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CRITICAL BARRIERS OF FOOD SUPPLY CHAIN MANAGEMENT AND APPLICATION OF BLOCKCHAIN TECHNOLOGY TO MITIGATE THEIR IMPACTS

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Food safety and food security have captured the significant attention of researchers. The main objective of this study is to identify the critical barriers of food supply chain management in the Indian context. For this, a decision-making trial and evaluation laboratory (DEMATEL) based approach is used. With an assessment of existing literature and consultation with food chain experts, 15 barriers have been identified for analysis. Critical barriers and their causal relationships are explored through the cause-and-effect diagram. Results of this study show that the barriers, namely "Lack of Government policy and regulation support" (B8) and "Extreme & diverse climate conditions in India" (B15), are the top two most critical and influential barriers. Recent advances in Blockchain technology have paved for mitigating the impact of these barriers on the performance of the food supply chain, and with the suitable intervention of Blockchain technology, many such barriers can be overcome, thereby improving food supply chain performance.

Keywords: Blockchain Technology, Food Supply Chain Management (FSCM), FSC Barriers, DEMATEL.

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1. INTRODUCTION

Food quality and food supply are major issues for the entire planet. The entire food management system has been affected by Covid-19 (Fan *et al*., 2021). The recent conflict between Russia and Ukraine has also disrupted the world's food supply chain and imperiled food security everywhere. The Food and Agriculture Organization (FAO) estimates that 26 nations get at least half of their wheat from Russia and Ukraine. The world's grain supply was made up of 52.32 million tonnes (7.8%) from Russia and 69.82 million tonnes (11.3%) from Ukraine. Sunflower oil is also exported internationally from Ukraine. 52 percent of all sunflower seed and oil exports worldwide in 2020 came from Ukraine. The war between two nations, Russia and Ukraine, is causing a decline in global stocks of wheat and grain (FAO, 2022).

The world population is growing exponentially. India has 2.40% of the world's surface area, yet it supports and sustains a huge 17.7% of the world's population. Food safety (FS) practices are difficult to implement in developing countries like India (Mangla *et al*., 2021). The food business is one of the most important manufacturing industries in many developing and developed countries (Egilmez *et al*., 2022). The living standards of people continue to rise, so the demand for quality food is rising. The service sectors have been rapidly expanding over the past five decades. There is a growing market for environmentally friendly goods and practices (Toktas-Palut *et al*., 2022). Small and mid-size enterprises in developing countries like India are more likely to collaborate often (Unhale *et al*., 2021). It has been observed that the food industry has gained widespread attention and developed quickly in the present scenario. The quality and safety of food are on top priority for good health and people's livelihood. There is no known probability distribution for customer demand (Hosseini-Motlagh *et al*., 2020). The Indian food industry is unorganized in nature and poses a significant challenge for researchers in terms of acquiring access to source data. Perishable product transportation is the most difficult task in a long supply chain network.

There is a shift in eating regimes of people toward value-added food categories, such as milk and other dairy products, fresh vegetables, ready-to-eat food products, and frozen meat (Patidar *et al*., 2022). The Indian food cold chain market is likely to develop at a faster pace in the future. India has unique biodiversity, which ensures the huge availability of fruits and vegetables throughout the year (Yadav *et al*., 2022). The capacity of the global cold chain sector is rapidly rising in emerging nations. For the food processing industry, the farmers are the main supplier, but still, they are not in the main supply chain loop. Around 35% to 40% of the food losses occur during processing and post-harvesting in India (FAO, 2019). Due to growing environmental concerns, the academic and industrial communities have recently shown a great deal of interest in the procedures of collecting abandoned products for recycling or remanufacturing (Chen *et al*., 2017). Cost and delivery time are

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two significant considerations taken into account while developing the supply chain (Seifbarghy *et al*., 2018).

In this paper, the usage of Blockchain technology (BT) in the food supply chain has been emphasized and examined by the authors. Academia and industry generally agree that blockchain technology is an appropriate means to tackle some of the most pressing problems in this sector. Information technology improves supply chain performance (Tripathy *et al*., 2016). Blockchain technology helps to develop a sustainable food supply chain (Saberi *et al*., 2018). The concept of FSCM in developing nations is in a nascent stage. Identified barriers put up multiple issues for the food processing organization and its supervisors. It is essential to identify and analyze identified critical barriers. Every organization wants to take maximum output with limited resources. Firms must prioritize and address the major barriers first. Hence, the present study aims to identify the barriers to implementing FSCM for the reduction of food loss. Further, it identifies the most influential barriers using the DEMATEL approach. The most widely used decision-making DEMATEL approach is used here to rank and identify the most critical barriers to FSCM implementation. This method is a powerful decision-making method that assists decision-makers in determining how to prioritize multiple criteria.

In this study, the authors have captured certain barriers which are specific to Indian FSCM. In the initial search, we identified 22 FSC barriers from the literature review. After that, we circulated the list of identified barriers among the FSC experts/academicians. They provided their valuable suggestions to us, and finally, we have selected 15 barriers for further studies. The listed barriers were sent to the food chain experts/practitioners and academicians, and based on their feedback, the final 15 barriers were considered for further analysis. Experts' opinion is sought to get context-specific barriers, and then an evaluation of interdependence relationships among barriers is done to find the critical ones using a visual structural model. The direct relation matrix (DRM) sheet was shown to FSCM experts to get their viewpoints on the correlation between paired barriers with the help of the 5-point DEMATEL technique. This is discussed in detail in the next section. With this background, the following objectives are set for this study.

- To identify and rank the barriers to efficient food supply chains in developing countries like India;
- To establish the relationship among these identified barriers using the DEMATAL approach
- Proposed Blockchain technology-based FSCM framework to mitigate the impacts of FSCM barriers

2. LITERATURE REVIEW

A review of numerous published national and international journal articles on FSC and the cold chain has been done. The research articles that were published between the years 2000 and 2022 have been studied. The online web of science databases was used to read the research articles. 15 barriers that were identified from the existing articles and the opinions of the expert academicians are listed. Table 1 gives a brief description of these barriers.

Table 1. Identified barriers of food chain management

Sr. No	Barriers	Description	Literature
B1	Lack of awareness about the use of (ICT) information and communications technology	For improving coordination and communication across the food cold chain, there is a need to build integrated well designed information systems.	Berger. H.(2007)
B2	Improper collaborative planning	The improper collaboration and planning between the various point of SC can lead to many inconsistencies at different levels like technological failures, labor issues, sales team forecasts, inventory management, etc.	Danne *et al*. (2008)
B3	Lack of professional skills	The present skill gaps in this industry are the result of fast development in food chain management processes with the latest technology change and not-so-quick adaption by academia.	Joshi *et al*. (2009)
B4	High cost for installation and operation	The operating cost of Indian cold storage is significantly high. The cost of installation is significantly higher due to the expense of importing equipment.	Swaminatham (2007)
B5	Lack of quality and safety measures	Many poor people are not much aware of food quality. They consume toxic food and get sick. Lack of quality checks is also a major issue.	Amjadi (2005); Sagheer *et al*. (2009)
B6	Too many intermediaries	Indian food supply chain is highly complex, and it consists of many stakeholders.	Roben, R. (2007)

B7	Lack of standardization	Lack of standardization impedes the efficiency of the food supply chain.	Joshi *et al*. (2009)
B8	Lack of Government policy and regulation support	To protect social and ethical values in the food supply chain, government rules and policies are essential.	Jharkharia *et al*. (2005)
B9	Insufficient tracing	A major barrier to a successful FSC is insufficient product tracing and tracking.	Jharkharia *et al*. (2005); Dong *et al*. (2021)
B10	Poor cold chain network	Because of a lack of infrastructure and a poor logistics system, it is difficult to convey goods and reach consumers.	Montanari *et al*. (2008)
B11	Inadequate education of growers/ farmers	There are few farmer training centers in India, and there are no established institutions to carry out this function.	Swaminatham (2007)
B12	Lack of interest of giant investors or entrepreneurs	Large investment firms are not taking enough interest to invest in food industries.	Patidar *et al*. (2022)
B13	Lack of intelligent food chain logistics in India	Lack of use of advanced technology in logistics systems results in disruptions.	Patidar *et al*. (2022)
B14	Unorganized distribution of food storage capacity	The key difficulty is the uneven distribution of cold storage facilities throughout the country.	Patidar *et al*. (2022)
B15	Extreme & diverse climate conditions in India	Extreme & diverse climate conditions pose a serious threat to strategic planning as a single plan cannot be effective across the nation, and multiple factors need to be considered.	Patidar *et al*. (2022)

Every country has its unique climate, social, environmental and infrastructural limitations, and advantages. Supply chain flexibility and organizational performance are linked together (Shukla *et al*., 2010). Hassanzadeh *et al*. (2022) have presented a study on ordering parameters and their impact on the supply chain network. This broad and complex supply chain is unsuccessful because of several difficulties and barriers to its efficient execution. Bohtan *et al*., 2018 have investigated the challenges to a successful supply chain management (SCM) deployment in public distribution systems using total interpretative structural modeling (TISM). Blockchain technology is becoming increasingly popular for a variety of agricultural applications (Kos *et al*., 2019). The application of this technology in the FSC has enhanced diverse aspects of the food management system (Lin *et al*., 2017). This method creates immutable ledger records. Growers, processors, distributors, retailers, consumers and government auditors can all connect and exchange product information on a single platform. Blockchain makes all transactions auditable and transparent. All blocks are connected and share the information. Blockchain can create a world or society of cooperation where all food supply chain stakeholders have equal rights to support or deny a statement or to check it. Advanced encryption mechanisms monitor the transactions. On food packaging, a QR code is printed that contains all of the data acquired throughout the supply network. Customers can search the QR code to get detailed stock traceability, including information on where the stock came from.

2.1 Application of Blockchain technology to mitigate impacts of FSCM barriers

The food supply chain is exceedingly complicated due to immense stress and massive demand. This complex nature leads to waste in the FSC network. As per the report presented by FAO 2019, the post-harvesting losses are more. The use of BT improves supply chain performance and enhances transparency and traceability (Sunny *et al*., 2020; Khan *et al*., 2022). BT is regarded as a reliable solution for restoring supply chain actors' and consumers' confidence through greater information flow and verifiability. Over the years, there have been several big supply chain interruptions in international events such as Covid-19, global inflation rate, extremely diverse climate change, geopolitical issues, etc. These uncertainties always create problems in supply chain growth. The FSCM's main issues are probably food losses at each level. In the FSCM, losses occur at various levels, including agricultural, distribution, and consumer. The use of BT in the FSC improves trust, transparency, and traceability. This can be done by incorporating all supply chain stakeholders and optimizing the supply chain from start to finish, resulting in a win-win situation for everyone concerned. Blockchain is a collaborative technology that allows all stakeholders to communicate real-time data in common cyberspace. The store data/records are immutable, transparent, and accessible at any time. Blockchain has huge potential to change FSC activities, which start from grower's farm to consumer fork. Blockchain technology has three basic pillars; Decentralization, Transparency, and Immutability. Decentralization refers to the movement of control and decision-making from a centralized system to a decentralized system. One of the main promises of blockchain technology, which provides a fully auditable and legitimate ledger of transactions, is to enable information transparency. Immutable data is data whose state cannot be changed once it has been created.

Figure 1 shows the three pillars of Blockchain technology. To ensure sustainable, strong, and efficient food security for present and future generations, it is important to connect all components of the food system. Safety, quality, traceability, and sustainability issues in the FSC have all been addressed using technological solutions such as blockchain. The researchers are enthusiastic about the concepts and application of blockchain technology in the FSCM. This game-changing technology delivers supply chain upheaval. Blockchain is a decentralized digital ledger that records and verifies user transactions and cannot be changed or destroyed. Transactions are carried out in blocks, each of which has its digital signature and a link to the preceding one. Blockchain technology-based food supply chain framework to mitigate the impacts of FSCM barriers is presented in Figure 2.

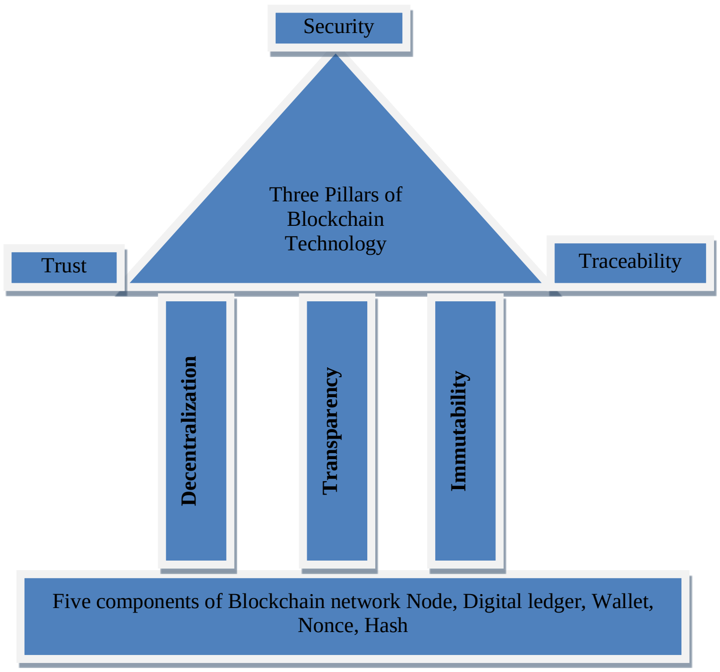

Figure 1. House of Blockchain Technology (Proposed)

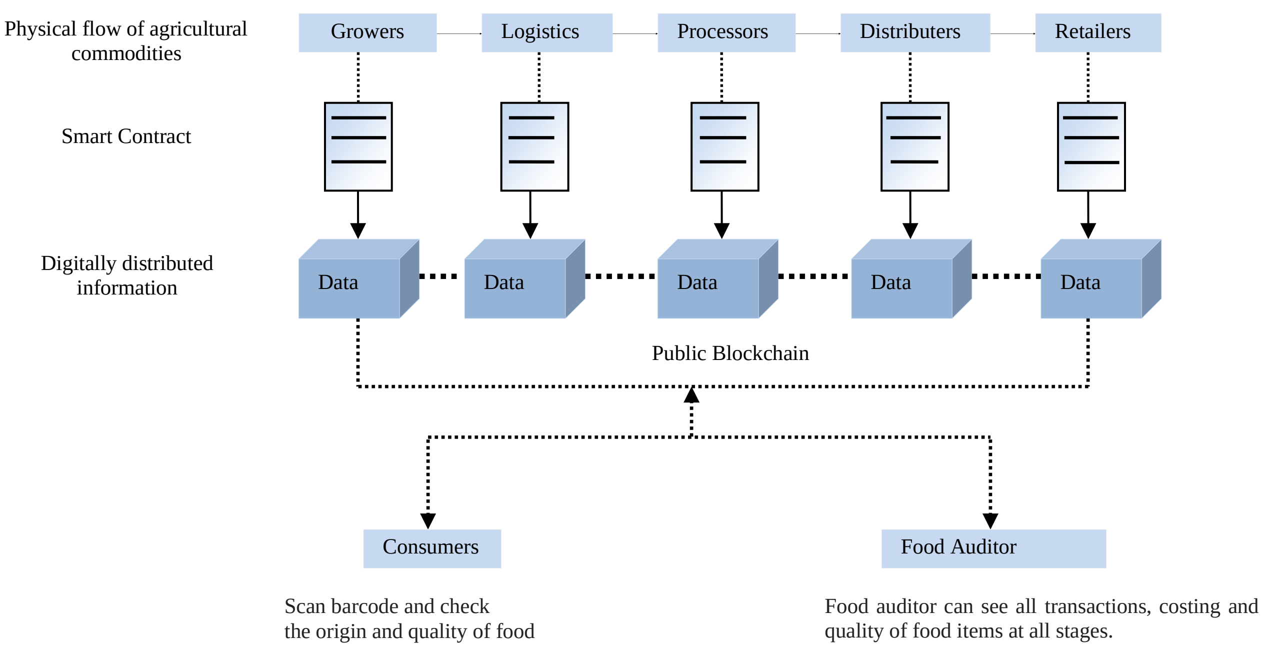

Figure 2. Blockchain technology-based FSCM framework to mitigate the impacts of FSCM barriers (Proposed)

It provides the consensus algorithm to agree on something collectively. Smart contracts are blockchain-based programs that execute when certain criteria are met. In the food supply chain, Smart contracts are especially beneficial for releasing funds, making ledger entries, and indicating when manual intervention is required. Different organizations have a different processes for making decisions (Ferrer *et al*., 2016). High-population countries face challenges with the distribution of goods and services. Nayeem *et al*. (2021) have proposed a trustworthy optimization approach to guard against probable fluctuations in the capacity and demand for relief distribution centers. The Non-dominated Sorting Genetic Algorithm is used to tackle bi-objective optimization issues (Maleki Vishkaei *et al*., 2019). Additionally, Smart contracts are also done between stakeholders utilizing distributed ledger technology and the smart web to gather information on container conditions during shipping (Kopyto *et al*., 2020). Due to blockchain smart contracts, buyers will be able to verify the authenticity of the seller's food quality assurances more swiftly (Olan *et al*., 2021).

3. METHODOLOGY USED FOR INVESTIGATING BARRIERS AND THEIR RANK USING DEMATEL

The DEMATEL method was applied to all 15 identified barriers. DEMATEL is a decision-making tool commonly used for modeling relationships among variables. This method can find the causal connection among the factors and divide these factors into two quadrants, one for the cause group and one for the effect group (Tzeng *et al*., 2007). Structural models are used to find out the relationships among the variables (Serdar Asan *et al*., 2021). The authors have requested experts to actively participate in this research study. After accepting the request, the Authors conducted a meeting with individual experts and were given a print copy of DRM and asked them to score. Each expert was assigned a score based on their assessment. In the next stage, all expert scores were collected, and they are used to prepare an average DRM matrix for further study. This systematic approach was adopted to gather the score from experts. This method involves the following four steps:

- **Step 1 (Formation of DRM):**
  There are ‘n’ barrier and ‘m’ food chain specialists who have expressed their judgments on the relationships and degree of correlation between the variables using the linguistic scale. Five levels of influence are; No influence (0), Low influence (1), Medium influence (3), High influence (3) and Very high influence (4). After collecting all of the expert responses, the average matrix (n x n) K is created.

- **Step 2 (Normalized DRM):**
  By dividing the DRM K by S, the n x n normalized X is generated where S is derived as follows:

$$S = \max\left(\sum_{j=1}^{n} Kij, \sum_{i=1}^{n} Kij\right)$$

$$(X) = \frac{K}{S}\, and \qquad X = [xij]nxn \qquad where \qquad 0 \le xij \le 1 \tag{1}$$

- **Step 3 (Total Relation Matrix (TRM)):**
  It can be calculated by the given equation:

$$T = X\,(I-X)^{-1}, \tag{2}$$

  where “*I*” is denoted by the (n × n) identity matrix.

- **Step 4 (Cause-and-Effect Values):**
  TRM is generated by the sum of the i^{th} row and the sum of the j^{th} column. The i^{th} row depicts causal influence, while the j^{th} column depicts effect influence. Ri and Cj are calculated in this step. DEMATEL approach for FSCM is introduced as illustrated in Figure 3. Figure 3 presents the systematic methodology adopted to identify critical barriers to FSCM in the Indian context.

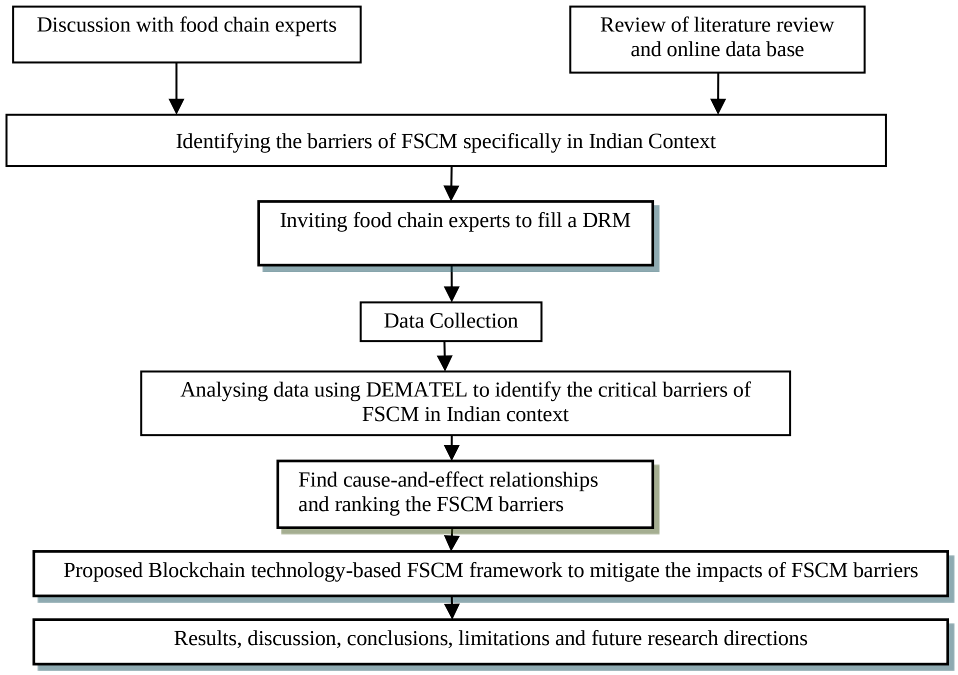

Figure 3. Flow chart of the methodology adopted to identify the critical barriers to FSCM in the Indian context.

3.1 Methodology for conducting the survey

A basic introduction of blockchain technology is presented in section 2. It has been found that BC is a very striking and novel technology to transform the food supply chain. Based on the theoretical foundation, a questionnaire is designed to gather experts' views on the use of blockchain technology in the food supply chain. To accomplish this task, a five-point Likert scale is used to get the responses of the experts. The score pattern of the scale is as follows: (1) strongly disagree, (2) disagree, (3) neutral, (4) agree, and (5) strongly agree. Expert opinions were sought in the third phase. Phase 4 entails the collection and analyzing the data. The research findings are explained at the final stage. The systematic method adopted for conducting the empirical investigation is shown in Figure 4.

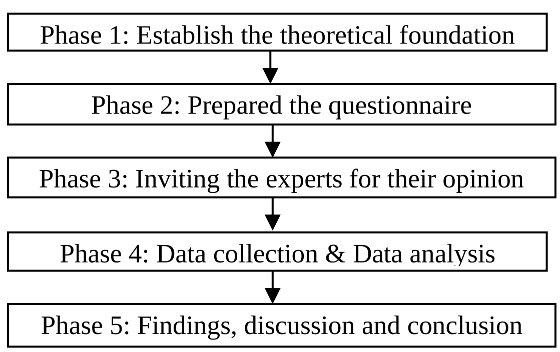

Figure 4. Methodology for conducting the survey

Since the study is specifically undertaken in an Indian context, we have included only Indian experts in the study. Twenty experts were considered for this research study. Fourteen experts are faculty in a reputed academic institution in India, and each has more than 20 years of experience in the domain. Four experts are from the food processing Industries. These experts work as a manager and have 10-20 years of experience. Two experts are managers from the cold storage, logistics and distribution industries and have 0-5 years of experience. Table 2 shows the experts' profiles.

Table 2. Experts' profile

Work experience (in years)	**Frequency %**
0-10 years	10%
10-20 years	20%
More than 20 years	70%
Qualification	**Frequency %**
Doctorate	70%
Master's or Professional Degree	30%
Types of Organization:	**Frequency %**
Food Processing Unit	20%
Storage, Logistics and Distribution	10%
Academic Institute	70%

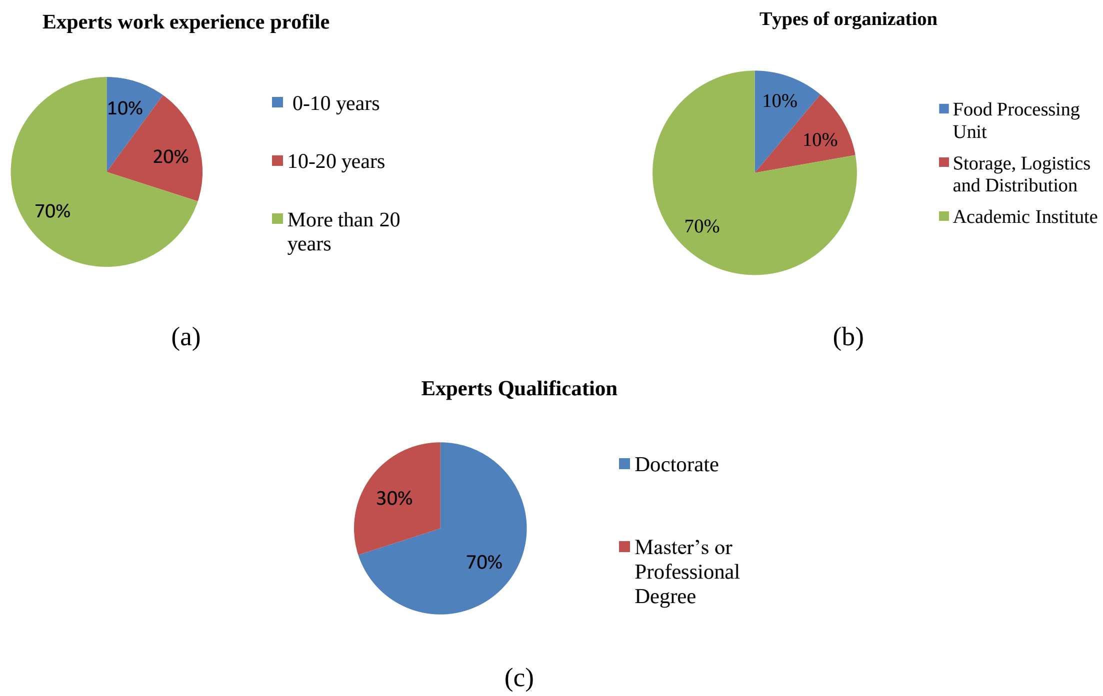

Figure 5. Categorization of experts; (a) Work experience; (b) Types of organization; and (c) Qualification

Figure 5c shows that 30% of experts hold a master's degree, and 70% are highly qualified, holding a doctorate. The questionnaire for the application of blockchain technology in the food supply chain was presented to these twenty experts to receive their responses. After that, we produced a final average matrix in order to analyze the scores. After finding the critical barriers of FSC, we have proposed a Blockchain technology-based FSCM framework to mitigate the impacts of FSCM barriers.

4. DEMATEL COMPUTATION METHOD

Step 1: The DRM X is prepared. The expert's opinion is taken and shown in Table 3. The average of all responses is considered the average DRM. All experts provided their opinions on 15*15 linguistic direct relation matrices to determine relationships and degree of correlation between the variables using a linguistic scale.

The DEMATEL methodology's remaining phases are carried out using the methods described in Section 3. Eq.1 is used in the second step to obtain 15*15 normalized DRM X by dividing the DRM X by S (S=38). Finally, the TRM is obtained, while the sum of the total influence matrix Tc and the ranking of barriers are calculated. Table 4 also shows the vector (Ri + Cj) and vector (Ri – Cj). Table 5 shows the cause-and-effect group. Figure 6 shows the derived Cause and effect diagram.

Table 3. Direct relation matrix (Average)

Sr. No	Barriers	Using a scale of 0–4 to determine all direct relationships between all 15 barriers as well as the strength of those relationships. The average of all responses is utilized to form the average matrix.															
			"B1"	**"B2"**	**"B3"**	**"B4"**	**"B5"**	**"B6"**	**"B7"**	**"B8"**	**"B9"**	**"B 10"**	**"B 11"**	**"B 12"**	**"B 13"**	**"B 14"**	**"B 15"**
B1	Lack of awareness about the use of ICT	**B1**	0	3	0	0	0	2	1	0	4	0	0	0	4	0	0
B2	Improper collaboration planning	**B2**	3	0	0	0	0	3	0	0	2	4	4	0	3	4	0
B3	Lack of professional skills	**B3**	3	4	0	2	4	1	4	0	3	2	0	0	3	0	0
B4	High cost for installation and operation	**B4**	2	0	0	0	3	4	0	0	3	4	2	4	0	0	0
B5	Lack of quality and safety measures	**B5**	0	0	0	0	0	2	3	0	0	0	0	0	2	0	0
B6	Too many intermediaries	**B6**	0	0	0	0	0	0	0	0	0	0	2	0	0	3	0
B7	Lack of standardization	**B7**	0	0	0	4	0	2	0	0	4	3	0	0	0	0	0
B8	Lack of Government policy and regulation support	**B8**	2	3	3	2	3	3	3	0	2	3	4	3	3	4	0
B9	Improper tracing	**B9**	0	0	0	0	0	3	0	0	0	0	3	0	0	0	0
B10	Poor cold chain network	**B10**	0	0	0	0	2	3	0	0	3	0	2	0	0	4	0
B11	Inadequate education of farmers	**B11**	3	0	0	0	3	0	3	0	0	0	0	0	0	0	0
B12	Lack of interest of giant investors or entrepreneurs	**B12**	3	4	3	0	3	3	3	0	0	4	4	0	4	4	0
B13	Lack of intelligent food chain logistics	**B13**	0	0	0	3	0	3	3	0	3	4	3	0	0	0	0
B14	Unorganized distribution of food storage capacity	**B14**	0	0	2	4	4	0	3	0	3	0	2	0	3	0	0
B15	Extreme & diverse climate conditions in India	**B15**	0	1	0	4	3	3	3	2	3	4	1	3	3	4	0

Table 4. Total relation matrix, R_i+C_j and R_i-C_j for the barriers and Cause & effect group

Barriers	**R_i**	**C_j**	**R_i+C_j**	**Rank**	**R_i-C_j**
B1	0.564	0.654	1.218	15	-0.090
B2	0.917	0.518	1.435	12	0.399
B3	1.062	0.292	1.354	13	0.770
B4	0.899	0.807	1.706	4	0.092
B5	0.274	1.037	1.311	14	-0.763
B6	0.218	1.423	1.641	7	-1.205
B7	0.511	1.091	1.602	8	-0.580
B8	1.666	0.053	1.719	3	1.613
B9	0.202	1.328	1.530	10	-1.126
B10	0.525	1.120	1.645	6	-0.595
B11	0.343	1.214	1.557	9	-0.871
B12	1.484	0.352	1.836	1	1.132
B13	0.727	0.960	1.687	5	-0.233
B14	0.864	0.933	1.797	2	-0.069
B15	1.526	0.000	1.526	11	1.526

Table 5. Cause and effect group

Cause Group	$(R_i - C_j)$ Positive	Effect Group	$(R_i - C_j)$ Negative
B8	1.613	**B6**	-1.205
B15	1.526	**B9**	-1.126
B12	1.132	**B11**	-0.871
B3	0.770	**B5**	-0.763
B2	0.399	**B10**	-0.595
B4	0.092	**B7**	-0.580
		B13	-0.233
		B1	-0.090
		B14	-0.069

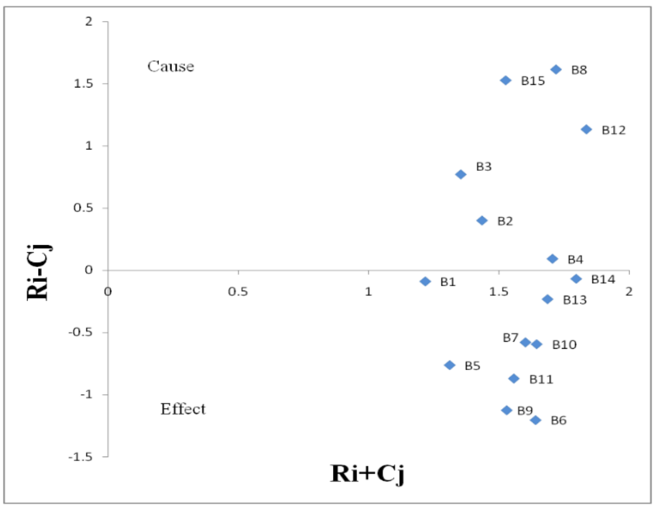

Figure 6. Cause and effect diagram

5. RESULTS AND DISCUSSION

This study included the DEMATEL method for the identification of critical barriers of FSCM in the Indian context and the implication of BC technology to mitigate the impact of these barriers. The results with discussion for the two above-pronged methodologies are presented in the following subsections.

5.1 Identification of critical barriers of FSCM using DEMATEL

Using the DEMATEL technique, the interrelationships between the identified fifteen barriers to FSCM are investigated in this study. The findings are presented in Figure 6. There are two groups; one is the cause barrier group, and the second is the effect barrier group. Classifications of these two groups are based on barriers relationship to other barriers. The following is an explanation of the research procedure and conclusions from the causal diagram (Figure 6). After analyzing the data through a systematic step-by-step calculation process, six barriers have appeared in the cause group, namely **“**Lack of Government policy and regulation support” (B8), “Extreme & diverse climate conditions in India” (B15), “Lack of interest of giant investor or entrepreneurs” (B12), “Lack of professional skills” (B3), “Improper collaboration planning” (B2), “High cost for installation and operation” (B4). Barrier B8 is a rank one in the cause group. Government policy and regulation support are very important for the overall development of supply chain infrastructure. In India, there are many states and central regulatory authorities which handle the entire food management system. In India, effective food control is undermined by the system, which results in huge food loss, and India ranked 94th on the global hunger index (GHI, 2020). It is further observed that barriers fifteen, twelve, two, three, and four are also in the cause group, and they significantly influence the system. Similarly, nine barriers have appeared in the effect group, namely “Lack of awareness about the use of ICT” (B1), “Unorganized distribution of food storage capacity” (B14), “Lack of intelligent food chain logistics” (B13), “Lack of standardization" (B7), "Improper tracing" (B9), "Lack of quality and safety measures" (B5), "Inadequate education of growers/ farmers (B11), "Poor cold chain network" (B10) and "Too many intermediaries" (B6). The barriers that are reflected in the effect group are highly influenced by cause group barriers. Thus, by improving cause group barriers, effect group barriers can be improved. It is oblivious that the cause group barriers need more attention than the effect group barriers.

The most significant causal barrier, "Lack of Government policy and regulation support" (B8), has the highest ($R_i – C_j$) value (1.613), which means B8 should require more attention for efficient FSCM. Table 5 shows that the influence impact degree of (B8) is 1.666 (R), which has ranked one among all-cause group barriers. From this study, it can be concluded that the B8 is the major barrier and requires the most attention in the food supply chain management system. "Extreme & diverse climate conditions in India" (B15) has a considerable impact on other barriers, with the IInd highest ($R_i – C_j$) value of 1.526. This barrier can be considered an external barrier and cannot be fully controlled. Moreover, B15 has the IInd highest (R_i - C_j) value (1.526) among all the barriers, which means this barrier influences the other barriers in a significant way. Similarly, "Lack of interest of giant investors or entrepreneurs" (B12) (1.132), "Lack of professional skills" (B3) (0.770), "Improper collaboration planning" (B2) (0.399), and "High cost for installation and operation" (B4) (0.092) have positive (Ri – Cj) values, which means these barriers also have a significant impact on other barriers.

The negative value of (Ri – Cj) indicates that the barriers are in the effect group and are mostly influenced by others. In this study, nine barriers appeared in the effect group. Effect group barrier, namely "Too many intermediaries" (B6), has the highest (Ri – Cj) value (-1.205) among all barriers, which means it is significant influence by other barriers. "Improper tracing" (B9) has the second-highest (Ri – Cj) value (-1.126). Supply Chain Management (SCM) is becoming more complicated. Similarly, B7, B10, B5 and B11 have moderate (Ri – Cj) values (-0.580), (-0.595), (-0.763) and (-0.871), respectively. It shows that these barriers are moderate influence by other barriers. B1, B14 and B13 have very low (Ri – Cj) values (-0.090), (-0.069) and (-0.233), respectively. It indicates that these barriers are mildly affected by other barriers.

5.2 Implications of BC technology to the food supply chain policymaker and researchers

Food policy is a key component catering to food supply chain management. It is challenging for legislators to create an effective food management policy (FMP) to ensure food security and food safety. Blockchain helps to develop a smart food policy system that strengthens the entire food management system and food security. BC provides accurate data to policymakers, which helps in making a food policy. The descriptive assessment is accomplished to examine the mean score. Mean scores are shown in Table 6. An analysis of data presented in Table 6 shows that all experts agreed that blockchain technology has the potential to transform the food supply chain. The minimum mean score is 4.00, and the maximum mean score is 4.50 on the five-point Likert scale. Table 6 shows Blockchain implications to the food supply chain policymaker and researchers.

Table 6. Blockchain implications to the food supply chain policymaker and researchers

Sr No.	FSC Challenges	Blockchain implications	Mean
1	Food Policy	The main difficulty with food policy is serving the end users at the right time with the right quantity. BC delivers transparency in FSC from "farm to fork", which results in a proper match between demand and supply. A sufficient supply of food controls unnecessary price fluctuations.	**4.50**
2	Food demand	It is very difficult to track and analyze the food consumption pattern in the existing supply chain model. This difficulty can be overcome by implementing BC in FSC. BC assists in identifying both the present and future food demands and also in assisting policymakers in formulating appropriate policy.	**4.10**
3	Food quality and testing	Food inspectors face a problem when it comes to testing a portion of food at every single level of the supply chain. BC-based FSC can solve this problem. In BC, the entire process is recorded in digital form. The food inspector can track the flow of food and evaluate the quality of the food at individual steps.	**4.00**
4	Food testing labs	It is essential to connect all food testing facilities to a single platform in order to strengthen the entire food management system. BC-based supply chain network unites all food testing facilitators on a single platform.	**4.20**
5	Government support	The implementation of policies that are beneficial to individuals is largely the responsibility of the government. BC provides data with accuracy to competent authorities so that they can develop an easy and accessible food policy for the benefit of the end-users.	**4.25**
6	Future research	BC reduces the barriers of FSC and creates a new opportunity in the domain.	**4.45**
7	Food waste	Blockchain technology can be used in the food supply chain to decrease food waste, identify food fraud, and track the sources of food in cases of contaminated sickness.	**4.35**
8	Food experts	Blockchain technology is being used by supply chain experts to streamline and accelerate the supply chain.	**4.00**
9	Sustainable supply chain	Researchers and industry practitioners must focus on implementing BC in the food supply chain. This technology is building a future sustainable supply chain while reducing the impacts of barriers.	**4.00**

10	BC-based FSC	Researchers and industry experts have to come together and promote a technology-based supply chain. Researchers should also present comparative studies of the BC-based FSC and generic FSC.	**4.45**
11	Distribution systems design	A decentralized, digitally distributed public ledger that connects all users on a single platform to share data in the form of digitally signed transactions.	**4.10**
12	Poor traceability	Asset traceability is possible because of the use of smart contracts on the blockchain.	**4.30**
13	Lack of transparency	Transparency is improved by using digital smart mutual contracts.	**4.10**
14	Security threats	Structured data with high security. Cryptographic techniques make a more reliable system.	**4.00**
15	Data tempering	Maintain immutable real-time data.	**4.00**

6. CONCLUSIONS, LIMITATIONS, AND FUTURE RESEARCH DIRECTIONS

Based on the analysis and interpretation of the results of the DEMATEL approach following conclusions are drawn:

- *"Lack of Government policy and regulation support" (B8)* is the most critical barrier. It is expected that the Government of India will focus on comprehensive policy formulations regarding food item quality, storage, transportation, cold chain, etc.
- *"Extreme & diverse climate conditions in India" (B15***)** is the second most critical barrier. The climate of India is varied, with a wide range of weather conditions over a large geographic area and different topography. Region-specific policies must be drawn to make them more effective and easy to implement.
- *"Lack of interest of giant investors or entrepreneurs" (B12)* is the third most critical barrier. The government of India needs to simplify the rules and regulations for interested investors to invest in the infrastructure required for FSCM, such as climate control warehouses, cold storage, silos and other modern food storage facilities.
- **"***Lack of professional skills" (B3)* causes group barrier and affect all other barriers because skilled manpower is required for managing an efficient food supply chain.
- *"Improper collaboration planning" (B2)* in FSCM is a cause barrier. To strengthen the FSCM, collaboration between supply chain partners is extremely essential.
- ***"****High cost for installation and operation" (B4) i*s a barrier related to cost. The operating cost of cold storage can be sustainably reduced by using renewable energy sources like solar, which has tremendous potential due to the hot climate of India.

6.1 Blockchain can be used to overcome these barriers

Less usage of ICT tools, insufficient tracing, improper collaborative planning, too many intermediaries, poor food cold chain network and lack of standardization process in FSC are critical barriers to the existing Indian food supply chain. Blockchain technology has the potential to overcome the impact of these barriers. Blockchain (BC) provides a decentralized distributed system to connect all stakeholders in a single network, which results in the effective utilization of ICT tools, and strong collaborative planning coupled with proper communication between the parties. Unwanted intermediates add to the cost of food products, which leads to customer dissatisfaction. Blockchain can significantly enhance the performance of the supply chain by facilitating quicker and more affordable product delivery, enhancing product traceability and facilitating access to funding. BC has the potential to fabricate a standard digital supply chain network that prohibits unwanted intermediaries in the FSC network accountable for the extra cost. The greatest challenge to long-term FSC is maintaining accurate data. BC maintains data records in the form of a digital ledger to eliminate data duplication, thus channelizing efforts to develop an effective and reliable food system.

Unorganized distribution of food storage capacity and lack of an intelligent food chain logistics system are the main impediments in developing an efficient India FSC network. These barriers impact can be overcome while implementing Blockchain technology in FSC. Existing warehousing facilities are not equipped with the latest tools and technology. As the demand for quality food increases, the challenges for food storage have also increased. Blockchain reduces the challenges existing in managing perishable inventory using a BC-based warehouse management system (WMS) system. The blockchain-based WMS allows warehouses, growers, manufacturers, suppliers, and distributor centers to connect to access real-time data. It optimizes the inventory management system and improves the productivity and efficiency of the system. It has the potential to make a system more flexible and fulfill the demand of the customer. BC is a digital tool that can improve the food system and policies. It aids the government policy-making authority to make sound food policies for food security to meet the Sustainable Development Goals of 2030. This transformation will attract giant investors in the domain field. BT can enhance end-user trust, delivery speed, and product efficiency. BT is reorganizing the food chain to help reduce waste, improve food safety, and lower the probability of a worldwide food crisis.

The key limitation of this study is that only a small number of experts were available for giving their opinion. However, if a large pool of experts from varied backgrounds contributes to the study, the results could be closer to the real situation. In the future, obtained results can be further validated using other MCDM techniques like fuzzy DEMATEL, Total interpretive structured modeling (TISM), Analytic network process (ANP), Grey relational analysis, etc., since other MCDM techniques may provide more insights into the criticality of barriers. These findings will be helpful to policymakers and experts of the food industry in creating strategies for overcoming barriers. Future studies should be focused on IoT and blockchain applications in the food supply chain. The integration of blockchain and IoT is another new research area for future study. This convergence of technologies will result in innovations in the food supply chain. It is important to explore how these technologies can help to achieve targets of sustainable FSC and support the entire food management system. Future more how these technologies synchronized all resources and helped the government to develop a better food policy can be explored. Researchers need to explore the application of blockchain, AI, and IoT technology in various tactical and strategic decisions related to FSCM.

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