E-ISSN:3125-1323

ARTICLE

Data-Driven Supply Chains and Sustainability in Agri-Food Processing

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Abstract
Data-driven supply chain management capability (DDSCMC) has become an essential organizational capability for enhancing supply chain effectiveness through improved data utilization, analytics, and decision support. Despite its growing importance, limited research has examined the mechanisms through which DDSCMC contributes to sustainable supply chain performance (SSCP) within agro-processing firms. Drawing upon Organizational Information Processing Theory (OIPT), this study investigates the relationship between DDSCMC and SSCP while examining the mediating role of supply chain transparency (SCT) and the moderating role of circular economy thinking (CET). Data were collected from 249 agro-processing firms in China and analyzed using structural equation modeling (SEM). The results reveal that DDSCMC positively influences both supply chain transparency and sustainable supply chain performance. Furthermore, supply chain transparency serves as a significant mediating mechanism through which DDSCMC enhances sustainability outcomes. The findings also demonstrate that circular economy thinking strengthens the positive effect of DDSCMC on transparency and amplifies its indirect contribution to sustainable supply chain performance. This study extends the application of Organizational Information Processing Theory by illustrating how data-driven supply chain capabilities promote sustainability through enhanced transparency and circular economy-oriented decision-making. The findings also provide practical guidance for agro-processing firms seeking to improve sustainability performance by strategically integrating data-driven management capabilities, transparency practices, and circular economy principles into their supply chain operations.

Keywords: Supply Chain Analytics; Sustainable Performance; Information Processing Capability; Supply Chain Governance; Circular Economy Orientation

Academic Editor: Daniel Wang

Received: March 4, 2026 | Revised: March 18, 2026 | Accepted: March 25,2026 | Published: April 6, 2026

Citation: Randikaparsa.I. (2026). *Data-driven supply chains and sustainability in agri-food processing. Current Perspective on Business Operations,* 2(2), 125–142..

1. Introduction

Agro-processing firms constitute a vital component of agricultural supply chains because they bridge agricultural producers and end consumers. Through their intermediary role, these firms significantly influence both the sustainability and overall effectiveness of supply chain operations (Xu et al., 2024; Uddin & Akhter, 2022). Beyond transforming agricultural inputs into value-added products, agro-processing firms contribute to shaping sustainable production and consumption practices throughout the supply chain network. Their strategic activities involve optimizing resource utilization, minimizing waste generation, and complying with environmental as well as social standards (Lee et al., 2024). Consequently, improving the sustainable supply chain performance of agro-processing firms is essential for achieving broader sustainability objectives within agricultural supply chains (Cantele et al., 2023; Yadav et al., 2022).

Recent advances in digital technologies, including big data, blockchain, and the Internet of Things (IoT), have created new possibilities for enhancing sustainability within agro-processing supply chains (Yadav & Majumdar, 2024). Big data technologies enable firms to monitor and track resource utilization, production activities, and waste generation in real time, thereby supporting more efficient resource allocation, lowering operational costs, and reducing unnecessary resource consumption (Kumar et al., 2024). Likewise, blockchain technology facilitates the development of traceability systems that help mitigate food fraud and product adulteration while improving information accuracy and strengthening trust among supply chain stakeholders, ultimately encouraging the adoption of sustainable supply chain practices (Menon & Jain, 2024; Camel et al., 2024). Furthermore, IoT technologies support continuous data collection and transmission, enhancing communication, coordination, and collaboration among supply chain partners and substantially improving supply chain transparency and resilience in agro-processing operations (Zhou et al., 2022; Kamble et al., 2020).

Despite these technological advancements, the mere adoption of digital infrastructure does not guarantee successful implementation of sustainable supply chain initiatives. For instance, tomato-processing firms in Punjab, India, implemented IoT-based systems to monitor microclimatic conditions in agricultural fields. However, inadequate capabilities in managing and integrating collected data created a mismatch between production planning and real-time environmental information, resulting in a 15% decline in production capacity. In contrast, Fonterra, a leading dairy cooperative in New Zealand, effectively combined IoT-generated data with transportation route optimization algorithms through its supply chain data management system, achieving a 22% reduction in carbon emissions per unit of product. These contrasting cases demonstrate that technology deployment alone is insufficient to generate sustainability benefits. Organizations must possess the ability to systematically collect, integrate, and analyze data from diverse sources to continuously improve supply chain operations and support sustainable development objectives. This organizational capability is referred to as Data-Driven Supply Chain Management Capability (DDSCMC) (Belhadi et al., 2024; Joshi et al., 2024). Therefore, strengthening DDSCMC is crucial for enabling agro-processing firms to achieve sustainable growth and maintain long-term competitiveness in increasingly dynamic markets.

Existing research on DDSCMC has predominantly concentrated on manufacturing and retail sectors, highlighting its role in enhancing supply chain efficiency, responsiveness, and cost management through digital technologies (Belhadi et al., 2024). Nevertheless, agro-processing supply chains possess unique characteristics, including seasonal variability, resource constraints, and sustainability-related challenges, which distinguish them from other industries. As a result, the application of DDSCMC within agro-processing contexts remains underexplored in the current literature. Moreover, studies examining sustainable supply chain performance in agro-processing firms have largely focused on issues such as resource efficiency, waste reduction, and environmental compliance (Le et al., 2024; Yadav et al., 2022), while paying limited attention to how DDSCMC can promote sustainability through enhanced data collection, integration, and analytical processes. Although these capabilities are increasingly recognized as important drivers of sustainability, the role of DDSCMC as a strategic supply chain management capability in improving sustainable supply chain performance has not yet been comprehensively investigated. Consequently, current literature does not adequately capture the broader transformational potential of DDSCMC, particularly regarding its contribution to sustainable supply chain performance within agro-processing firms.

To address this gap, the present study adopts Organizational Information Processing Theory (OIPT) as its theoretical foundation. OIPT posits that organizations can improve decision-making quality and organizational performance by effectively processing information, thereby reducing information asymmetry and uncertainty (Hauβmann et al., 2012). This theoretical perspective is particularly relevant to agro-processing supply chains, where demand volatility, seasonal fluctuations, and resource limitations create substantial information-processing challenges. In such environments, sustainability outcomes depend heavily on the organization's capacity to integrate and process information in a timely and effective manner.

Drawing upon OIPT, this study proposes that Supply Chain Transparency serves as a mediating mechanism linking DDSCMC and Sustainable Supply Chain Performance. Supply Chain Transparency refers to the extent to which suppliers intentionally and proactively disclose operational, planning, and strategic information to agro-processing firms (Li et al., 2025; Budler et al., 2024; Zhu et al., 2018). Within agro-processing supply chains, DDSCMC enhances the collection, integration, and analysis of information, thereby reducing information asymmetry and facilitating more efficient information processing. These improvements contribute to higher-quality decision-making, greater operational efficiency, and stronger trust and collaboration among supply chain participants. Accordingly, Supply Chain Transparency represents a critical mechanism through which DDSCMC influences Sustainable Supply Chain Performance. Based on this reasoning, the first research question is proposed:

RQ1: Does Supply Chain Transparency mediate the relationship between Data-Driven Supply Chain Management Capability and Sustainable Supply Chain Performance in agro-processing firms?

In addition, OIPT highlights the importance of goal clarity in enhancing organizational capabilities and reducing uncertainty (Yadav et al., 2024). Within agro-processing supply chains, Circular Economy Thinking emphasizes efficient resource utilization, waste minimization, and lifecycle sustainability, making it highly compatible with the principle of goal clarity emphasized by OIPT (Le, 2023). By providing a clearer sustainability orientation, Circular Economy Thinking can strengthen supply chain transparency and reinforce the effectiveness of DDSCMC in supporting sustainability objectives. Therefore, this study proposes the following research question:

RQ2: Does Circular Economy Thinking moderate the relationship between Data-Driven Supply Chain Management Capability and Sustainable Supply Chain Performance in agro-processing firms?

This study makes three primary theoretical contributions. First, it extends the application of OIPT by examining the direct influence of DDSCMC on Sustainable Supply Chain Performance in agro-processing firms. Second, it clarifies the mediating role of Supply Chain Transparency in the relationship between DDSCMC and Sustainable Supply Chain Performance. Third, it identifies the moderating effect of Circular Economy Thinking, highlighting its importance in advancing sustainable supply chain development. Collectively, these contributions provide a deeper understanding of how DDSCMC enhances Sustainable Supply Chain Performance in agro-processing firms while offering valuable implications for both scholars and supply chain practitioners.

2. Materials and Methods

Sustainable Supply Chain Performance (SSCP) has become a strategic objective for agro-processing firms due to their central position within agricultural supply chains. These firms are not only responsible for transforming agricultural products into value-added outputs but also play a significant role in ensuring food safety, improving resource utilization, minimizing environmental impacts, and promoting farmers' economic welfare and social equity (Camel et al., 2024). Their activities typically encompass cleaning, packaging, processing, preservation, and distribution functions, all of which directly influence sustainability outcomes across the supply chain. Given the diversity of agricultural products and processing requirements, sustainable supply chain management practices vary considerably across different agro-processing sectors. Consequently, improving SSCP has become a critical concern for both researchers and practitioners seeking to enhance the long-term sustainability of agri-food systems (Guo et al., 2025).

Previous studies have identified several factors that contribute to sustainable supply chain performance in agricultural processing firms. Managerial awareness and commitment toward sustainability have been recognized as essential drivers of sustainable supply chain initiatives (Akhtar et al., 2016). In addition, stakeholder pressures originating from customers, competitors, governmental agencies, and environmental organizations have been shown to encourage firms to adopt sustainable supply chain practices (Mangla et al., 2018). Profit-oriented motivations, governmental support, and policy incentives have likewise been identified as important determinants of sustainability-related outcomes in agro-processing firms. Nevertheless, traditional agricultural supply chain management has often relied heavily on managerial experience and intuition, which may be inadequate for coping with increasing market volatility, environmental uncertainty, and sustainability challenges. With the emergence of the digital economy, researchers have increasingly emphasized the role of digital technologies and data analytics in improving sustainable supply chain performance (Gunasekaran et al., 2017).

Within this context, Data-Driven Supply Chain Management Capability (DDSCMC) has emerged as a critical organizational capability. DDSCMC refers to a firm's ability to develop and utilize cross-functional data infrastructure and analytical routines that transform data from multiple sources into actionable insights capable of supporting operational and strategic decision-making (Cui et al., 2024; Yu et al., 2018). This capability extends beyond the mere adoption of digital technologies and reflects an embedded organizational competence supported by data integration architectures, decision-support systems, governance mechanisms, and analytical routines (Al-Khatib, 2022; Le et al., 2024). Through DDSCMC, organizations can integrate information across manufacturing, procurement, logistics, customer management, and supplier management functions, enabling enhanced coordination, responsiveness, and decision quality throughout the supply chain (Suoniemi et al., 2020).

Although DDSCMC shares similarities with Big Data Analytics Capability (BDAC), important distinctions exist between these constructs. BDAC primarily emphasizes technological and analytical competencies for processing large, diverse, and rapidly changing datasets (Lee et al., 2024). DDSCMC, however, focuses on the operational integration and application of data capabilities throughout supply chain activities, thereby facilitating coordination, collaboration, and decision-making across organizational boundaries (Suoniemi et al., 2020). Existing studies have demonstrated the importance of DDSCMC in manufacturing, logistics, and e-commerce environments characterized by operational complexity and extensive data availability (Al-Khatib, 2022; Le et al., 2024). DDSCMC has been linked to enhanced decision-making, risk monitoring, organizational adaptability, and inter-organizational collaboration (Dubey et al., 2024).

However, despite growing scholarly attention, empirical research investigating DDSCMC within agricultural supply chains remains relatively limited. Agricultural supply chains exhibit unique characteristics, including biological variability, seasonality, geographical dispersion, perishability, and substantial environmental uncertainty, all of which create complex information-processing challenges. Existing studies have primarily focused on digital technologies such as IoT and big data platforms within agri-food systems (Kamble et al., 2020; Nayal et al., 2022), while relatively little attention has been devoted to understanding how DDSCMC is developed, operationalized, and leveraged as an organizational capability. Consequently, significant theoretical and empirical gaps remain regarding the mechanisms through which DDSCMC contributes to sustainability within agricultural supply chains.

Another important construct within sustainable supply chain management is Supply Chain Transparency (SCT). Although SCT has received increasing scholarly attention (Garcia-Torres et al., 2024; Morgan et al., 2023), its conceptual boundaries remain subject to debate due to frequent confusion with related concepts such as visibility and traceability. Supply chain visibility generally refers to a firm's ability to access, interpret, and utilize accurate and timely information across organizational boundaries (Swink et al., 2024; Li et al., 2025). Traceability, by contrast, focuses on the technical ability to track and trace products throughout the supply chain (Sodhi & Tang, 2019; Budler et al., 2024). SCT differs from both concepts because it emphasizes the intentional and proactive disclosure of operational, planning, and strategic information among supply chain participants (Li et al., 2025; Sodhi & Tang, 2019). In agro-processing supply chains, transparency is reflected in suppliers' willingness to share information related to production planning, resource utilization, environmental performance, operational activities, and strategic decisions.

Prior studies have demonstrated that SCT contributes to improved information symmetry, stronger trust among supply chain partners, reduced coordination costs, and lower operational uncertainty (Dubey et al., 2020; Gligor et al., 2022). Within agro-processing environments, suppliers' proactive disclosure of information regarding production batches, equipment performance, environmental conditions, and resource utilization enables focal firms to improve quality control, planning accuracy, and supplier monitoring processes (Zhang et al., 2022). Furthermore, transparency supports compliance with regulations concerning food safety, environmental protection, and product traceability while enhancing corporate reputation and stakeholder confidence. Therefore, SCT serves as an important mechanism through which organizations can strengthen collaboration and improve sustainable supply chain outcomes.

In addition to organizational capabilities and transparency mechanisms, Circular Economy Thinking (CET) has emerged as an increasingly important strategic orientation supporting sustainability initiatives. Circular economy principles emphasize resource regeneration, waste reduction, value retention, and lifecycle sustainability (Velenturf & Purnell, 2021; Malhotra, 2024). These principles are particularly relevant in agro-processing industries where production activities frequently generate substantial quantities of organic waste and by-products (Bakır & Aral, 2025). CET represents a collective managerial mindset that influences how organizations interpret sustainability challenges and identify opportunities for resource recovery, recycling, productivity improvement, and environmental stewardship (Le, 2023). Rather than functioning solely as an operational practice, CET serves as a strategic cognitive orientation that shapes organizational priorities and guides managerial decision-making processes.

As a strategic orientation, CET influences the manner in which organizations utilize information and deploy analytical capabilities. Firms embracing CET tend to prioritize information concerning waste recovery, resource regeneration, environmental impacts, and circular value creation (Le, 2023). Consequently, CET becomes integrated into analytics-driven system improvements and operational decision-making processes, enabling organizations to align economic performance objectives with environmental and social sustainability goals. By facilitating the transformation of waste streams into valuable resources, CET contributes to enhanced resource efficiency, regulatory compliance, supply chain resilience, and long-term competitiveness (Kumar et al., 2023).

The theoretical foundation of this study is Organizational Information Processing Theory (OIPT), which argues that organizational performance depends on the alignment between information-processing requirements and information-processing capabilities (Hauβmann et al., 2012). According to OIPT, organizations operating in uncertain environments must either reduce information-processing requirements or enhance their information-processing capacity to maintain effective decision-making and coordination (Nematollahi & Tajbakhsh, 2020). This perspective is particularly relevant to agro-processing supply chains because these environments are characterized by biological variability, seasonal fluctuations, perishability, resource constraints, and increasingly stringent sustainability regulations (Zhang et al., 2022). Within this context, DDSCMC represents a critical information-processing capability that enables organizations to integrate fragmented information, perform advanced analytics, and generate actionable insights capable of reducing uncertainty and improving performance.

Building upon OIPT, this study proposes that DDSCMC positively influences SSCP. Enhanced information-processing capabilities enable firms to improve forecasting accuracy, optimize resource allocation, reduce waste, improve operational efficiency, and support sustainability objectives across economic, environmental, and social dimensions (Riggs et al., 2023; Nyamah et al., 2022; Ali et al., 2023; Joshi et al., 2024; Zhou et al., 2022; Liu et al., 2022). Therefore, the following hypothesis is proposed:

H1. Data-Driven Supply Chain Management Capability positively influences Sustainable Supply Chain Performance.

OIPT further suggests that enhanced information-processing capabilities facilitate more effective information exchange across organizational boundaries. Through data integration, analytics, and digital platforms, firms possessing strong DDSCMC can reduce information asymmetry and improve information accessibility, thereby fostering greater transparency within supply chain relationships (Yu et al., 2018; Zhu et al., 2018; Morgan et al., 2023). Accordingly, the following hypothesis is proposed:

H2. Data-Driven Supply Chain Management Capability positively influences Supply Chain Transparency.

Supply chain transparency contributes to sustainability by reducing uncertainty, improving coordination, strengthening stakeholder trust, and facilitating compliance with environmental and social standards (Zhang et al., 2022; Jia et al., 2019). Transparent supply chains enable organizations to better monitor environmental impacts, resource utilization, and supplier behavior while promoting accountability and collaboration among stakeholders. Consequently, the following hypothesis is proposed:

H3. Supply Chain Transparency positively influences Sustainable Supply Chain Performance.

According to OIPT, information-processing capabilities influence organizational performance through changes in information structures and information flows (Yadav et al., 2024). DDSCMC strengthens firms' ability to collect, integrate, and analyze information, thereby enhancing transparency through improved information sharing and traceability (Liu et al., 2022; Schäfer, 2023). Increased transparency subsequently improves sustainability performance by supporting more informed decision-making and collaborative responses to operational challenges. Therefore, the following hypothesis is proposed:

H4. Supply Chain Transparency mediates the relationship between Data-Driven Supply Chain Management Capability and Sustainable Supply Chain Performance.

Finally, OIPT suggests that information-processing requirements are shaped by strategic orientations and organizational priorities (Cui et al., 2024). CET influences the manner in which organizations utilize information generated through DDSCMC by emphasizing sustainability objectives, waste reduction, resource recovery, and circular value creation (Le, 2023). Firms with stronger CET are therefore more likely to leverage transparency and data-driven insights to support sustainable supply chain initiatives (Dubey et al., 2019; Yuan & Pan, 2023; Belhadi et al., 2024; Fang et al., 2024; Joshi et al., 2024; Schäfer, 2023). Accordingly, the following hypothesis is proposed:

H5. Circular Economy Thinking positively moderates the indirect relationship between Data-Driven Supply Chain Management Capability and Sustainable Supply Chain Performance through Supply Chain Transparency.

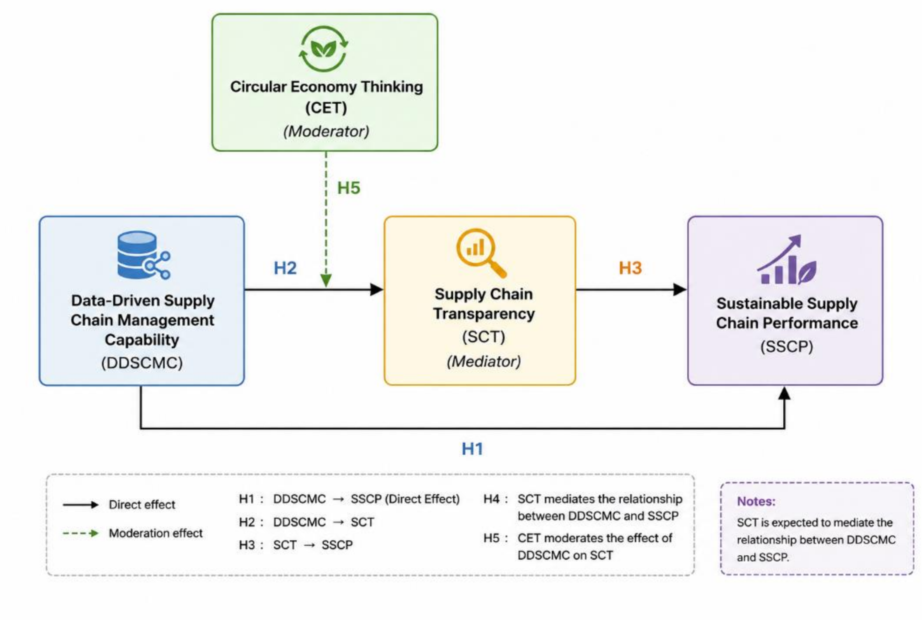

Figure 1. Proposed Research Framework

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Following the development of the conceptual framework and hypotheses, a quantitative survey approach was employed to empirically examine the proposed relationships among Data-Driven Supply Chain Management Capability (DDSCMC), Supply Chain Transparency (SCT), Circular Economy Thinking (CET), and Sustainable Supply Chain Performance (SSCP). The study focused on agro-processing firms operating in China, including organizations engaged in tea processing, livestock processing, ecological fishery processing, and herbal medicine processing. To capture regional diversity and enhance representativeness, firms were selected from the eastern, central, and western regions of China using directories provided by provincial agricultural bureaus.

The target respondents were middle- and senior-level managers as well as personnel responsible for purchasing, production, operations, logistics, and sustainability-related functions. These individuals were selected because of their direct involvement in supply chain activities and their familiarity with sustainability practices implemented within their organizations. Data collection was conducted in three waves between June and December 2022. A total of 512 agro-processing firms were invited to participate in the survey, resulting in 308 returned questionnaires. After eliminating incomplete responses and removing outliers identified through the Mahalanobis distance procedure, 249 valid questionnaires were retained for subsequent analysis, yielding an effective response rate of 80.84%. To avoid duplication and ensure data independence, only one questionnaire from each firm was included in the final dataset.

Table 1. Characteristics of Sample Firms and Respondents

Characteristics	Category	Frequency	%
Firm size	Less than 100	26	10.44
	100–1000	68	27.31
	1000–10,000	82	32.93
	More than 10,000	73	29.32
Geographic region	Eastern region	74	29.72
	Central region	86	34.54
	Western region	89	35.74
Tenure in the firm	Less than 5 years	36	14.45
	5–10 years	128	51.41
	More than 10 years	85	34.14

To ensure the reliability and validity of the measurement instruments, all constructs were adapted from previously validated scales. Because the survey was administered in China, a rigorous back-translation procedure was implemented to ensure linguistic equivalence and conceptual consistency between the original English version and the Chinese version of the questionnaire. Following established translation guidelines, bilingual scholars and researchers with expertise in supply chain management and sustainability translated the original instrument into Chinese and subsequently translated it back into English. The translated versions were compared and refined to eliminate inconsistencies arising from cultural differences and interpretation bias.

All measurement items were assessed using a seven-point Likert scale ranging from 1 (“strongly disagree”) to 7 (“strongly agree”), with the midpoint value of 4 representing a neutral response. Sustainable Supply Chain Performance (SSCP) was measured using nine items adapted from Nayal et al. (2023) and Kamble et al. (2020). Consistent with the Triple Bottom Line perspective, the scale captured economic, environmental, and social dimensions of sustainability performance. Data-Driven Supply Chain Management Capability (DDSCMC) was measured using four items adapted from Yu et al. (2018), assessing firms’ capabilities in utilizing data-driven approaches across manufacturing, operational management, customer management, and supplier management functions. Supply Chain Transparency (SCT) was assessed using eight items derived from Zhu et al. (2018), focusing on the extent to which upstream suppliers share operational, planning, and strategic information with focal agro-processing firms. Circular Economy Thinking (CET) was measured using four items adopted from Le (2023), evaluating the degree to which organizations incorporate circular economy principles into their analytics and decision-making activities, including waste reduction, energy conservation, productivity enhancement, and adaptation to changing market conditions.

To control for potential confounding effects, firm size and geographic region were incorporated as control variables. Firm size was measured based on the number of employees and categorized into four groups: fewer than 100 employees, 100–1,000 employees, 1,000–10,000 employees, and more than 10,000 employees. Geographic region was classified into eastern, central, and western China. The inclusion of these control variables was justified by previous studies suggesting that organizational resources, institutional environments, regulatory pressures, and market conditions may influence sustainability performance outcomes (Mangla et al., 2018; Ghadge et al., 2019).

Table 2. Measurement Items and Sources

Model	χ^2	df	χ^2/df	CFI	TLI	IFI	RMSEA
Four-factor model	807.373	439	1.839	0.912	0.917	0.907	0.035
Model including the four factors and the method factor	715.126	422	1.695	0.915	0.922	0.909	0.033

Because survey-based studies may be susceptible to non-response bias, a series of diagnostic procedures were conducted. Following the recommendations of Armstrong and Overton (1977), early and late respondents were compared using independent sample t-tests and chi-square analyses. Additionally, demographic characteristics associated with excluded questionnaires were compared with those retained in the final sample. The results revealed no statistically significant differences in firm size ($p = 0.356$), respondent tenure ($p = 0.442$), or other demographic characteristics. Furthermore, chi-square analyses indicated that all p-values exceeded the recommended threshold of 0.05, suggesting that non-response bias was unlikely to affect the representativeness of the sample (Armstrong & Overton, 1977; Van de Vijver & Leung, 1997).

Given that all variables were collected through a single survey instrument, common method bias (CMB) was also examined. Several procedural remedies were implemented during questionnaire design to minimize this concern. First, independent and dependent variables were placed on separate pages of the questionnaire. Second, clear instructions were provided to respondents, and the order of measurement items was varied across different rounds of data collection to reduce potential sequence effects (Baker et al., 2016). Subsequently, Harman's single-factor test was conducted as an initial statistical assessment. The results indicated that the largest factor explained only 24.685% of the total variance, which is substantially below the threshold commonly associated with serious common method bias. Moreover, four factors with eigenvalues greater than one emerged from the exploratory factor analysis, further suggesting that common method bias was not a dominant issue.

To provide additional evidence, an unmeasured latent method factor was incorporated into the confirmatory factor analysis model. Although the inclusion of the method factor slightly improved model fit indices, the differences between the original model and the method-factor model were minimal. The values of χ^2/df, CFI, TLI, IFI, and RMSEA remained largely unchanged, indicating that common method variance did not significantly influence the study results (Spector et al., 2017; Podsakoff et al., 2024).

Table 3. Assessment of Common Method Bias

Variables	Measurement Items	Factor Loadings	Cronbach's Alpha	CR	AVE
SSCP	SSCP1	0.876	0.938	0.946	0.664
	SSCP2	0.734			
	SSCP3	0.829			
	SSCP4	0.843			
	SSCP5	0.782			
	SSCP6	0.784			
	SSCP7	0.844			

Variables	Measurement Items	Factor Loadings	Cronbach's Alpha	CR	AVE
	SSCP8	0.802			
	SSCP9	0.816			
DDSCMC	DDSCMC1	0.793	0.899	0.905	0.677
	DDSCMC2	0.891			
	DDSCMC3	0.779			
	DDSCMC4	0.888			
SCT	SCT1	0.761	0.927	0.930	0.623
	SCT2	0.879			
	SCT3	0.719			
	SCT4	0.818			
	SCT5	0.706			
	SCT6	0.878			
	SCT7	0.752			
	SCT8	0.799			
CET	CET1	0.826	0.877	0.889	0.687
	CET2	0.757			
	CET3	0.775			
	CET4	0.898			

The reliability and validity of the measurement model were subsequently evaluated using Confirmatory Factor Analysis (CFA). Prior to conducting CFA, Bartlett's Test of Sphericity and the Kaiser–Meyer–Olkin (KMO) measure were employed to assess the suitability of the data for factor analysis. The results produced a KMO value of 0.872 and a significant Bartlett's Test result ($p < 0.001$), confirming the adequacy of the dataset for factor analysis (Hair Jr et al., 2021).

Principal Component Analysis (PCA) with Varimax rotation and Kaiser normalization was then performed. After eight iterations, the rotated component matrix converged successfully, and all measurement items demonstrated factor loadings exceeding the recommended threshold of 0.50. The highest loading was observed for CET (0.938), whereas the lowest acceptable loading was recorded for SCT (0.574). Importantly, no substantial cross-loadings were identified, indicating satisfactory construct validity and supporting the appropriateness of the measurement model (Hair Jr et al., 2021; Nayal et al., 2022).

Internal consistency reliability was assessed using Cronbach's Alpha (CA) and Composite Reliability (CR). The results demonstrated that all constructs exceeded the recommended threshold of 0.70, indicating strong reliability. Specifically, the CA values for SSCP, DDSCMC, SCT, and CET ranged from 0.877 to 0.938, while CR values ranged from 0.889 to 0.946. These findings confirm that the measurement scales exhibit satisfactory internal consistency and stability.

Convergent validity was evaluated using Average Variance Extracted (AVE). All AVE values exceeded the recommended threshold of 0.50, ranging from 0.623 to 0.687, indicating that the constructs adequately captured the variance of their respective indicators. Discriminant validity was assessed using both the Fornell–Larcker criterion and the Heterotrait–Monotrait Ratio (HTMT). The square roots of the AVE values exceeded all corresponding inter-construct correlations, supporting discriminant validity. Furthermore, HTMT values ranged from 0.134 to 0.621, remaining well below the recommended threshold of 0.85 (Henseler et al., 2015). Collectively, these results confirm that the measurement model possesses satisfactory reliability, convergent validity, and discriminant validity.

Table 4.Discriminant Validity Results

Variables	Mean	S.D.	1	2	3	4
1. SSCP	4.375	0.736	**0.815**			
2. DDSCMC	5.287	0.611	0.385**	**0.823**		
3. SCT	4.828	0.725	0.472**	0.292**	**0.789**	
4. CET	5.912	0.562	0.463**	0.117*	0.271**	**0.829**

Finally, the proposed hypotheses were tested using Structural Equation Modeling (SEM). SEM was selected because it enables the simultaneous examination of direct, indirect, and conditional relationships among latent constructs while accounting for measurement error. The analysis proceeded in two stages. First, the measurement model was evaluated to confirm the adequacy of reliability and validity. Second, the structural model was assessed to test the direct effects, mediating role of Supply Chain Transparency, and moderating effect of Circular Economy Thinking within the proposed research framework. This analytical approach provides a comprehensive assessment of the relationships among DDSCMC, SCT, CET, and SSCP and is consistent with prior studies investigating complex sustainability-related phenomena within supply chain contexts (Hair Jr et al., 2021).

Interventionary studies involving animals or humans, and other studies that require ethical approval, must list the authority that provided approval and the corresponding ethical approval code.

3. Results

The proposed hypotheses were evaluated using Structural Equation Modeling (SEM) in Mplus 8.0. Compared with conventional SEM software such as AMOS and PLS-SEM, Mplus provides several advantages for mediation analysis, particularly through the implementation of bootstrap estimation procedures that improve the accuracy of indirect effect testing and confidence interval estimation. This approach enables a more robust examination of mediation mechanisms while simultaneously providing comprehensive model fit statistics.

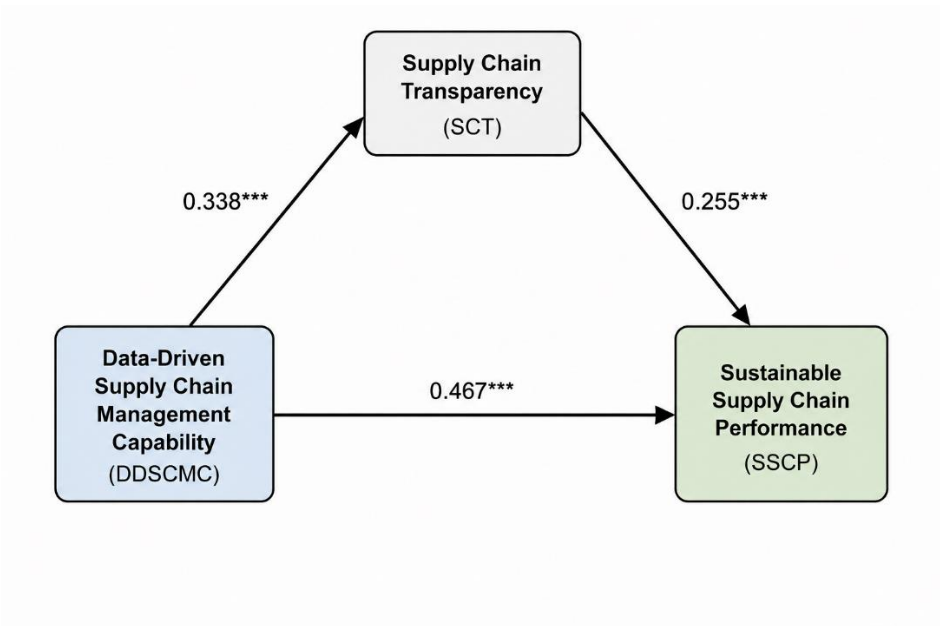

Figure 2. Structural equation model. Note: Hypothesis paths are marked with a standardized path coefficient. ***P < 0.001.

The structural model demonstrated satisfactory goodness-of-fit indicators, suggesting that the proposed framework adequately represented the observed data (χ^2/df = 1.758, SRMR = 0.029, CFI = 0.934, TLI = 0.937, RMSEA = 0.034). The results of the hypothesis testing are presented in Figure 2 and Table 5.

Table 5. Hypothesis Test Results

Path Relationships	β	Boot SE	95% CI Lower	95% CI Upper	p
DDSCMC → SSCP	0.467	0.071	0.192	0.472	0.000
DDSCMC → SCT	0.311	0.064	0.138	0.392	0.000
SCT → SSCP	0.255	0.069	0.114	0.378	0.000
DDSCMC → SCT → SSCP	0.080	0.028	0.031	0.149	0.006
Firm Size → SSCP	0.069	0.048	-0.062	0.124	0.518
Central Region → SSCP	0.037	0.054	-0.066	0.141	0.489
Western Region → SSCP	0.044	0.057	-0.071	0.152	0.441

The direct effect analysis revealed that Data-Driven Supply Chain Management Capability (DDSCMC) exerted a significant positive influence on Sustainable Supply Chain Performance (SSCP) ($\beta = 0.467$, $p < 0.001$), supporting H1. DDSCMC was also found to positively affect Supply Chain Transparency (SCT) ($\beta = 0.311$, $p < 0.001$), thereby supporting H2. Furthermore, SCT exhibited a significant positive effect on SSCP ($\beta = 0.255$, $p < 0.001$), providing support for H3. These findings indicate that firms with stronger data-driven supply chain management capabilities tend to achieve higher levels of transparency and sustainability performance within their supply chains.

With regard to the control variables, neither firm size nor geographic region showed significant effects on sustainable supply chain performance. Firm size was not significantly associated with SSCP ($\beta = 0.069$, $p > 0.05$). Likewise, the effects of the central and western regions, relative to the eastern region, were statistically insignificant ($\beta = 0.037$, $p > 0.05$; $\beta = 0.044$, $p > 0.05$). These results suggest that the observed relationships among DDSCMC, SCT, CET, and SSCP are not driven by differences in organizational scale or regional location.

The mediating role of Supply Chain Transparency was subsequently examined using a bias-corrected bootstrap procedure. The indirect effect of DDSCMC on SSCP through SCT was statistically significant ($\beta = 0.080$, $p < 0.01$), with a 95% confidence interval ranging from 0.031 to 0.149. Since the confidence interval did not include zero, the mediation effect was confirmed. This finding indicates that DDSCMC contributes to sustainable supply chain performance not only directly but also indirectly through the enhancement of supply chain transparency. Therefore, H4 was supported.

To assess the conditional indirect effect, the coefficient product approach proposed by Hayes (2017) was employed. The results revealed that Circular Economy Thinking (CET) significantly strengthened the mediating effect of SCT in the relationship between DDSCMC and SSCP. The moderated mediation effect was significant, with a 95% confidence interval of [0.021, 0.196], excluding zero, and an effect size of 0.176. These findings indicate that organizations characterized by stronger circular economy thinking are better able to leverage data-driven supply chain management capabilities and transparency practices to improve sustainable supply chain performance. Consequently, H5 was supported.

Endogeneity Assessment

Considering that the study relied on cross-sectional and single-source survey data, the potential presence of endogeneity arising from omitted variables, simultaneity, or reverse causality was further assessed. Following the recommendations of Park and Gupta (2012) and Eckert and Hohberger (2023), the Gaussian Copula (GC) approach was employed as an instrument-free method for correcting potential endogeneity bias. Compared with traditional instrumental variable techniques, the Gaussian Copula approach does not require external instruments and avoids concerns regarding instrument validity and exclusion restrictions. Instead, it controls for endogeneity through copula terms derived from the distributional characteristics of potentially endogenous variables (Zeng et al., 2025; Eckert & Hohberger, 2023).

Prior to implementing the Gaussian Copula procedure, the normality of the potentially endogenous constructs was examined. Shapiro–Wilk tests indicated significant departures from normality for both DDSCMC and SCT ($p < 0.05$), thereby satisfying the non-normality requirement necessary for Gaussian Copula identification.

Subsequently, Gaussian Copula terms were generated for DDSCMC and SCT and incorporated into the structural model. As reported in Table 6, the copula term associated with DDSCMC was not significantly related to SSCP ($\beta = 0.041$, Boot SE = 0.164, $p = 0.276$) or SCT ($\beta = 0.032$, Boot SE = 0.177, $p = 0.335$). Similarly, the copula term associated with SCT did not significantly predict SSCP ($\beta = 0.028$, Boot SE = 0.219, $p = 0.472$). According to Park and Gupta (2012), a non-significant copula coefficient indicates that the explanatory variable is not systematically correlated with the structural disturbance term. Therefore, the findings provide evidence that endogeneity is unlikely to materially affect the estimated relationships within the proposed model, supporting the robustness and validity of the empirical results.

4. Discussion

4.1. Theoretical Contributions

This study contributes to the sustainable supply chain management literature in several important ways, particularly within the context of agro-processing firms.

First, the findings establish Data-Driven Supply Chain Management Capability (DDSCMC) as a significant driver of Sustainable Supply Chain Performance (SSCP). While previous studies have primarily emphasized the role of DDSCMC in enhancing operational effectiveness, responsiveness, and supply chain efficiency (Guo et al., 2023; Liu et al., 2022), research examining its contribution to sustainability outcomes remains limited. Existing literature has also highlighted potential drawbacks associated with data-driven capabilities, including resource diversion and increased exposure to operational risks (Xu et al., 2023; Yuan & Pan, 2023). The present study extends this stream of research by demonstrating that DDSCMC contributes not only to operational improvements but also to broader sustainability objectives encompassing economic, environmental, and social dimensions. These findings position DDSCMC as a strategic capability that supports sustainable value creation rather than merely serving as an operational enhancement mechanism.

Second, this research advances the understanding of Supply Chain Transparency (SCT) by identifying its mediating role in the relationship between DDSCMC and SSCP. Previous studies have consistently emphasized transparency as a critical factor in fostering trust, facilitating information exchange, and improving collaboration among supply chain partners (Rogerson & Parry, 2020). However, limited empirical evidence has explained how transparency translates data-driven capabilities into sustainability outcomes. The results indicate that SCT serves as a crucial mechanism through which DDSCMC improves sustainable supply chain performance. By reducing information asymmetry, enhancing information quality, and facilitating more effective coordination among supply chain actors, transparency enables organizations to maximize the sustainability benefits generated by data-driven management practices. This finding enriches existing literature by clarifying the process through which DDSCMC influences sustainability performance and by demonstrating how transparency mitigates potential challenges associated with data-driven operations, including misaligned objectives and inefficient resource allocation (Xu et al., 2023). Furthermore, the study reinforces and extends prior discussions regarding the strategic importance of transparency in achieving collaborative and sustainable supply chain systems (Rogerson & Parry, 2020).

Third, this study contributes to the growing body of knowledge concerning Circular Economy Thinking (CET) by demonstrating its moderating role in strengthening the sustainability effects of DDSCMC. Circular economy principles emphasize waste minimization, resource efficiency, product lifecycle extension, and environmental stewardship, and previous studies have documented their positive contribution to resource optimization and environmental sustainability (Le, 2023). Although some scholars have explored the integration of digital technologies and circular economy practices to support sustainable development (Nayal et al., 2022; De Angelis & Ianulardo, 2024), empirical evidence regarding the interaction between DDSCMC and CET remains scarce, particularly within agro-processing supply chains. The present findings indicate that CET enhances the effectiveness of DDSCMC by providing clear sustainability-oriented priorities for resource management and decision-making. Through the reinforcement of transparency mechanisms and the alignment of data utilization with sustainability objectives, CET strengthens the contribution of DDSCMC to sustainable supply chain performance.

Finally, this study extends the application of Organizational Information Processing Theory (OIPT). Traditional OIPT conceptualizes information processing as an internal organizational capability developed to cope with environmental uncertainty (Hauβmann et al., 2012; Cui et al., 2024). The findings broaden this perspective in two significant ways. First, they demonstrate that information-processing capabilities can influence outcomes beyond organizational boundaries. Specifically, DDSCMC encourages greater transparency among upstream suppliers, thereby reshaping information structures throughout the supply chain network. Second, by incorporating Circular Economy Thinking as a strategic contingency factor, this study integrates managerial cognition into the OIPT framework and highlights how strategic priorities influence the deployment and utilization of information-processing capabilities. Collectively, these findings expand OIPT from a firm-level adaptation perspective toward a broader supply chain information governance framework that incorporates both inter-organizational relationships and strategic sustainability orientations.

4.2. Managerial Implications

The findings of this study provide several practical implications for agro-processing firms seeking to improve sustainable supply chain performance through data-driven management approaches.

First, organizations should recognize DDSCMC and SCT as complementary capabilities that jointly contribute to sustainability improvement. Given the inherent characteristics of agricultural supply chains, including perishability, seasonal variability, quality fluctuations, and dependence on multiple stakeholders, agro-processing firms should prioritize the development of integrated digital infrastructures capable of supporting real-time information collection, monitoring, and coordination throughout the supply chain. Practical initiatives may include the implementation of Internet of Things

(IoT) sensors, RFID-based traceability systems, centralized data platforms, and digital monitoring tools capable of tracking sourcing activities, logistics conditions, production processes, and environmental indicators. These technologies can improve visibility and transparency while enabling faster and more informed decision-making.

In addition, firms should strengthen their analytical capabilities to ensure that data resources are effectively translated into actionable insights. This may involve recruiting data analytics professionals, developing employee training programs, and establishing collaborations with technology providers, agri-tech companies, and digital platform operators. Such investments can help organizations improve forecasting accuracy, optimize resource allocation, reduce operational inefficiencies, and support sustainability-oriented decision-making across supply chain functions.

The results also highlight the importance of transparency in agricultural supply chains. Because agro-processing firms frequently depend on smallholder farmers, cooperatives, and geographically dispersed suppliers, transparent information-sharing mechanisms are essential for establishing trust, ensuring product quality, and supporting long-term collaboration. Managers should therefore encourage the development of digital communication platforms that facilitate information exchange between upstream suppliers and focal firms. Enhanced traceability systems can provide stakeholders with greater visibility regarding product origins, production conditions, environmental performance, and compliance standards, thereby strengthening both operational performance and stakeholder confidence.

Furthermore, the significant moderating role of Circular Economy Thinking suggests that sustainability benefits derived from DDSCMC can be amplified when organizations adopt a stronger circular economy orientation. Agro-processing firms should integrate circular economy principles into their strategic planning processes and utilize data-driven insights to identify opportunities for resource recovery, waste valorization, and environmental improvement. For example, firms may leverage data analytics to identify productive uses for agricultural by-products such as soybean meal, rice husks, fruit pomace, or livestock waste. These initiatives can transform waste streams into value-generating resources while simultaneously reducing environmental impacts and operational costs.

Moreover, agro-processing firms can utilize data-driven insights to convert agricultural waste streams into higher-value outputs, including organic animal feed, bio-based materials, and renewable energy sources. Real-time monitoring systems may also be employed to track water consumption, soil conditions, and carbon emissions across the supply chain, enabling organizations to implement differentiated sourcing strategies and adaptive environmental management practices that are tailored to local ecosystem characteristics. To ensure the sustainability of these initiatives, Circular Economy Thinking should be institutionalized throughout the organization through strong leadership commitment, active employee participation, and close collaboration with upstream suppliers and agricultural producers. Embedding circular economy principles into organizational culture and operational decision-making can transform sustainability from a compliance-oriented obligation into a strategic source of innovation, resilience, and shared value creation within agro-processing supply chains.

Finally, managers should view sustainability objectives as integral components of digital transformation initiatives rather than as separate organizational goals. The integration of DDSCMC, SCT, and CET provides a comprehensive pathway through which agro-processing firms can enhance supply chain resilience, improve stakeholder relationships, strengthen environmental performance, and achieve long-term competitive advantages in increasingly dynamic and sustainability-oriented markets.

5. Conclusions

This study develops and empirically validates a conceptual framework based on Organizational Information Processing Theory (OIPT) to investigate the influence of Data-Driven Supply Chain Management Capability (DDSCMC) on Sustainable Supply Chain Performance (SSCP) in agro-processing firms. Using data collected from 249 agro-processing firms, the findings provide strong empirical support for the proposed model.

The results demonstrate that DDSCMC significantly improves both Supply Chain Transparency (SCT) and Sustainable Supply Chain Performance, confirming the strategic importance of data-driven capabilities in enhancing organizational decision-making, operational effectiveness, and sustainability outcomes (Talwar et al., 2021). The findings further reveal that SCT positively contributes to sustainable supply chain performance by facilitating information sharing, strengthening stakeholder trust, and improving collaboration across supply chain networks (Schäfer, 2023; Sodhi & Tang, 2019). Moreover, SCT serves as a significant mediating mechanism through which DDSCMC enhances sustainability performance, indicating that the integration, analysis, and utilization of data across the supply chain are essential for improving transparency and achieving sustainability objectives (Kumar et al., 2024). The results also confirm the moderating role of Circular Economy Thinking (CET), demonstrating that a stronger circular economy orientation enhances the effectiveness of DDSCMC and strengthens its contribution to sustainable supply chain performance through improved transparency.

Overall, this study highlights that sustainable supply chain performance in agro-processing firms can be substantially enhanced through the synergistic integration of data-driven supply chain management capabilities, supply chain transparency, and circular economy thinking. By extending the application of Organizational Information Processing Theory to the context of sustainable agro-processing supply chains, this research provides valuable theoretical insights and practical guidance for organizations seeking to improve sustainability performance while strengthening competitiveness in increasingly complex and dynamic supply chain environments.

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