IF
NN1	0.264	0.244	0.185	0.103	0.204
NN2	0.312	0.328	0.079	0.093	0.188
NN3	0.216	0.269	0.153	0.101	0.260
NN4	0.330	0.328	0.100	0.156	0.086
NN5	0.369	0.324	0.138	0.077	0.093
NN6	0.215	0.326	0.155	0.127	0.177
NN7	0.241	0.223	0.068	0.119	0.350
NN8	0.227	0.245	0.052	0.120	0.357
NN9	0.228	0.283	0.071	0.129	0.289
NN10	0.275	0.329	0.171	0.160	0.066
Average Importance	0.268	0.290	0.117	0.118	0.207
Normalized percentage (%)	92.37%	100.00%	40.43%	40.89%	71.44%

FSCM, Food supply chain management; SP, Sustainable agricultural performance; RU, Resources utilization; SAP, Sustainable agricultural practices; IF, Sustainable agricultural practices × Government support.

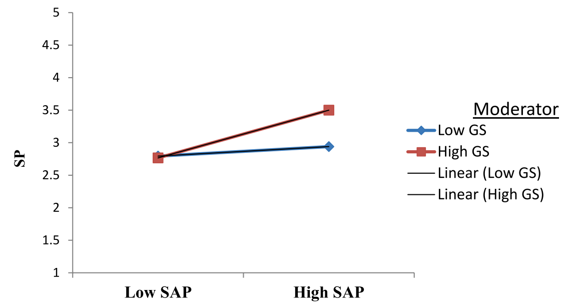

FIGURE 4
Moderation analysis.

5.2 Limitations and direction for future research

The study's findings significantly contribute to understanding the relationship between food supply chain management, resource utilization, and sustainable agricultural practices/sustainable agricultural performance within the Chinese market. Nevertheless, there exist several limitations that provide avenues for further investigation. Firstly, the limitation of data collection in Changsha, Wuhan, and Guangzhou could affect the generalizability of the findings in other areas with varying agricultural practices and socio-economic contexts. Moreover, using structured questionnaires for data collection might lead to common biases. Although the two-step SEM-ANN approach is methodologically sound, it might introduce biases in capturing complex interrelationships among variables. Future researchers should investigate the relationship between graphical areas and diverse agricultural contexts. Additionally, incorporating data from multiple sources, including multi-level data collection and secondary sources, would offer more comprehensive insights. Future researchers can consider other moderating variables that would be relevant to investigate their interaction with sustainable agricultural performance, such as environmental legislation, innovation in farming practices, and market access. In addition, the analysis of farmers' behavioral intention and socio-demographical data, including income, education, and financial services, could be useful in understanding how these factors affect the use and performance of sustainable agriculture practices.

5.3 Conclusion and practical implications

This study provides comprehensive insights into the dynamics between food supply chain management, resource management, sustainable agriculture, and sustainable agricultural performance in China's agricultural industry. The findings highlighted the critical mediating role of sustainable agricultural practices in transforming effective food supply chain management and efficient resource utilization into improved sustainable agricultural performance. The results also show the sequential mediation established through the use of resources and sustainable practices, which shows that sustainability is interrelated and reliant on factors. Notably, the study reveals the moderating effect of governments' support in enhancing the relationship between adopting sustainable practices and performance, stressing the value of policy measures in optimizing sustainability impact. These findings have key practical implications for agricultural stakeholders in China. Agribusiness and farmers should adopt efficient food supply chain management practices, where resources would be optimally used by adopting precision agriculture technologies and improving water management systems. The essential role of sustainable agricultural practices indicates that farmers should be encouraged to increase their deployment of crop rotation, integrated pest management, and conversation tillage. Government and policymakers are encouraged to consider mechanisms that offer incentives for sustainable agriculture, including innovative support structures such as funding and technical support. The findings highlight the importance of education and training, technological investment, and the development of efficient monitoring and evaluation systems to enhance sustainability in the agricultural sector. Moreover, a collaborative environment among farmers, agribusinesses, institutions, and government agencies can enhance innovation and knowledge sharing. In addition, markets for sustainably produced agricultural products might further improve the incentives to adopt sustainable practices. On these fronts, China will come closer to a more resilient agricultural system while being productive, caring for the environment, and socially responsible.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors without undue reservation.

Author contributions

SE: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. YZ: Conceptualization, Formal analysis, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. QB: Data curation, Formal analysis, Methodology, Writing – review & editing.

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Conflict of interest

The authors declare that the research 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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References

Ab Hamid, M. R., Sami, W., and Sidek, M. H. M. (2017). Discriminant validity assessment: use of Fornell & Larcker criterion versus HTMT criterion. *J. Phys. Conf. Ser.* 890:012163. doi: 10.1088/1742-6596/890/1/012163

Agbelusi, J., Arowosegbe, O. B., Alomaja, O. A., Odunfa, O. A., and Ballali, C. (2024). Strategies for minimizing carbon footprint in the agricultural supply chain: leveraging sustainable practices and emerging technologies. *World J. Adv. Res. Rev.* 23, 2625–2646. doi: 10.30574/wjarr.2024.23.3.2954

Alhumaid, K., Habes, M., and Salloum, S. A. (2021). Examining the factors influencing the mobile learning usage during COVID-19 pandemic: an integrated SEM-ANN method. *IEEE Access* 9, 102567–102578. doi: 10.1109/ACCESS.2021.3097753

Alwosheel, A., van Cranenburgh, S., and Chorus, C. G. (2018). Is your dataset big enough? Sample size requirements when using artificial neural networks for discrete choice analysis. *J. Choice Model.* 28, 167–182. doi: 10.1016/j.jocm.2018.07.002

Anggono, B. D., Wahanisa, R., and Melina, C. (2023). Determinants of sustainable land use change in agricultural utilization and environmental performance. *Int. J. Energy Econ. Policy* 13, 545–551. doi: 10.32479/ijeep.14443

Anwar, M., Khattak, M. S., Popp, J., Meyer, D. F., and Máté, D. (2020). The nexus of government incentives and sustainable development goals: is the management of resources the solution to non-profit organisations? *Technol. Econ. Dev. Econ.* 26, 1284–1310. doi: 10.3846/tede.2020.13404

Ardekani, Z. F., Sobhani, S. M. J., Barbosa, M. W., and de Sousa, P. R. (2023). Transition to a sustainable food supply chain during disruptions: a study on the Brazilian food companies in the Covid-19 era. *Int. J. Prod. Econ.* 257:108782. doi: 10.1016/j.ijpe.2023.108782

Balafoutis, A., Beck, B., Fountas, S., Vangeyte, J., Van der Wal, T., Soto, I., et al. (2017). Precision agriculture technologies positively contributing to GHG emissions mitigation, farm productivity and economics. *Sustainability* 9:1339. doi: 10.3390/su9081339

Barney, J. B., and Arikan, A. M. (2005). "The resource-based view: origins and implications" in The Blackwell Handbook of Strategic Management, 123–182. Available at: https://onlinelibrary.wiley.com/

Bopp, C., Engler, A., Poortvliet, P. M., and Jara-Rojas, R. (2019). The role of farmers' intrinsic motivation in the effectiveness of policy incentives to promote sustainable agricultural practices. *J. Environ. Manag.* 244, 320–327. doi: 10.1016/j.jenvman.2019.04.107

Calegari, A. (2020). Crop rotation and cover crop on no-tillage. II Congresso Mundial sobre Agricultura Conservacionista. Available at: https://www.researchgate.net/publication/341039462 (Accessed February 06, 2021).

Cao, X., Ren, J., Wu, M., Guo, X., Wang, Z., and Wang, W. (2018). Effective use rate of generalized water resources assessment and to improve agricultural water use efficiency evaluation index system. *Ecol. Indic.* 86, 58–66. doi: 10.1016/j.ecolind.2017.12.016

Chaudhuri, R., Chatterjee, S., and Vrontis, D. (2024). "Investigating the supply chain performance of agribusiness firms from the IT capability and government support perspectives" in Agribusiness innovation and contextual evolution, volume II: Technological, societal and channel advancements (Springer), 209–233.

Chopra, R., Magazzino, C., Shah, M. I., Sharma, G. D., Rao, A., and Shahzad, U. (2022). The role of renewable energy and natural resources for sustainable agriculture in ASEAN countries: do carbon emissions and deforestation affect agriculture productivity? *Res. Policy* 76:102578. doi: 10.1016/j.resourpol.2022.102578

Duan, J., Ren, C., Wang, S., Zhang, X., Reis, S., Xu, J., et al. (2021). Consolidation of agricultural land can contribute to agricultural sustainability in China. *Nat. Food* 2, 1014–1022. doi: 10.1038/s43016-021-00415-5

Fornell, C., and Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *J. Mark. Res.* 18, 39–50. doi: 10.1177/002224378101800104

Hair, J. F. Jr., Matthews, L. M., Matthews, R. L., and Sarstedt, M. (2017). PLS-SEM or CB-SEM: updated guidelines on which method to use. *Int. J. Multiv. Data Anal.* 1, 107–123. doi: 10.1504/IJMDA.2017.087624

Hariram, N. P., Mekha, K. B., Suganthan, V., and Sudhakar, K. (2023). Sustainalism: an integrated socio-economic-environmental model to address sustainable development and sustainability. *Sustainability* 15:10682. doi: 10.3390/su151310682

Hayat, N., Al Mamun, A., Nasir, N. A. M., Selvachandran, G., Nawi, N. B. C., and Gai, Q. S. (2020). Predicting Sustainable Farm Performance—Using Hybrid Structural Equation Modelling with an Artificial Neural Network Approach *Land* 9:289. doi: 10.3390/land9090289

Hoang, V. (2021). Modern short food supply chain, good agricultural practices, and sustainability: a conceptual framework and case study in Vietnam. *Agronomy* 11:2408. doi: 10.3390/agronomy11122408

Hoque, A. (2018). Does government support policy moderate the relationship between entrepreneurial orientation and Bangladeshi SME performance? A SEM approach. *Int. J. Bus. Econ. Manag. Stud.* 6, 37–59.

Houkai, W. (2022). China's rural development in the 14th five-year plan period. *Chin. Econ.* 17, 2–11.

Hu, Y., Liu, J., Zhang, S., Liu, Y., Xu, H., and Liu, P. (2024). New mechanisms for increasing agricultural Total factor productivity: analysis of the regional effects of the digital economy. *Econ. Anal. Policy* 83, 766–785. doi: 10.1016/j.eap.2024.07.017

Ivanovich, C. C., Sun, T., Gordon, D. R., and Ocko, I. B. (2023). Future warming from global food consumption. *Nat. Clim. Chang.* 13, 297–302. doi: 10.1038/s41558-023-01605-8

Joshi, S., Singh, R. K., and Sharma, M. (2023). Sustainable Agri-food supply chain practices: few empirical evidences from a developing economy. *Glob. Bus. Rev.* 24, 451–474. doi: 10.1177/0972150920907014

Kamaluddin, A. (2023). The role of Rice cultivation techniques, farm management and natural resources on agricultural development in Indonesia: moderating role of government support. *AgBioforum* 25, 23–31.

Kamble, S. S., Gunasekaran, A., and Gawankar, S. A. (2020). Achieving sustainable performance in a data-driven agriculture supply chain: a review for research and applications. *Int. J. Prod. Econ.* 219, 179–194. doi: 10.1016/j.ijpe.2019.05.022

Kumar, M., Sharma, M., Raut, R. D., Mangla, S. K., and Choubey, V. K. (2022). Performance assessment of circular driven sustainable Agri-food supply chain towards achieving sustainable consumption and production. *J. Clean. Prod.* 372:133698. doi: 10.1016/j.jclepro.2022.133698

Li, D., Wang, X., Chan, H. K., and Manzini, R. (2014). Sustainable food supply chain management. *Int. J. Prod. Econ.* 152, 1–8. doi: 10.1016/j.ijpe.2014.04.003

Liang, T., Zhang, Y.-J., and Qiang, W. (2022). Does technological innovation benefit energy firms' environmental performance? The moderating effect of government subsidies and media coverage. *Technol. Forecast. Soc. Chang.* 180:121728. doi: 10.1016/j.techfore.2022.121728

Lykogianni, M., Bempelou, E., Karamaouna, F., and Aliferis, K. A. (2021). Do pesticides promote or hinder sustainability in agriculture? The challenge of sustainable use of pesticides in modern agriculture. *Sci. Total Environ.* 795:148625. doi: 10.1016/j.scitotenv.2021.148625

Martínez-Falcó, J., Sánchez-García, E., Millan-Tudela, L. A., and Marco-Lajara, B. (2023). The role of green agriculture and green supply chain management in the green intellectual capital–sustainable performance relationship: a structural equation modeling analysis applied to the Spanish wine industry. *Agriculture* 13:425. doi: 10.3390/agriculture13020425

Mastos, T., and Gotzamani, K. (2022). Sustainable supply chain management in the food industry: a conceptual model from a literature review and a case study. *Food Secur.* 11:2295. doi: 10.3390/foods11152295

Mwalupaso, G. E., Korotoumou, M., Eshetie, A. M., Alavo, J.-P. E., and Tian, X. (2019). Recuperating dynamism in agriculture through adoption of sustainable agricultural technology-implications for cleaner production. *J. Clean. Prod.* 232, 639–647. doi: 10.1016/j.jclepro.2019.05.366

Nayal, K., Raut, R. D., Narkhede, B. E., Priyadarshinee, P., Panchal, G. B., and Gedam, V. V. (2023). Antecedents for blockchain technology-enabled sustainable agriculture supply chain. *Ann. Oper. Res.* 327, 293–337. doi: 10.1007/s10479-021-04423-3

Ozlu, E., Arriaga, F. J., Bilen, S., Gozukara, G., and Babur, E. (2022). Carbon footprint management by agricultural practices. *Biology* 11:1453. doi: 10.3390/biology11101453

Patel, S. K., Sharma, A., and Singh, G. S. (2020). Traditional agricultural practices in India: an approach for environmental sustainability and food security. *Energy Ecol. Environ.* 5, 253–271. doi: 10.1007/s40974-020-00158-2

Puntsagdorj, B., Orosoo, D., Huo, X., and Xia, X. (2021). Farmer's perception, agricultural subsidies, and adoption of sustainable agricultural practices: a case from Mongolia. *Sustainability* 13:1524. doi: 10.3390/su13031524

Putterill, H. C. D. (2023). Identifying inefficiencies in the food system: how to feed 9.7 billion people in 2050.

Rahman, A. U., Wen, F., and Amjad, F. (2024). Role of sustainable business model, industry 4.0, crowdfunding, and stakeholders' pressure toward firm's sustainability: a SEM-ANN approach. *Bus. Strateg. Environ.* 33, 7409–7426. doi: 10.1002/bse.3869

Rahman, A. U., Wen, F., Amjad, F., and Ullah, R. (2023). Exploring the impact of crowdfunding and collaborations on firm survival through crisis management in the context of Pakistan: Technology Analysis & Strategic Management, 1–17.

Saikanth, K., Singh, B. V., Sachan, D. S., and Singh, B. (2023). Advancing sustainable agriculture: a comprehensive review for optimizing food production and environmental conservation. *Int. J. Plant Soil Sci.* 35, 417–425. doi: 10.9734/ijpss/2023/v35i163169

Sapbamrer, R., and Thammachai, A. (2021). A systematic review of factors influencing farmers' adoption of organic farming. *Sustainability* 13:3842. doi: 10.3390/su13073842

Sarkar, S., Skalicky, M., Hossain, A., Brestic, M., Saha, S., Garai, S., et al. (2020). Management of crop residues for improving input use efficiency and agricultural sustainability. *Sustainability* 12:9808. doi: 10.3390/su12239808

Sharma, R., Kamble, S. S., Gunasekaran, A., Kumar, V., and Kumar, A. (2020). A systematic literature review on machine learning applications for sustainable agriculture supply chain performance. *Comput. Oper. Res.* 119:104926. doi: 10.1016/j.cor.2020.104926

Shi, S., Zhou, S., Lei, Y., Harrison, M. T., Liu, K., Chen, F., et al. (2024). Burgeoning food demand outpaces sustainable water supply in China. *Agric. Water Manag.* 301:108936. doi: 10.1016/j.agwat.2024.108936

Sikandar, F., Erokhin, V., Xin, L., Sidorova, M., Ivolga, A., and Bobryshev, A. (2022). Sustainable agriculture and rural poverty eradication in Pakistan: the role of foreign aid and government policies. *Sustainability* 14:14751. doi: 10.3390/su142214751

Tan, Y., Hai, F., Popp, J., and Oláh, J. (2022). Minimizing waste in the food supply chain: role of information system, supply chain strategy, and network design. *Sustainability* 14:11515. doi: 10.3390/su141811515

Tian, H., Lu, C., Pan, S., Yang, J., Miao, R., Ren, W., et al. (2018). Optimizing resource use efficiencies in the food–energy–water nexus for sustainable agriculture: from conceptual model to decision support system. *Curr. Opin. Environ. Sustain.* 33, 104–113. doi: 10.1016/j.cosust.2018.04.003

Trivellas, P., Malindretos, G., and Reklitis, P. (2020). Implications of green logistics management on sustainable business and supply chain performance: evidence from a survey in the greek Agri-food sector. *Sustainability* 12:10515. doi: 10.3390/su122410515

Ullah, R., Ahmad, H., Rehman, F. U., and Fawad, A. (2023). Green innovation and sustainable development goals in SMEs: the moderating role of government incentives. *J. Econ. Admin. Sci.* 39, 830–846. doi: 10.1108/JEAS-07-2021-0122

Ur Rahman, A., and Amjad, F. (2024). The role of green finance, infrastructure, and technological capabilities in enhancing competitiveness resilience of Pakistani manufacturing firms: a sequential mediation–moderation analysis. *Clean Techn. Environ. Policy*, 1–16. doi: 10.1007/s10098-024-02837-8

Waiyawuththanapoom, P., and Jermsittiparsert, K. (2022). The role of sustainable HRM in supply chain, profitability and resource utilization. *Uncert. Supply Chain Manag.* 10, 365–374. doi: 10.5267/j.uscm.2022.1.002

Wernerfelt, B. (1989). From critical resources to corporate strategy. *J. Gen. Manag.* 14, 4–12. doi: 10.1177/030630708901400301

Xiang, W., and Gao, J. (2021). How does perceived value affect kiwi growers' sustainable application of green agricultural Technology in China?-moderating effect analysis based on government support.

Yadav, R. K., and Dagar, J. C. (2016). Innovations in utilization of poor-quality water for sustainable agricultural production. *Innov. Saline Agric.*, 219–263. doi: 10.1007/978-81-322-2770-0_11

Yontar, E., and Ersöz, S. (2021). Sustainability assessment with structural equation modeling in fresh food supply chain management. *Environ. Sci. Pollut. Res.* 28, 39558–39575. doi: 10.1007/s11356-021-13478-5

Zhang, J., and Drury, M. (2024). Sustainable agriculture in the EU and China: a comparative critical policy analysis approach. *Environ. Sci. Pol.* 157:103789. doi: 10.1016/j.envsci.2024.103789

Zhao, X., Wang, P., and Pal, R. (2021). The effects of agro-food supply chain integration on product quality and financial performance: evidence from Chinese agro-food processing business. *Int. J. Prod. Econ.* 231:107832. doi: 10.1016/j.ijpe.2020.107832