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Examining DEMATEL-Based Challenges to Blockchain Adoption in the Agricultural Food Supply Chain of India

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Abstract
Blockchain technology possesses the capacity to markedly enhance agri-food supply chains by rendering them more transparent, traceable, and sustainable. Notwithstanding its potential, numerous obstacles impede its implementation, particularly within the Indian setting. This report examines the primary obstacles hindering the extensive adoption of blockchain in India's agri-food sector. Through a comprehensive analysis of current research and expert insights, twelve significant impediments were identified. The study employed the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method to elucidate the interrelationships among these barriers. The findings indicated that seven of the barriers are fundamental causes, whilst the other five are primarily consequences of those factors. The absence of supportive policies and inadequate infrastructure are among the most pressing concerns that substantially hinder adoption. The results offer significant guidance for Indian policymakers and stakeholders seeking to address these difficulties and promote the incorporation of blockchain into the nation's agri-food supply chain.

Keywords: Blockchain adoption, DEMATEL, barriers, agri-food supply chain, India, policy insights

1. Introduction
The Agri-Food Supply Chain (AFSC) in India is a multifaceted system encompassing sourcing, production, post-harvest handling, storage, processing, and distribution (Behzadi et al., 2018; Zhao et al., 2019). It faces unique challenges such as food safety concerns, environmental variability, price volatility, and perishability (Ahumada & Villalobos, 2009). Incidents like the E. coli outbreak in Germany have heightened global demand for transparency in food systems (European Food Safety Authority, 2011; Xin & Stone, 2008). To address these challenges, traceability and trust mechanisms have gained prominence. The Fourth Industrial Revolution has accelerated digital technology adoption in AFSCs, including Blockchain Technology (BCT), Information and Communication Technologies (ICT), Internet of Things (IoT), Radio Frequency Identification (RFID), and Cloud Computing (Bumblauskas et al., 2020; Jamil et al., 2022; Panigrahy & Panda, 2025; Shrivastava & Pal, 2019). Among these, BCT is particularly transformative.

Blockchain functions as a decentralized, tamper-evident ledger linking data blocks via cryptographic hashes, ensuring integrity and transparency (Casino et al., 2021; Iftekhar & Cui, 2021). It enables end-to-end traceability, aiding in identifying quality/safety issues, minimizing waste, and providing verifiable data on origin, production, and labeling (Chaganti et al., 2022; Hang et al., 2020; Pranto et al., 2021; Ting et al., 2022). In India, BCT-based traceability has been explored in dairy, eggs, beef, and soybean sectors (Casino et al., 2021; Iftekhar & Cui, 2021; Yadav et al., 2020) , and supports sustainability in fertilizer use, water management, and energy optimization (Jamil et al., 2022; Padmavathi et al., 2024; Senthilmurugan & Chinnaiyan, 2021). Globally, BCT is being deployed in initiatives such as IBM Food Trust (with Walmart, Unilever, Nestlé), Carrefour's adoption of the same, China's Blockchain Food Safety Alliance, and projects like Provenance (tuna), Bumble Bee–SAP (seafood), and OpenSC (Patagonian toothfish) (Jamil et al., 2022; Kshetri, 2019; Panigrahy & Panda, 2025; Patti et al., 2024; Tan et al., 2018; Xu et al., 2020).

India, facing rising food demand due to a projected population of over 1.6 billion by 2050, also grapples with significant food insecurity—over 20% of the population is malnourished, and foodborne illnesses exceed 90 million cases annually (Patti et al., 2024; Yadav et al., 2020; Yadav & Singh, 2019; World Health Organization, 2022; Zhao et al., 2019). Consequently, BCT offers potential for improving food safety, traceability, and sustainability. Pilot studies include blockchain traceability models for olive oil (Tunisia) (Ktari et al., 2022), the "SmartRice" BCT-RFID framework in India (Gugulothu & Nandhini, 2023), cocoa supply chain applications (Kraft & Kellner, 2022) , and greenhouse gas tracking frameworks (Praveen et al., 2021). Despite promise, BCT adoption in India remains limited due to weak digital infrastructure and an unclear regulatory environment (Patti et al., 2024; Yadav, 2021). While barriers have been explored in Africa, China, and Latin America (Patti et al., 2024; Pranto et al., 2021), India's specific socio-economic and policy context requires tailored analysis. This study addresses three research questions:

RQ1: What are the main barriers to BCT implementation in India's AFSC?

RQ2: How are these barriers causally interrelated?

RQ3: Can a hierarchical structure of these barriers inform strategic interventions?

To answer these, a literature review and expert consultations are synthesized. The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method is applied to model causal relationships among the barriers, supporting policy and strategic planning for effective BCT integration in India's AFSC.

2. Blockchain Technology (BCT)

Blockchain Technology (BCT) is a decentralized digital ledger that records transactions across cryptographically linked blocks. Each block contains a unique hash referencing its predecessor, ensuring tamper-evidence—any alteration disrupts subsequent hashes, preserving data integrity (Patti et al., 2024). Operated via a distributed network of nodes, each maintaining a full copy of the ledger, BCT enhances transparency and eliminates single-point failure risks (Yadav & Singh, 2019). Core features include decentralization, immutability, consensus mechanisms, and smart contracts. Decentralization ensures shared access, while immutability prevents unauthorized data modification (Ktari et al., 2022). Smart contracts are self-executing agreements that trigger actions when conditions are met, reducing intermediaries and delays (Akazue et al., 2023). Consensus algorithms maintain ledger consistency across nodes. Proof of Work (PoW) requires solving computational puzzles, offering high security but high energy costs. Proof of Stake (PoS) selects validators based on asset ownership, improving efficiency and sustainability. Other models include Practical Byzantine Fault Tolerance (PBFT), Proof of Capacity, Proof of Burn (PoB), and Proof of Elapsed Time (PoET), each suited to specific contexts. These protocols ensure trust, accuracy, and secure validation of transactions within blockchain networks.

2.1 Applications of BCT in the AFSC

2.1.1 Improving Food Safety and Quality

The decentralized, tamper-resistant nature of Blockchain Technology (BCT) enhances traceability in food supply chains by enabling end-to-end monitoring from farm to consumer. In India, this transparency supports rapid contamination detection, efficient recalls, and reduced foodborne risks. Integrated systems combining BCT, IoT, and smart contracts have been proposed for poultry supply chains to ensure product freshness and safety (Iftekhar & Cui, 2021). In the fruit juice sector, BCT with smart contracts and machine learning enables automated quality assessments (Senthilmurugan & Chinnaiyan, 2021). Similarly, blockchain-based traceability frameworks in the beef industry aim to improve safety, particularly during health crises such as COVID-19 (Ktari et al., 2022).

2.1.2 Advancing Sustainability Objectives

Blockchain technology advances sustainability in India's food systems by reducing waste, optimizing resources, and promoting social equity (Hang et al., 2020). Integrating blockchain with IoT enables smart irrigation and energy-efficient greenhouse management (Senthilmurugan & Chinnaiyan, 2021). In the cocoa supply chain, blockchain enhances transparency and fair trade, addressing authenticity and corruption issues common in India's fragmented markets (Kraft & Kellner, 2022).

2.1.3 Enhancing the Integrity of Data Protection

Blockchain's immutability and consensus mechanisms effectively secure sensitive agricultural data (Xu et al., 2020). For instance, in aquaculture, blockchain-enabled smart contracts automate farming processes and prevent data tampering (Chaganti et al., 2022). Another approach integrates blockchain with the InterPlanetary File System (IPFS) to manage agricultural traceability data (Praveen et al., 2021). Real-time sensor data and multimedia are stored on IPFS, while blockchain records their hash addresses, ensuring authenticity, integrity, and security.

3. Adoption of Blockchain Technology in India

Blockchain adoption in India is advancing through government–private sector collaboration. Andhra Pradesh and Telangana have piloted blockchain for land record management to enhance transparency and prevent tampering, with Andhra Pradesh partnering with Zebi for secure property transaction recording (Patti et al., 2024). In agri-food, companies like Agri10x and StaTwig leverage blockchain for supply chain transparency, fair farmer compensation, fertilizer monitoring, and organic certification verification (Patti et al., 2024). The Maharashtra Skill Development Department, with LegitDoc, introduced blockchain-based digital diplomas to combat credential fraud; similar efforts exist in Gujarat and Karnataka. The government explores blockchain for secure digital identity in Aadhaar and IndiaStack, with pilots improving citizen data protection and public service access (Senthilmurugan & Chinnaiyan, 2021). In finance, the Reserve Bank of India evaluates a Central Bank Digital Currency, while banks and startups pilot blockchain for cross-border payments, supply chain finance, and bond issuance. The Indian Ports Association pilots blockchain at Mumbai and Visakhapatnam ports to enhance cargo and customs operations (Padmavathi et al., 2024). Despite growth across governance, finance, agriculture, education, logistics, healthcare, and real estate, challenges remain in regulation, scalability, and infrastructure. The National Blockchain Strategy aims to address these barriers (Bumblauskas et al., 2020).

4. Obstacles to the Adoption of Blockchain Technology

Blockchain technology has transformative potential for India's agricultural and food supply chains but remains in early adoption stages. A systematic literature review across Scopus, Web of Science, and ScienceDirect identified key barriers hindering widespread implementation (Panigrahy & Panda, 2025; Yadav, 2021; Xu et al., 2020; Yadav & Singh, 2019). Infrastructure deficits in rural areas—where smallholder farmers produce nearly 85% of India's food—limit reliable electricity, internet access, and affordable digital devices, constraining blockchain deployment (Patti et al., 2024). The evolving regulatory environment lacks comprehensive policies for agricultural blockchain applications, causing uncertainty among investors and stakeholders (Panigrahy & Panda, 2025; Yadav, 2021; Yadav et al., 2020). Limited technical expertise and low digital literacy among farmers further restrict adoption, necessitating targeted capacity-building (Yadav et al., 2020). Scalability challenges arise from India's vast, heterogeneous sector, where existing platforms (e.g., Bitcoin, Ethereum) cannot match transaction volumes typical of traditional systems (Ting et al., 2022; Yadav et al., 2020). Security and privacy concerns persist, especially regarding sensitive agricultural data; balancing transparency and confidentiality between public and private blockchains is critical for trust (Senthilmurugan & Chinnaiyan, 2021). High implementation costs—including hardware, software, IoT integration, energy, and transaction fees—disproportionately affect smallholders and SMEs, while larger agribusinesses are better equipped to adopt blockchain (Patti et al., 2024; Seranmadevi et al., 2022; Ting et al., 2022; Xu et al., 2020; Yadav, 2021; Yadav et al., 2020). Addressing these interconnected barriers is essential for policymakers, developers, and supply chain actors to enable scalable, secure, and inclusive blockchain integration in India's agri-food systems.

5. Methodological Framework

Section 3 identified multiple interrelated barriers to blockchain adoption in India's agri-food supply chains, necessitating a systematic modelling approach. Various multi-criteria decision-making (MCDM) techniques—such as Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Interpretative Structural Modelling (ISM), and Decision-Making Trial and Evaluation Laboratory (DEMATEL)—have been employed to analyze complex systems (Casino et al., 2021). Table 1 summarizes their strengths and limitations: AHP establishes hierarchies but ignores interdependencies (Patti et al., 2024; Yadav, 2021; Xu et al., 2020; Ting et al., 2022; Seranmadevi et al., 2022; Yadav et al., 2020); ISM captures causal links but lacks quantification of relationship strength (Gugulothu & Nandhini, 2023); ANP considers interdependencies but is complex (Patti et al., 2024). DEMATEL effectively reveals cause-effect relationships, categorizing barriers into cause and effect groups with visual mapping (Chaganti et al., 2022; Hang et al., 2020; Pranto et al., 2021; Ting et al., 2022). Its robustness has been demonstrated in agriculture (Ktari et al., 2022) , energy (Patti et al., 2024) , education (Patti et al., 2024) , and construction (Seranmadevi et al., 2022). Notably, DEMATEL has been applied to blockchain adoption challenges in India's agriculture (Yadav, 2021) and China's fisheries sector (Yadav & Singh, 2019) , confirming its appropriateness. Figure 3 depicts the research framework: literature review, expert validation, and a structured DEMATEL analysis.

Phase One: Developing the Average Influence Matrix

The initial phase of the DEMATEL methodology involves constructing an n x n direct influence matrix, where

n represents the number of identified barriers or criteria. Each matrix element quantifies the influence of one barrier over another using a five-point scale: 0 (no influence), 1 (low), 2 (moderate), 3 (strong), and 4 (very strong). Subject matter experts independently evaluate and complete this matrix based on their knowledge. The individual expert matrices are then aggregated by averaging to form a consensus-based composite influence matrix, as formalized in Equation (1), consolidating expert judgments systematically.

$$A = \begin{bmatrix} 0 & \cdots & a_{n1} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & 0 \end{bmatrix} \quad (1)$$

Upon the creation of the average matrix A, wherein each element aij denotes the extent of influence exerted by factor i upon factor j, the subsequent step is:

Step 2: Standardisation of the Direct-Relation Matrix

The normalised direct-relation matrix DDD is computed to guarantee that the values within the matrix are calibrated to a uniform scale, thereby facilitating consistent and precise further analysis.

This is accomplished through the application of the formula:

$$D=M\times A \quad (2)$$

where M is the normalization coefficient, determined by:

$$M = \frac{1}{max_{1\leq i\leq n} \sum_{j=1}^{n} a_{ij}} \quad (3)$$

M can be understood as the inverse of the highest total of the components found in any row of the average matrix A. This procedure guarantees that every entry in the normalised matrix D resides within a defined range, thereby enhancing the clarity and dependability of the interpretation of the causal relationships among the barriers.

Table 1: Methods and limitations

Method	**Description**	**Strengths**	**Limitations**
DEMATEL	Classifies variables according to their potential causes and effects in order to discover their interrelationships.	Proficient in comprehending causal linkages among variables.	Fails to comprehensively handle intricate interdependencies among components.
ISM	Investigates contextual relationships among variables, assessing their influence and interdependencies.	Beneficial for depicting intricate systems and comprehending interdependencies.	Does not elucidate direct causal linkages as proficiently as DEMATEL.
AHP	Establishes a hierarchical framework of decision-making factors, excluding interdependencies.	Delivers a coherent, organised hierarchy of elements.	Fails to consider interdependencies among elements.
ANP	Models the interdependencies among elements, providing flexibility in representing intricate interactions.	Capable of modelling intricate interrelations, hence offering a more accurate depiction of systems.	More complex and difficult to apply due to mathematical intricacies.

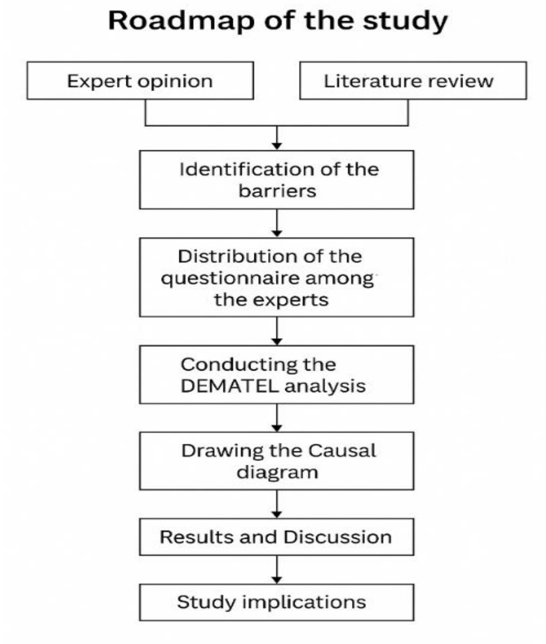

Fig. 3 Flow of study

• **Step 3: Total relation matrix**

The total relation matrix is represented by

$$T: T = [t_{ij}]_{nxn}$$

It is calculated using Eq. (4):

$$T = D(1 - D)^{-1} \qquad (4)$$

where the self is the Step 4: Calculation of Row and Column Summations The row sum (R) and column sum (C) represent the aggregate values of each row and each column within the comprehensive relation matrix T. Their computations adhere to the principles delineated in equations (5) and (6).

Step 4: Calculation of Row and Column Summations

The row sum (R) and column sum (C) represent the aggregate values for each row and each column within the comprehensive relation matrix T. Their computations adhere to the principles delineated in equations (5) and (6).

$$R = \left[\sum_{j=1}^{n} t_{ij}\right]_{nx1} \qquad (5)$$

$$C = \left[\sum_{j=1}^{n} t_{ij}\right]_{1xn} \qquad (6)$$

The aggregation of rows and columns, denoted as (R + C), signifies the comprehensive importance of factor i within the system. On the other hand, the distinction (R – C) signifies the overall impact of factor i on the system. In particular, when (R – C) yields a positive result, factor i operates as a causal factor, while a negative value categorises it as an effect factor. Generally, the cause group functions autonomously and acts as the catalyst for the effect group.

Step 5: Establish a threshold value

The threshold value serves to eliminate inconsequential effects, thereby guaranteeing that only the noteworthy values in matrix T—those surpassing the threshold—are preserved for visualisation. The threshold is established through the calculation of the mean of the elements within matrix T.

Step 6: Formulating the Cause-Effect Diagram

A cause-effect diagram is constructed utilising the dataset (R + C; R – C). This depiction:
• The vertical axis represents the (R – C) values, demonstrating the net effect of each factor.
• The horizontal axis delineates (R + C) values, signifying the comprehensive importance of elements within the system.

Step 7: Formulating the Causal Map

A causal map is constructed to elucidate the interconnections among various factors, as explored in pertinent research. The process of construction adheres to several fundamental principles:
• The foundation rests upon matrix T. • Values within the matrix that do not meet the threshold are systematically excluded, thereby enhancing the clarity of the representation. Five Applications of the Proposed Methodology

6. Recognition of Obstacles

Section 3 identified eight key barriers to BCT adoption in the Indian AFSC. A panel of twenty experts validated these barriers using the DEMATEL methodology, which remains effective with smaller sample sizes (Patti et al., 2024). Prior studies have applied DEMATEL with expert panels ranging from 3 to 12 members (Seranmadevi et al., 2022). Table 2 summarizes the expert panel's profile. Through an online discussion, the experts reviewed the literature, validated the initial barriers, and proposed four additional ones, resulting in a total of twelve barriers. They also recommended grouping these barriers into four main categories for improved clarity. Table 3 presents the complete list of the twelve validated barriers.

7. Implementation of the DEMATEL Method

A structured questionnaire was meticulously crafted to evaluate the interrelations among the identified barriers. Scholars assessed these relationships employing a 5-point linguistic scale, as elaborated in Section 4.
• Table 4 delineates the average matrix A.
• Table 5 presents the normalised matrix D.
• Table 6 presents the comprehensive relation matrix T.
• The calculated threshold value of 0.134 functions to exclude values of negligible significance, as elaborated in Section 4.
• Table 7 delineates the values of (R + C) and (R – C).

Figure 4 presents the cause-effect diagram, elucidating the directional influence of the barriers. Furthermore, Figure 5 illustrates the causal interactions, employing Pajek, a dedicated software for network analysis and visualization (Gugulothu & Nandhini, 2023; Kraft & Kellner, 2022; Panigrahy & Panda, 2025; Patti et al., 2024). This depiction illustrates that nodes represent obstacles, whereas arrows denote the direction of relationships (Ktari et al., 2022).

Table 2 Expert profile

Field	Education	Number	Experience (years)
Academics	PhD	5	15–20
Academics	Master's	4	5–9
AFSC	Master's	3	15–20

AFSC	Master’s	3	5-10
Information technology (IT)	Master’s	3	8–14
Information technology (IT)	Master’s	3	5–10

Table 3 Obstacles to BCT Implementation in the AFSC

	Code	Barrier	Description	References
Financial	B11	High Implementation Cost	Deploying BCT demands significant upfront investment and consumes considerable energy, contributing to elevated implementation expenses.	(Seranmadevi et al., 2022; Xu et al., 2020)
	B12	Delayed Return on Investment	Stakeholders in the AFSC may be discouraged from adopting BCT if the time to recoup investment is perceived as too long.	Experts opinion
Technical	B21	Scalability Issues	BCT may struggle with limited scalability, causing slow transactions and reduced data transmission efficiency.	(Chaganti et al., 2022; Hang et al., 2020; Iftekhar & Cui, 2021; Jamil et al., 2022; Panigrahy & Panda, 2025; Senthilmurugan & Chinnaiyan, 2021; Ting et al., 2022)
	B22	Security and Privacy Concerns	Blockchain faces various cyber threats such as 51% attacks, DNS and DDoS attacks, and double-spending. Moreover, its transparency can expose user activities.	(Patti et al., 2024; Xu et al., 2020; Yadav, 2021)
	B23	Inflexibility (Immutability)	Once data is recorded on the blockchain, it cannot be changed—even in cases of input errors, making corrections difficult.	Experts opinion
	B24	Time-Intensive Data Entry	Uploading information to the blockchain is often a lengthy process, potentially reducing the competitiveness of stakeholders.	Experts opinion

Knowledge & Cultural	B31	Resistance to Technological Change	Many AFSC stakeholders are hesitant to adopt innovative technologies like BCT due to unfamiliarity or discomfort.	(Chaganti et al., 2022; Hang et al., 2020)
	B32	Limited Technical Know-How	Smallholder farmers and similar users often lack the digital skills and motivation needed to implement BCT effectively.	(Jamil et al., 2022; Panigrahy & Panda, 2025; Senthilmurugan & Chinnaiyan, 2021; Shrivastava & Pal, 2019)
	B33	Distrust in the Technology	Skepticism about the usefulness and trustworthiness of BCT is common among AFSC participants.	(Patti et al., 2024; Pranto et al., 2021; Ramaul et al., 2024; Seranmadevi et al., 2022; Ting et al., 2022; Xu et al., 2020; Yadav, 2021)
External	B41	Regulatory Deficiencies	Currently lack sufficient regulations and policies to facilitate the use of blockchain technology.	(Patti et al., 2024; Pranto et al., 2021; Ramaul et al., 2024; Seranmadevi et al., 2022; Ting et al., 2022; Xu et al., 2020; Yadav, 2021; Yadav et al., 2020)
	B42	Underdeveloped Infrastructure	India's IT infrastructure is still growing, and in many areas, consistent internet access—crucial for BCT—is unreliable.	(Seranmadevi et al., 2022; Yadav, 2021)
	B43	Insufficient Reliable Data	To function effectively, BCT must integrate accurate field data from IoT devices, sensors, and other external sources. However, technology in many Indian farming regions is still underdeveloped.	Experts opinion

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Table 4: Average Direct Influence Matrix (A)

From \ To	**B11**	**B12**	**B21**	**B22**	**B23**	**B24**	**B31**	**B32**	**B33**	**B41**	**B42**	**B43**
B11	0	2.417	0	0	0	1.083	2.444	2.556	1.111	2.222	2.111	1.889
B12	2.258	0	0	0	0	0.75	2.5	2.333	2.333	2.917	2.167	1
B21	2.25	1.267	0	1.167	0	2.25	2.167	2	1.917	2.25	1.25	1
B22	2.75	1.5	0.833	2.667	0	1.167	2.417	2.5	2.167	2	0	0
B23	0.5	0	0	2.583	0	0.917	1.667	1.417	0.917	1.667	1	0
B24	1.167	0.833	2.667	0	0	0.5	2.417	0.667	0	0	0	0
B31	1.333	0.667	0	0	0	0	0	2.25	0.917	2.083	0	0
B32	0.5	0.333	1.917	2.167	1.75	1.417	2.5	0	2	2	2	0
B33	1.917	1.5	0	0	0	0	0	2	2.083	2	0	0
B41	1.417	1.25	1.333	1	0.917	1.083	1.417	1.75	2.083	2	1	0
B42	2.5	2.25	2.5	2.417	1.083	1.167	1	0.75	0.333	2.083	0	2.5
B43	2.417	1.083	1.833	1.583	1.667	1.833	1.667	0.833	2.25	1	1.833	0

Table 5: Normalized Matrix (D)

From\To	**B11**	**B12**	**B21**	**B22**	**B23**	**B24**	**B31**	**B32**	**B33**	**B41**	**B42**	**B43**
B11	0	0.103	0	0	0	0.046	0.104	0.109	0.047	0.094	0.096	0.086
B12	0.11	0	0	0	0	0.032	0.106	0.099	0.099	0.093	0.092	0.043
B21	0.095	0.092	0	0.05	0	0.117	0.092	0.085	0.081	0.093	0.052	0.042
B22	0.117	0.064	0.035	0	0	0.05	0.108	0.112	0.097	0.089	0	0
B23	0.021	0	0	0.11	0	0.04	0.061	0.052	0.034	0.071	0.042	0
B24	0.05	0.025	0.113	0	0	0	0.094	0.029	0	0	0	0
B31	0.057	0.018	0	0	0	0	0	0.088	0.04	0.079	0	0
B32	0.02	0.02	0.08	0.09	0.06	0.05	0.09	0	0.07	0.06	0.07	0

	1	4	1	2	4		6		5	9	9	
B33	0.081	0.074	0	0	0	0	0	0.088	0	0.088	0	0
B41	0.05	0.053	0.047	0.053	0.049	0.056	0.049	0.062	0.076	0	0.062	0
B42	0.096	0.076	0.096	0.082	0.056	0.04	0.042	0.054	0.021	0.073	0	0.1
B43	0.093	0.046	0.068	0.057	0.061	0.068	0.061	0.055	0.086	0.1	0.078	0

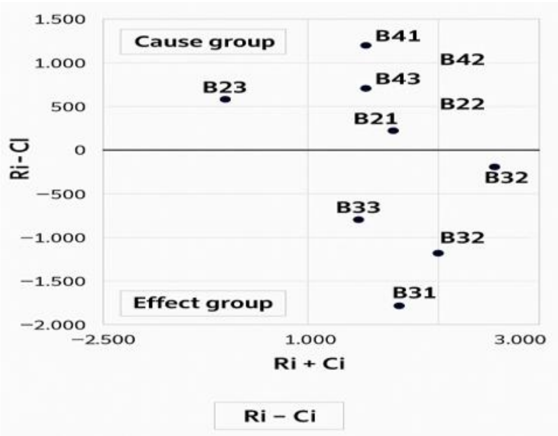
Table 6: Total Influence Matrix (T)

From \ To	**B11**	**B12**	**B21**	**B22**	**B23**	**B24**	**B31**	**B32**	**B33**	**B41**	**B42**	**B43**
B11	0.103	0.168	0.067	0.064	0.034	0.105	0.219	0.216	0.138	0.134	0.138	0.124
B12	0.193	0.072	0.054	0.051	0.031	0.083	0.204	0.209	0.193	0.077	0.135	0.084
B21	0.169	0.148	0.043	0.066	0.021	0.153	0.195	0.183	0.157	0.042	0.037	0.028
B22	0.207	0.133	0.082	0.165	0.023	0.101	0.219	0.214	0.207	0.147	0.071	0.031
B23	0.065	0.036	0.023	0.146	0.012	0.026	0.135	0.11	0.063	0.025	0.013	0.011
B24	0.106	0.077	0.141	0.033	0.017	0.041	0.179	0.042	0.079	0.028	0.021	0.015
B31	0.093	0.064	0.026	0.028	0.026	0.03	0.203	0.191	0.047	0.087	0.038	0.034
B32	0.089	0.063	0.112	0.132	0.082	0.056	0.186	0.206	0.043	0.083	0.089	0.044
B33	0.116	0.041	0.018	0.024	0.039	0.027	0.216	0.215	0.13	0.029	0.025	0.017
B41	0.172	0.139	0.121	0.113	0.074	0.11	0.191	0.191	0.139	0.04	0.118	0.074
B42	0.218	0.182	0.173	0.171	0.071	0.116	0.207	0.149	0.083	0.049	0.202	0.14
B43	0.221	0.127	0.126	0.128	0.091	0.132	0.197	0.157	0.181	0.043	0.117	0.066

Table 7: Influence Scores and Classification of Barriers to Blockchain Technology Adoption in India’s Agricultural Food Supply Chain (AFSC)

Barrier	R (Influence Given)	C (Influence Received)	R + C (Prominence)	R – C (Relation)	Cause/Effect Group
B11	1.342	1.481	2.823	-0.139	Effect
B12	0.902	0.897	1.8	0.005	Cause
B21	1.014	0.652	1.666	0.361	Cause

B22	1.228	0.858	2.085	0.37	Cause
B23	0.508	0	0.508	0.508	Cause
B24	0.588	0.719	1.307	-0.131	Effect
B31	0.25	2.112	2.362	-1.862	Effect
B32	0.579	1.912	2.489	-1.335	Effect
B33	0.395	1.395	1.791	-1	Effect
B41	1.516	0.236	1.752	1.281	Cause
B42	1.522	0.559	2.08	0.963	Cause
B43	1.369	0.389	1.758	0.98	Cause



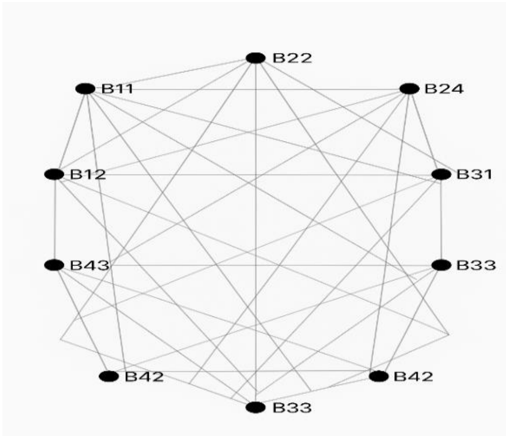


Fig. 4 The Cause Effect Diagram

Fig. 5 The cause and effect relationship map for the barriers

8. Findings

The DEMATEL analysis (Table 7, Figure 2) identified twelve key barriers to BCT adoption in AFSC, classified into cause and effect groups based on their (R–C) scores. The cause group includes seven barriers: absence of regulation (B41), inadequate infrastructure (B42), unreliable data accessibility (B43), scalability and speed limitations (B21), security and privacy challenges (B22), immutability issues (B23), and concerns over return on investment (B12). The effect group comprises five barriers: time-consuming implementation (B24), high implementation costs (B11), lack of trust (B33), insufficient technical skills and motivation (B32), and resistance to blockchain culture (B31). Notably, the cause group predominantly involves technical and external factors, while the effect group relates to cultural and knowledge-based challenges. Evaluating overall influence (R+C values) revealed that high implementation costs (B11), lack of technical expertise and motivation (B32), and resistance to blockchain culture (B31) are the most impactful barriers despite their lower direct influence. These findings underscore the need for targeted policy and research efforts addressing these critical challenges.

8.1 Significances of the Research

This study systematically analyses barriers to blockchain technology (BCT) adoption in India's agri-food sector using a cause-and-effect framework. Regulatory gaps (B41) are the primary barrier, reflecting the absence of a unified legal framework for agricultural blockchain despite advances in digital finance regulation. Inadequate infrastructure (B42), including unreliable rural internet and limited digital tools, critically impedes deployment. Data quality issues (B43), driven by manual collection, threaten blockchain integrity and highlight the need for IoT and remote sensing integration. Technical challenges—scalability, security, privacy—undermine stakeholder trust, exacerbating cultural barriers such as distrust (B33), skill deficits (B32), and resistance (B31). High implementation costs (B11) are closely linked to these factors, intensifying economic constraints. Strategic investments in rural digital infrastructure, government-backed R&D, and capacity-building programs are essential. Public incentives targeting aggrotech startups and cooperatives can further promote adoption. Government initiatives supporting IoT adoption and farmer training, alongside private sector innovations, offer promising enablers for overcoming these interconnected challenges.

9. Conclusion

This study employed the DEMATEL method to identify key barriers to blockchain technology (BCT) adoption in India's agricultural supply chain. Regulatory gaps (B41), infrastructure limitations (B42), and data inaccuracy (B43) were found most critical. The results inform policymakers to establish comprehensive regulations ensuring ethical and secure BCT use, promote research on scalability, security, and integration, and implement digital literacy programs for farmers and stakeholders. Supporting precision agriculture adoption through training, financial incentives, and improved rural connectivity is vital, alongside financial aid for smallholders to address economic constraints. Limitations include reliance on expert judgment, which may introduce subjectivity. Future research should incorporate empirical techniques such as Structural Equation Modeling (SEM) or Interpretive Structural Modeling (ISM), expand expert panels, and test the model in varied geographic contexts, including developed economies. Given blockchain's rapid evolution, ongoing monitoring of emerging challenges is essential.

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