Application of blockchain technology in the agri-food system: a systematic bibliometric visualization analysis and policy imperatives

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Abstract

Purpose – Blockchain technology (BCT), since its emergence touted to be disruptive, is gaining momentum, especially in the agri-food system owing to its multiple benefits.

Design/methodology/approach – The authors attempted to conduct a systematic bibliometric visualization analysis of the BCT in the agri-food system. The analysis investigated the list of countries and institutions that conducted research on BCT in agriculture, growth trend analysis in research publications, bibliographic coupling of journals using the VOSviewer tool, and the countries and institutions researching BCT.

Findings – The authors discovered that China, the USA and India were the highly active countries in BCT research and publication. However, India has only limited research collaboration with other countries as compared to China and the USA. The keyword analysis indicates the role of BCT in order to maintain the transparency of the supply chain by means of protecting the privacy of the personal data of the stakeholders.

Research limitations/implications – More research related to the implementation of BCT in livestock, fishery and agro-forestry sector is recommended.

Social implications – The case examined is of particular interest as it is concerned with efficient supply chain management.

Originality/value – This study adds value and evidence to the scope and benefits of BCT by providing a comprehensive literature review, with a special focus on the opportunities and challenges concerned with implementation of BCT in the Indian agri-food system.

Highlights

(1) Blockchain technology (BCT) – a promising tool to resolve issues in agriculture supply chain.

(2) BCT ensures transparency and protection of information along the supply chain transactions.

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(3) China, the USA and India are the highly active countries in BCT research and publication.
(4) Multiple potential benefits to stakeholders are attributed to the BCT in the agri-food system.
(5) The key challenge is to bridge the digital gap between developed and developing nations.
(6) Future research on BCT should aim at easing and undistorted competition among stakeholders.

Keywords Blockchain, Bibliometric analysis, Food traceability, Bitcoin, Food safety, Scientometrics
Paper type Research paper

1. Introduction

Dating back to the innovation of Bitcoin, which became the first digital currency using the ideas set out in a white paper (Nakamoto, 2008), blockchain technology (BCT henceforth) has firmly entrenched in the interest of many international researchers to dig into its applications among various fields (Alt, 2018). All over the globe, nevertheless of the magnitude of economic development, people are transferring value toward food in view of their better well-being. These values are inherited with greater food safety, food trust and traceability to the genesis of its production, and also a few environmental enthusiasts care about the environmental footprint of its production (Tripoli and Schmidhuber, 2020).

To encompass a few of the many food values of people all around the world, BCT has become a disruptive technology. Technically, it is a decentralized ledger that stores the data of every transaction in the respective blocks along each step of the supply chain in chronological order by the specific stakeholder (Alt, 2020). Each transaction executed in the public ledger is shared among the involved parties on a peer-to-peer network (Figure 1). Each transaction is verified by the consensus of the involved parties in the supply chain. The distributed consensus and anonymity are the major characteristics of BCT (Kollmann *et al.*, 2020). The blockchain is seen as the main technological innovation because it stands as a "trustless" proof mechanism of all the transactions in the network (Swan, 2015; Marella *et al.*, 2020). BCT does not involve any third parties or intermediaries, thereby reducing the processing cost while enhancing the security, efficiency of transactions, trustworthiness and traceability. BCT has a wider application in various fields and

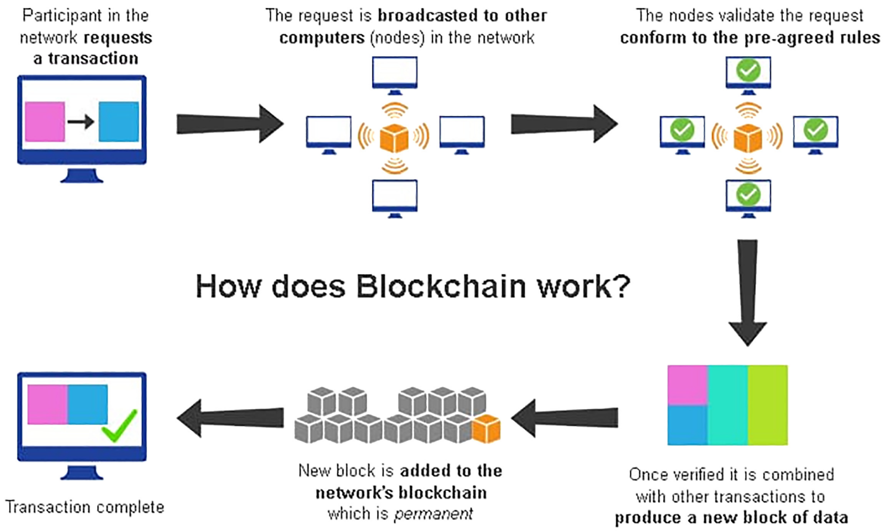

Figure 1.
Steps involved in blockchain

Source(s): https://www.corcentric.com/blog/introduction-to-blockchain-technology/

diverse sectors such as supply chain, Internet of Things (IoT), health care, privacy, business and data management (Casino *et al.*, 2019). The potential benefits of BCT to simplify the workflow with greater efficiency, transparency and traceability in every industry are enormous, and the private sector is already partnering with the United Nations to explore more into its applications across various fields of the UN system (Bacchi, 2017). Agriculture is no lesser to its wider applications. Key issues and challenges in agriculture include transparency and efficiency along the supply chains, which is putting the farmers and consumers at disadvantage (Xu *et al.*, 2021). The issues and challenges regarding transparency and traceability of food supply chain and increased transaction costs are addressed by the BCT using smart contracts in agriculture (Liu *et al.*, 2020). Smart contract is a computerized transaction protocol, which convert contractual basis into code and integrate them into hardware or software so that the code is implemented by itself. This eliminates the need for trusted intermediaries (see Figure 2).

Blockchain also helps in processing the data and makes them available to the farmers in a more understanding way using algorithms. In addition, the data are available to every participant in the market and thus improve the efficiency in production and aid in sustainability of the agri-food systems (Lin *et al.*, 2020a, b). BCT also plays a key role in optimizing the payrolls to the farmers in case of any natural weather adversities during the crop period. The other applications of BCT in e-commerce and trade of agricultural products are still in its infancy stage.

Although BCT is considered as a technological breakthrough with humongous potential to enhance the traceability as well as transparency in the supply chains, still its applications particularly in agricultural supply chains are seriously lacking. There are limited studies on the applications, benefits and challenges of BCT as well as understanding the performance of BCT in agri-food supply chains. There is a need to study the practical implications of blockchain in improving the traceability in food supply chains as well as its application in policy frameworks (Lin *et al.*, 2017).

Therefore, this article aims to include the above-mentioned research gaps by answering the following questions:

(1) How BCT is gaining momentum worldwide and which countries are more emphasizing on BCT?

(2) What are the potential benefits of BCT for agricultural sector?

(3) What are the opportunities and constraints in the application of BCT in improving the overall performance of agri-food supply chains?

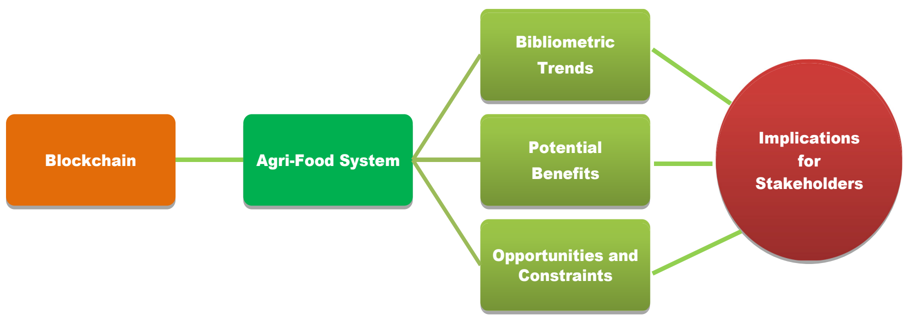

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Figure 2. Conceptual design of the study

This research focuses on the bibliometric analysis of BCT as well as its application in agri-food system.

2. Conceptual framework and methods

A bibliometric study was conducted involving a good number of publications in the subject area since its emergence to 2020. Agric* application was used to study the dynamics of publication activity in the field of blockchain. *Blockchain* and *Agric* were the keywords used for retrieving the publications from the "Web of Science" database. We used "Web of Science" owing to its greater depth of scientific publications database and citations, whereas "Scopus" focuses on more modern sources because its database was founded later, and it's relatively "younger." We chose "Web of Science" database because the papers are representatives of high-level literature database and also reflects scholarly interest toward BCT research (Ipek, 2019). Each article in "Web of Science" is shortlisted as per the subject categories; therefore, it is easy to use VoSviewer tool to visualize the potential usefulness and research areas involved in blockchain (Xu *et al.*, 2019). The publications in non-English, duplicates and non-relevant papers were discarded from the total retrieved list. Following bibliometric indicators were presented in the current study: (1) Web of science categories, (2) research themes, (3) growth trend analysis, (4) keyword analysis, (5) institutions and countries, and (6) co-occurrence of citation and their relationship among authors. In the second stage of research, visualization of thematic contiguity of the articles was imparted using VOSviewer software tool, which enabled to create the co-occurrences network maps.

The network maps consist of several differently colored circles, and circles that have a single color form a cluster. Distantly located circles are having weak relations among them. Moreover, the number of links between two circles depicts the interaction between the concerned items (Eyal, 2017; Panchenko *et al.*, 2020).

3. Results and discussion

3.1 Web of science categories

The top 20 web of science categories area are shown in the Table 1 below alongside their associated publications. A majority of the retrieved articles were in the Computer Science Information Systems, Engineering Electrical Electronic and Telecommunications categories with a share of 29.6, 24.9 and 23.7%, respectively. In this analysis, articles in the agricultural category did not fall in the top 20, which alluded to the newness in applying the technology for this application.

Table 1 depicts different areas of subject which are involved in blockchain research. The Computer Science Information System grabbed more attention with a record count of 50 which constitutes 29% of the total number of record counts involved in BCT. Engineering Electrical Electronic and Telecommunications; these two web of science categories had also played a vital role in the innovation of blockchain with record counts of 42 and 40, respectively. Cryptography has been considered as a major element of blockchain that is developed to overcome the disadvantages that appeared due to malicious information and unethical use of the decentralized information system (Avital, 2018). Cryptography uses two validations: encryption and decryption that act as security strengthening tools for user's private information transmitted between the sender and receiver (Kshetri, 2017). Modern cryptography was used to hasten the development in the subject areas like Law, Environmental Sciences, Green Sustainable Science Technology, Computer Science Theory Methods, Computer Science Software Engineering and Environmental Studies etc. by means of data integrity and user authentication (Caro *et al.*, 2018). The subsequent areas of interest are Management, Computer Science Interdisciplinary Applications, Computer Science

No.	Web of science categories	Record count	Percentage
1	Computer Science Information Systems	50	29.6
2	Engineering Electrical Electronic	42	24.9
3	Telecommunications	40	23.7
4	Law	17	10.1
5	Environmental Sciences	16	9.5
6	Green Sustainable Science Technology	13	7.7
7	Computer Science Theory Methods	12	7.1
8	Computer Science Software Engineering	11	6.5
9	Environmental Studies	10	5.9
10	Management	9	5.3
11	Computer Science Interdisciplinary Applications	8	4.7
12	Computer Science Hardware Architecture	6	3.6
13	Chemistry Analytical	5	3.0
14	Engineering Environmental	5	3.0
15	Food Science Technology	5	3.0
16	Instruments Instrumentation	5	3.0
17	Business	4	2.4
18	Computer Science Artificial Intelligence	4	2.4
19	Energy Fuels	4	2.4
20	Engineering Industrial	4	2.4

Source(s): Authors' own creation

Table 1. Web of science categories

Hardware Architecture, Chemistry Analytical, Engineering Environmental, Food Science Technology, Computer Science Artificial Intelligence and Energy Fuels etc., which are improving the trust and transparency in the system by employing distributed ledger technique to eliminate the errors derived from other centralized ledger technologies (Firdaus *et al.*, 2019). Currently, BCT is considered as an important aspect of developing a safe and trusted environment for secure transactions as well as maintenance of user privacy.

3.2 Research themes

Table 2 depicts the top 20 research themes related to the BCT. Computer science led with 72 articles, which contributed 42.6% to the total research articles taken under consideration, followed by Engineering (56 articles, 33.1%) and Telecommunications (40 articles, 23.7%). Agriculture, with 4 articles, contributes only 2.4% to the total research articles, which indicates that there is immense underlying potential for conducting research in the field of agri-food system. The research interest in blockchains in the agriculture sector is showing an upward trend as more and more researchers, companies and scientists add to the existing knowledge base in the field (Carrefour, 2018; Demestichas *et al.*, 2020).

3.3 Growth trend analysis

Table 3 and Figure 3 demonstrated the growing tendency in the publications and citations in the field of BCT from 2017 to 2020. It is worth noting that the concept of the IoT was first used in 1999. Despite that, the first research article devoted to BCT was published in 2008. In 2017, only five articles were published on blockchain, which contributes 3% to the total number of publications considered from 2017 to 2020. However, the number of publications showed an upward trend with a number of 54 (32.1%) and 94 publications (56%) in 2019 and 2020, respectively. The total number of citations in 2020 was 811, which increased approximately 45% as compared to 2019. These results depict a growing tendency to apply the technology owing to its aforementioned advantages compared to pre-existent techniques of supply chain

No.	Research themes	Record count	Percentage
1	Computer Science	72	42.6
2	Engineering	56	33.1
3	Telecommunications	40	23.7
4	Government Law	19	11.2
5	Environmental Sciences Ecology	18	10.7
6	Business Economics	16	9.5
7	Science Technology Other Topics	14	8.3
8	Chemistry	9	5.3
9	Food Science Technology	5	3.0
10	Instruments Instrumentation	5	3.0
11	Agriculture	4	2.4
12	Energy Fuels	4	2.4
13	Information Science Library Science	4	2.4
14	Operations Research Management Science	4	2.4
15	Physics	4	2.4
16	Materials Science	3	1.8
17	Mathematics	3	1.8
18	Social Sciences Other Topics	3	1.8
19	Transportation	3	1.8
20	Construction Building Technology	2	1.2

Source(s): Authors' own creation

Table 2.
Major research themes involved in blockchain

Year	Records	Percentage
No. of Published Items		
2020	94	56
2019	54	32.1
2018	15	8.9
2017	5	3
Total Citations		
2020	811	70.8
2019	290	25.3
2018	42	3.7
2017	3	0.2

Source(s): Authors' own creation

Table 3.
Growth trend analysis

(Liu *et al.*, 2021). Lin *et al.* (2020a, b) proposed that reforms are needed in the agricultural sector to use new innovations and techniques to enhance accountability and transparency and hence the growth in use of BCT.

3.4 Keyword analysis

For analyzing the research conducted in BCT, a total number of 523 keywords were identified by VOSviewer and the minimum number of occurrences of a keyword was set as 2. Out of 523 keywords, 110 keywords met the threshold and their co-occurrence is depicted in Figure 4. The result of the bibliometric analysis is presented in six clusters, which define the thematic proximity in the subject and also indicate the future research directions (Dujak and Sajter, 2019). The biggest cluster presents the research related to BCT with the keywords as blockchain, enforcement, Bitcoin, insights etc. with an intention to explore the role of BCT in

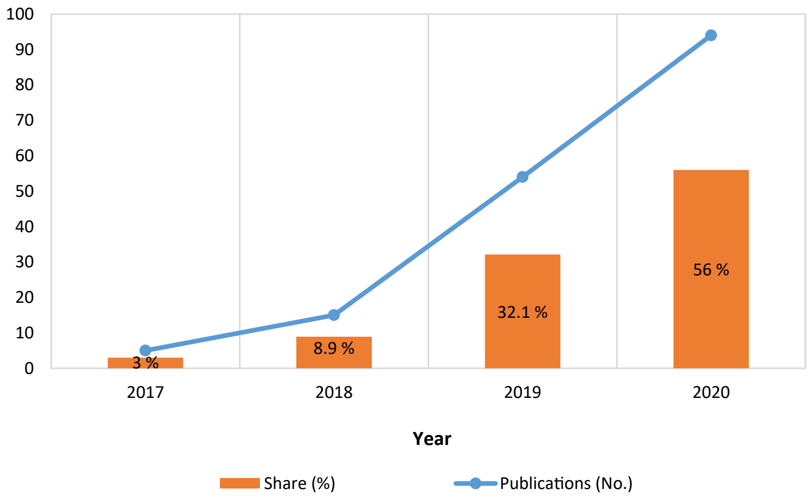

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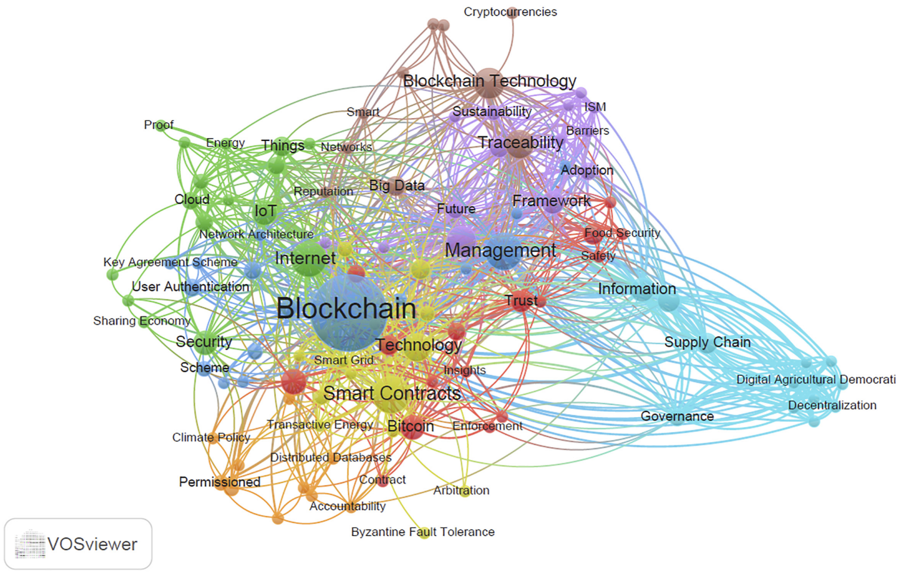
Figure 3. Dynamics of published documents on blockchain from 2017 to 2020



Source(s): Authors' own analysis using VoSViewer tool

Figure 4. Network map of blockchain keywords

transparency of the supply chain. The second cluster presents the documents related to the concept of BCT, which highlights the link between traceability and blockchain. Moreover, there is also a comprehensive study on sustainability in the food industry. The third cluster opens the research directions toward the IoT, which aims to explore the impact of the Internet on the security and transparency of the supply chain with due attention to protect the privacy of personal data of the stakeholders. The fourth cluster covered the publications regarding smart contracts that establish a useful link between the information management and smooth functioning of the supply chain network (Kumar *et al.*, 2020). This relevant theme includes the issues related to the governance in decentralization of the food distribution system for ensuring food safety (Tian, 2017). The fifth cluster emphasized on the influence of BCT for enhancing the trust and maintaining a safe net in the agriculture system. It should be noted that it is relevant for further investigation on the themes of BCT, IoT, smart contracts, traceability, food safety etc.

3.5 Institutions and countries

A total of 347 institutions were involved in research on BCT in agriculture applications. The first 15 are shown in Table 4. Institutions of the Republic of China including Beijing Institute of Technology and Beijing University of Posts and Telecommunications lead with the most articles at 4.1 and 2.4%, respectively.

A total of 51 countries were involved in the BCT in agriculture research. The first 15 were listed in Table 5. China had the highest number of publications ($n = 47$, 27.8%), while the USA and India came the second and third, respectively, with 11.8 and 9.5% of the retrieved publications. Overall, the inclusion of developing and fast developing nations of Asia in the research on BCT was predominant in comparison to the poor developing nations of Africa. This was associated with the financial and human development capacity of the former compared to the latter as highlighted in other bibliometric analysis by Wang *et al.* (2018) and Izuchukwu *et al.* (2020). The bibliographic coupling of countries and institutions as shown in Figures 6 and 7 confirmed this trend.

3.6 Bibliographic coupling of identified journals

Figure 5 shows the interrelationship of the various journals whose publications were searched and based on the VOSviewer analysis. Articles related to the Institute of Electrical and Electronics Engineers (IEEE) were predominant. This is because IEEE focuses on technology enhancement and is therefore involved in the research on BCT. In specific, the IEEE Access had the highest number of searched articles evident from the big circle depicting its inter-linkage with other articles. The “Journal of Cleaner production” and “Sustainability” also had a higher number of articles and their inter-linkages were strong

Table 4.
Topmost institutions involved in blockchain research

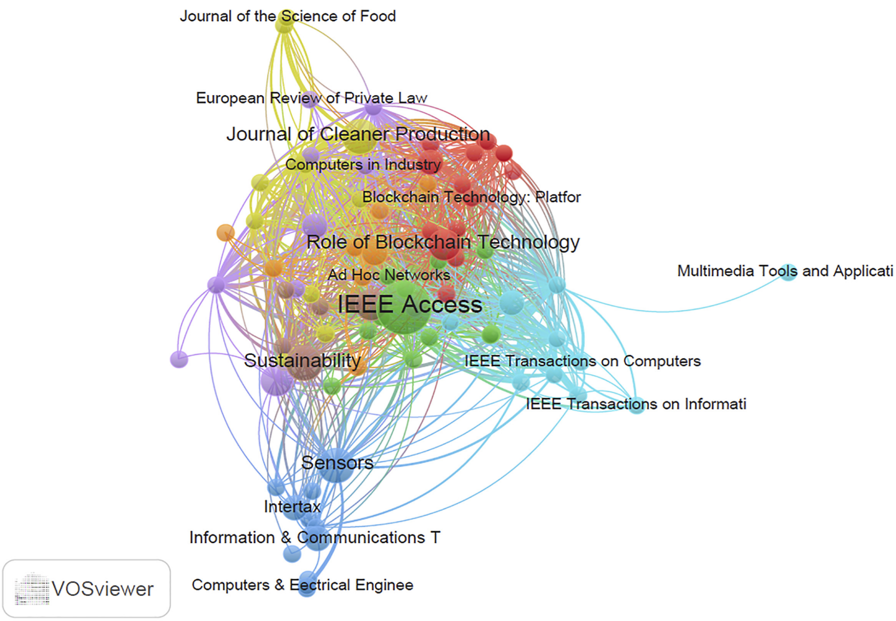
No.	Institutions	Record count	Percentage
1	Beijing Institute of Technology	7	4.1
2	Beijing University of Posts Telecommunications	4	2.4
3	King Saud University	4	2.4
4	Changsha University of Science Technology	3	1.8
5	Commonwealth Scientific Industrial Research Organization	3	1.8
6	Jeju National University	3	1.8
7	Macau University of Science Technology	3	1.8
8	Sungkyunkwan University	3	1.8
9	Technical University of Berlin	3	1.8
10	Technical University of Denmark	3	1.8
11	Xiamen University of Technology	3	1.8
12	Zhengzhou University of Light Industry	3	1.8
13	Catholic University Pusan	2	1.2
14	Chaoyang University of Technology	2	1.2
15	Comsats University, Islamabad	2	1.2

Source(s): Authors’ own analysis

No.	Countries	Record count	Percentage
1	China	47	27.8
2	USA	20	11.8
3	India	16	9.5
4	South Korea	13	7.7
5	England	12	7.1
6	Spain	11	6.5
7	Germany	10	5.9
8	Italy	9	5.3
9	Australia	8	4.7
10	Russia	8	4.7
11	France	7	4.1
12	United Arab Emirates	7	4.1
13	Denmark	6	3.6
14	Pakistan	6	3.6
15	Taiwan	5	3.0

Source(s): Authors' own creation

Table 5.
Country with blockchain research and publications



Source(s): Authors' own analysis using VoSViewer tool

Figure 5.
Network map of most popular journals for blockchain research articles

(Miau and Yang, 2018). This observation is associated with the potential of BCT to detect agricultural supply chain malfunctions and fraud and at the same time, improve food quality and safety (Dabbagh *et al.*, 2019; Xiong *et al.*, 2020).

3.7 Bibliographic coupling of institutions

Figure 6 depicts the collaborative network among a number of institutions from different countries. The same-colored node in the network represents single collaboration among

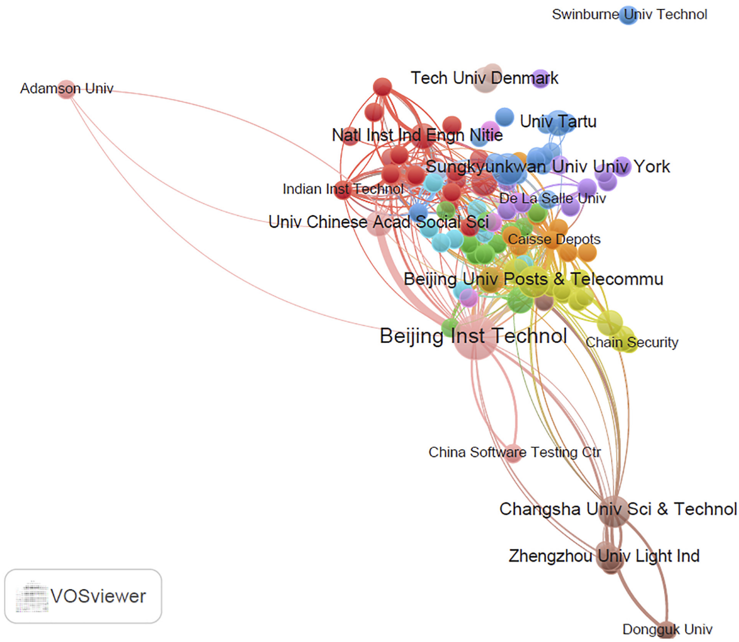


Figure 6.
Institutional collaborations for blockchain research

Source(s): Authors' own analysis using VoSViewer tool

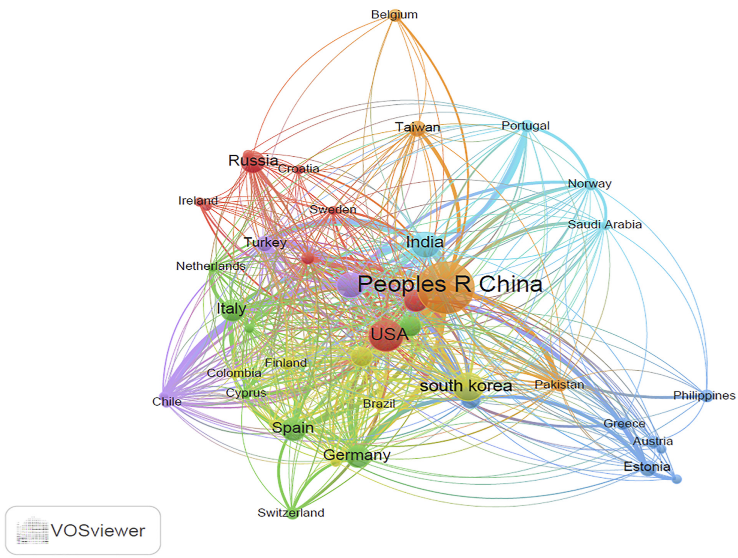


Figure 7.
Bibliographic coupling among the countries in blockchain research

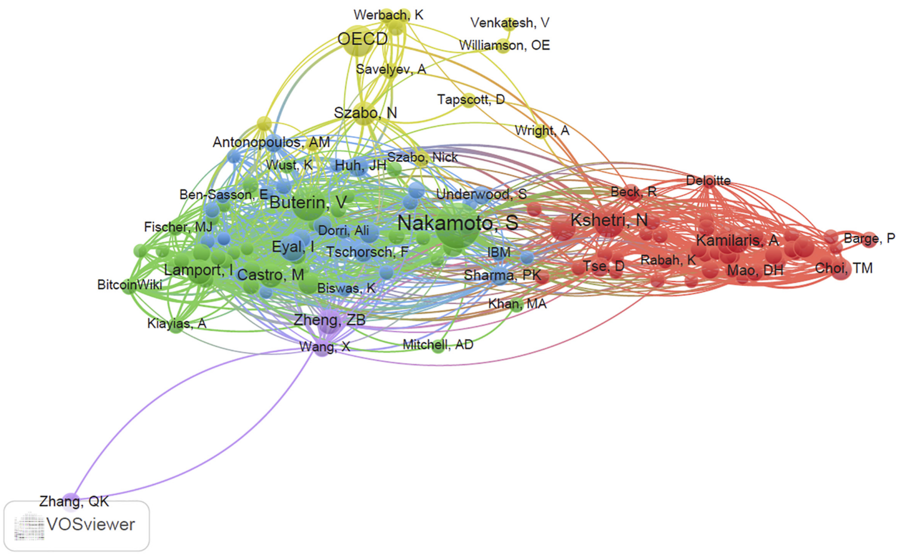
Source(s): Authors' own analysis using VoSViewer tool the institutions. The Beijing Institute of Technology is having the largest node, which indicates its largest network of collaboration with other institutions in blockchain research (Cao *et al.*, 2017). It collaborates with China software testing center, Hong Kong Polytechnic University and University of Chinese Academics, Adamson University and Social Science, which is presented by the pink-colored node. Red- and blue-colored nodes consist of 13 collaborations each, while purple-colored nodes have 10 and green-colored nodes have 9 numbers institutional collaborations (both domestic and overseas) regarding the BCT. This figure poses a clear idea that the Chinese institutions preferred to collaborate within their own country than the overseas institutions, due to their similar interest for exploring the potential of blockchain in IoT (Lopes and Pereira, 2019; Dwivedi *et al.*, 2019).

3.8 Bibliographic coupling of countries

In order to depict the active collaborations in the field of blockchain research, Figure 7 is used to detect the circle of network among the countries. The colored nodes represent the total number of research articles published on BCT by a country with active collaboration with partner countries (Puthal and Mohanty, 2019). As per the figure, China is having the highest number of collaborations with countries like Taiwan and Pakistan, followed by the USA, India and South Korea, Russia, Italy, Spain and Germany. Currently, India is having active collaborations with Portugal, Norway and Saudi Arabia for conducting research on BCT as well as publishing articles regarding its potential implications in various subject areas of research.

3.9 Co-occurrence of citation and their relationship among authors

Co-occurrence of cited authors showed that a total of 3943 authors were found by the software but the minimum number of citations of an author was set as 5 and 131 results met this threshold. Their co-occurrence was as shown in Figure 8. "Nakamoto Satoshi," a pseudonym referring to unknown individuals or groups who coined the BCT terminology in 2009



Source(s): Authors' own analysis using VoSViewer tool

Figure 8. Network map of co-occurrence of citations among the authors

(Rawat *et al.*, 2020), had the strongest interrelationships compared to other authors and in terms of citations. Authors that shared similar color in their VOSviewer interrelationships were likely to have collaborated in research and publications and cited one another.

Co-citation occurrence of sources showed that a total of 3,379 sources were found by the software. The minimum number of citations per source was set as 5 and 160 sources met this condition. Their co-occurrence was as shown in Figure 9. Just as was the case in bibliographic coupling of sources, the IEEE articles dominated in the co-occurrence and had high number of citations (Maslova, 2017). The Lecture Notes in Computer Science (LNCS), which publishes conference proceedings on novel developments in computer science including BCT, also had a high number of articles and citations. Evidently, BCT research is growing due to its potential to redefine economic sectors such as agriculture, revolutionize companies and businesses, and have profound impacts as Ghosh (2019) highlighted (see Figure 10).

4. Potential benefits of blockchain in agri-food system

A huge technological progress has paved a way for decentralized ledger such as blockchain to widen its application fields. We have outgrown the age of BCT being in the hands of only the financial sector. Today, its application has even reached to food production and might even lighten the burden of complexity in the food system. Agri-food system becomes one of the beneficiaries of the BCT because it offers features like traceability (Shew *et al.*, 2021), transparency, saves time in the value chain of agricultural products and minimizes the burden in collecting information (Bogomolov *et al.*, 2019). A "Distributed Ledger Technology" like blockchain enables tracking of tamper proof data from each stage of the agricultural supply chain using digital fingertip, QR codes, RFID chips, facial recognition for livestock, crypto-anchors, etc. Therefore, implementation of

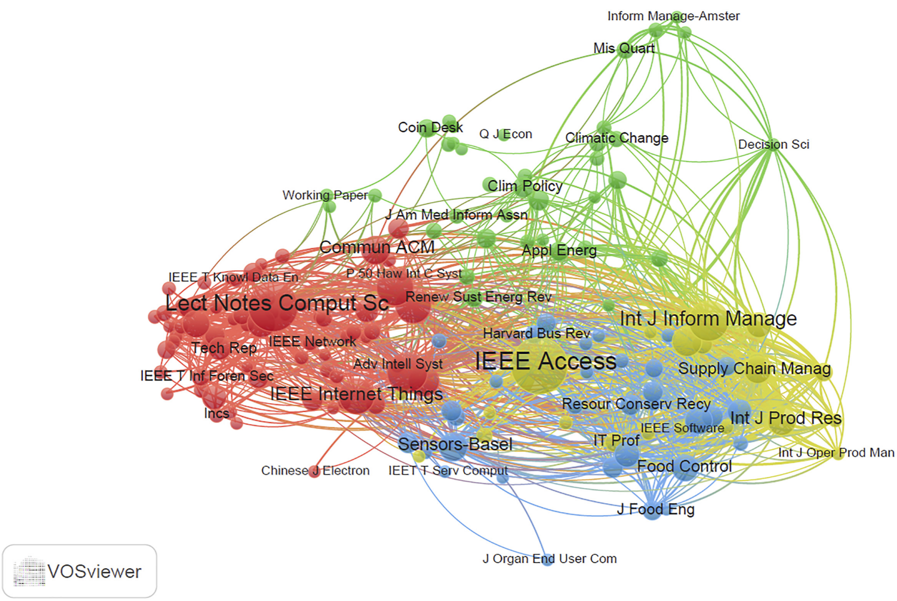
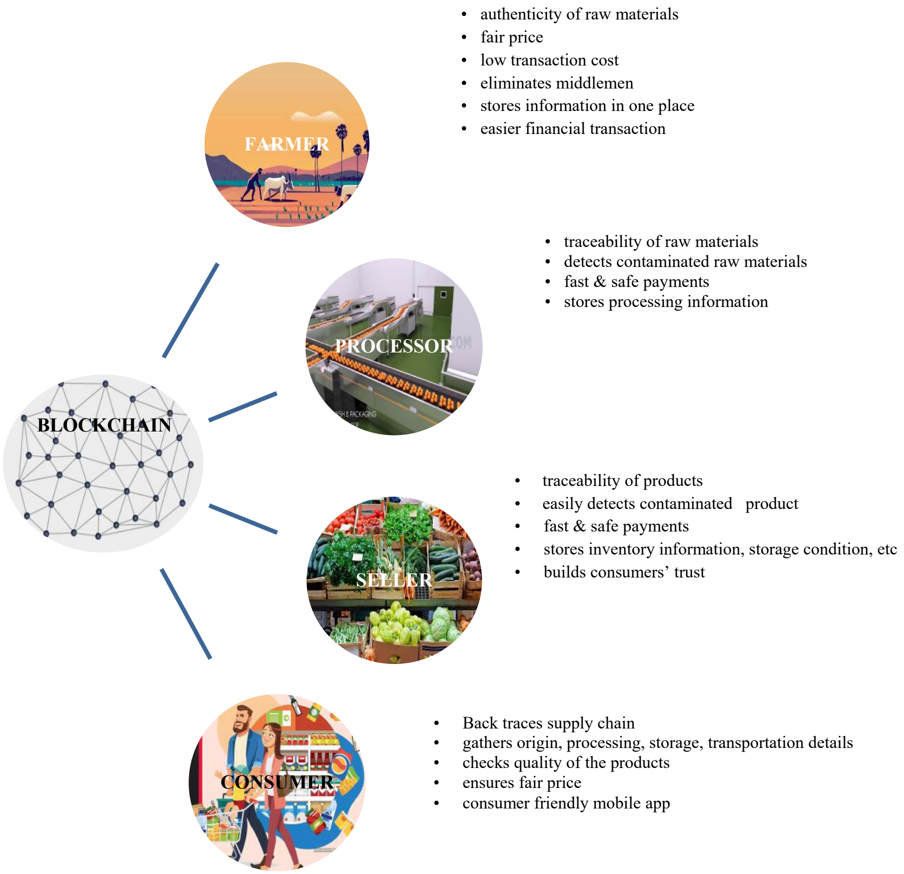


Figure 9. Network map of co-occurrence of citations among the topmost journals

Source(s): Authors' own analysis using VoSViewer tool



Source(s): Authors' own compilation

Figure 10.
Benefits of BCT in agri-food supply chain

digitalization through BCT may be a game changer in the agri-food system (Tripoli and Schmidhuber, 2018).

4.1 Food safety and integrity

The goal of the BCT is to instill trust by providing transparency and traceability. Existing challenges include the lack of transparency and traceability in supply chains and food fraud alone has financial costs of approximately US$ 40 billion annually (Faye, 2017). The lengthy food supply chain hinders the consumers to address their concerns directly to the producers (Ge *et al.*, 2017), which consequently limits the information accessible regarding the items they purchase. The unidirectional interaction among the stakeholders of the supply chain can be turned to bidirectional by linking all aspects of the supply chain with a traceable and immutable data system (George *et al.*, 2019; Xu *et al.*, 2020). Successful supply chain management requires traceability that develops from complete transparency (Chan *et al.*, 2019). Moreover, when there is an increase in data being linked to the BCT, tracing fraud can become easier using cross checks due to the immutability of data and hence lowers the chance of fraud in the food system (Ge *et al.*, 2017). As a result, blockchain-based traceability approach for agri-food system can improve not just traceability and sustainability management but also consumer trust and purchase willingness (Matzembacher *et al.*, 2018).

4.2 Time and cost benefits

Tracing the initial origin of food in a supply chain takes considerable time before. For instance, Salmonella infections of Maradol Papayas took 2 months to discover the source of contamination (Malik *et al.*, 2018). Tracing the origin of mango from farm to fork took more than a week in the earlier Walmart System but took only 2.3 s using the BCT (Yadav and Singh, 2019). BCT can reduce time in data tracing as well as reduce the inefficiency of heavy paper settlement in the food supply chain (Kamilaris *et al.*, 2019). Louis Dreyfus company traded 60 thousand tons of the US soybeans to Chinese government using the BCT and the whole logistics took only a week, which is an 80% reduction in time (Bogomolov *et al.*, 2019).

4.3 Financial transaction

BCT provides fast and safe payments methods at a reduced cost. Since there is no requirement of approval from the bank, payment made through the BCT model completes in less than 10 min which used to take 2–5 days using traditional methods and only costs less than $2 regardless of the transaction amount. The increase in financial transaction efficiency in the supply chain will lead to better financial inclusion in the agri-food system (Sandeep *et al.*, 2021). The blockchain can also serve as a verification source for the recorded transactions as it can store information permanently and securely. Therefore, the Blockchain Ledger can replace the financial reports for auditing purposes which saves time as well as cost. Agriculture supply based on blockchain can simplify each stage of food distribution. The potential benefits of BCT on agri-food systems can be explained by highlighting its benefits on stakeholders of the food supply chain (Alkahtani *et al.*, 2021).

4.4 Farmers

Through BCT, farmers can easily check the authenticity of the purchased raw materials. Smart contracts based on blockchain enable farmers to easily sell their produce in the market at a fair price without the need to involve middlemen. It also enables two parties to transact directly, producers may procure raw materials from the farmers. It lowers the transaction cost and ensures prompt payment settlement to farmers (Awan *et al.*, 2019; Lin *et al.*, 2020a, b; Khan *et al.*, 2022). Farmers adopt different methods for storing information, which makes their job tedious and inconveniences them in sharing required information to their business partners. BCT offers the solution to this by storing all information such as cultivation methods, crop quality, inputs used, weather conditions etc. in one place, which saves time, energy and cost (Awan *et al.*, 2019; Suthar *et al.*, 2019).

4.5 Processors

The information on raw materials purchased for processing is only one click away on their smartphones. Processing methods, batch number, information about factory and its equipment, packaging information, storage condition etc. can be stored in blockchain for the buyers to access so that their confidence and loyalty may be gained (Xu *et al.*, 2020).

4.6 Wholesalers and retailers

Procurement managers can obtain the information of the products purchased in a short time using the BCT and can easily pin point the contaminated product without the need to recall all the products (Lin *et al.*, 2020a, b). They can also add inventory information, storage condition, sanitation practice etc. in the BCT to enable consumers to access the environmental footprint of the product (Zhao *et al.*, 2019).

4.7 Consumers

According to a survey conducted by "Label Insight," 73% of the consumers are willing to pay more for products that demonstrate transparency. Consumers can back trace the supply chain as all the stages involved are digitally linked using the blockchain. They can gather the origin, processing, storage and transportation details of the products, and also whether they get fair payment by simply scanning the QR code associated with the product on mobile app (Xu *et al.*, 2020) Therefore, along with greater transparency and traceability to consumers, BCT brings trust into the system (Galvez *et al.*, 2018). Due to the coronavirus disease 2019 (COVID-19) pandemic and food fraud incidents bombarding us day-to-day, consumers' concerns about food provenance and quality are becoming more and more. There has been a high demand for certified food and meat in Wuhan supermarkets after the disease outbreak (Iftekhar *et al.*, 2020). According to the World Economic Forum (WEF), BCT can help tackle supply chain failures exposed by the COVID-19 pandemic and boost the economic recovery process (May, 2020). Therefore, BCT is the need of the hour to provide food safety and integrity demanded by the world.

5. Opportunities and challenges in the agri-food system

5.1 Opportunities in the agricultural sector

Despite being first applied to Bitcoin, utility of BCT is gradually being realized in multiple sectors including agriculture. Many start-ups like AgriChain, TE-FOOD, AgUnity, Agri10x, AgriDigital, Ripe, AgriLedger, Demeter, FarmFirst, Etherisc, OwlChain, VeganNation and Worldcover are already trying to resolve various agricultural issues using BCT (Xu *et al.*, 2020). The key areas in which this technology can prove helpful to agriculture are discussed below.

5.1.1 Food safety and traceability. Although blockchain is thought to be a potentially revolutionary technology, there are numerous research gaps due to the dearth of knowledge on its usage to enhance the food traceability through full information transparency and security aspects of the food chains (Kim and Laskowski, 2018; Yiannas, 2018; Feng *et al.*, 2020). The need for tracing complete farm to fork movement of the agriculture products is increasingly being felt with rising awareness regarding food safety and quality and preference for fresh and organic produce (Prashar *et al.*, 2020; Casino *et al.*, 2019). The BCT can be used to trace the origin of the product, its growing conditions, date and time of irrigation, application of fertilizers, pesticides, movement and time taken to reach the consumer (Bastas and Liyanage, 2018). Moreover, it helps in tracing the product quickly and at a lower cost than the conventional method. Consumers can rely on this technology if they want to ensure that the product has been grown in a specific area, like in the case of Geographical Indicator (GI), imported goods or local farm produce, and also to check the quality specifications in case of exported products (Almeida *et al.*, 2018; Hallak and Tacsir, 2022).

5.1.2 Timely and transparent payment mechanism. Agriculture supply chains are often complex and financial settlements take time due to the involvement of large number of actors. Delay in payments proves stressful, specifically to small farmers who immediately require cash for further investment and to meet their consumption needs. Moreover, asymmetric market and price information give rise to various malpractices, which ultimately lead to farmer exploitation. Blockchain offers a mechanism for quick and transparent payments. Codes can be generated for automatic payments immediately after the transaction of a commodity. The cash transactions are visible to all the members within the chain, which reduces the probability of fraud or deduction of any additional charges (Hu *et al.*, 2021). Thus, BCT can be proved as timesaving as well as adding more security and transparency in the system. Record-Keeping: BCT can ease the work of record-keeping and prevent tampering. Records related to the purchase of inputs, inventory, stocks, sale of output, balance sheets etc. can be maintained with the help of BCT. Another major use can be for maintaining records related to land ownership. Accurate digital data of land records will not only minimize the number of disputes between individuals but will also assist bankers, researchers, policymakers, government and other organizations working in the field of agriculture.

5.1.3 Supply chain management. Ensuring added value to the consumers is essential for any business to survive, especially when the competition between organizations is evolving into the competition between supply chains (George *et al.*, 2019). Food supply chains can be made more efficient and transparent by utilizing the BCT. It creates a unique level of credibility that contributes to a more sustainable food industry. The entire information of a product from field to fork, like origin, soil quality, storage temperature and shipping details, can be recorded by using blockchain. Companies like Walmart, Alibaba and JD.com are already using the BCT to track the entire process of food production, processing and sales (Xiong *et al.*, 2020). Tracking financial and physical transactions can also help us in identifying the weak points in the chain. It can also help in reducing the number of intermediaries and cost involved in the movement of commodities (Owot *et al.*, 2023). Warehouse managers can easily keep a track of the products, their storage condition and expiration dates. Informed decisions regarding inventory and product stock can further enhance the profitability of the firms by minimizing wastage.

5.1.4 Credit and insurance. Another widely discussed potential application of BCT in the agriculture sector can be in the field of credit and insurance. Well-maintained credit history using BCT can increase the access of farmers to formal lending agencies. Information on weather and crop production can be integrated with smart contracts, whereby payments can be approved automatically in case of extreme weather events. This can help in reducing the transaction time, thereby increasing the efficiency.

Besides, there can be a plethora of scope for BCT in agriculture that is still unexplored, like technology-based trust among supply chain stakeholders (Agrawal *et al.*, 2021). It can be effectively used for rectifying the agricultural issues arising due to information asymmetry or lack of transparency.

5.2 Challenges ahead

The BCT seems promising, but its implementation has its own challenges, especially to developing countries where a majority of the farmers lack sufficient knowledge about maintaining records (Xu *et al.*, 2021). Intensive training is required to equip such farmers with the necessary skills, for the minimization of errors and insertion of accurate data at the initial level. BCT platforms should use regional languages, instead of English for wider acceptance and user-friendly experience. Another major hindrance in the usage of BCT can be the unavailability of mobile phones with all the stakeholders or the lack of stable Internet facilities. Though coverage of mobile phones is continuously increasing, network connectivity and uninterrupted Internet access is also required for efficient operation (Wamba and Queiroz, 2020). In addition to this, as of now, the technology itself suffers from multiple limitations. The data-intensive applications such as monitoring and controlling farming by sensor networks require fast storage speed and low network latency (Lin *et al.,* 2020a, b). Many researchers have expressed their doubts regarding the efficient handling of a large number of transactions by using the BCT, while others have raised concerns about the privacy of data (Zhao *et al.*, 2019). Burke (2019) proposes that the agri-food supply chain is complex and reluctant to blockchain adoption due to lack of technological expertise of stakeholders, multiple transformation activities of the products, larger area of distribution of chains and the extremely heterogeneous nature of functions by stakeholders. Accessibility to the BCT, governance and sustainability, policy and regulation rules, as well as the bridging the digital gap between developed and developing countries are among the key challenges highlighted in order to achieve successful adoption of such emerging technologies (Kamilaris *et al.*, 2019; Bons *et al.*, 2020). Cost-effectiveness of the technology is one more aspect that affects its adoption. Only a low-cost technology can prove its inclusiveness in developing countries as a majority of the agricultural households have low income and they might not be able to invest more in a new technology. The BCT might require substantial initial investment, which can hamper its widespread adoption. Hitherto, there have been no uniform regulations with respect to the BCT. Bitcoin, the most popular application of BCT faces restrictions in several countries. Therefore, all the countries need to work together in order to build a proper regulatory framework so that misuse of the platform and exploitation of users can be avoided. Fallacies regarding the BCT need to be addressed to realize its potential to the full extent.

6. Conclusions and policy implications

The application of BCT has witnessed a commendable rate of adoption in recent years (Nash, 2016). From the boom pertaining to cryptocurrency transfers, blockchain is now used in various fields, replacing the traditional *modus operandi* of public entities (Allison, 2015). BCT is a recently popularized system; hence, the whole new set of rules and regulations are to be framed, and existing ones need to be amended. Privacy and copyright issues are some of the concerns to receive primary consideration as the system is of decentralized data management (Gabison, 2016). In this section, we would focus on the major policy imperatives pertaining to the adoption of BCT in the agriculture sector.

6.1 Agri-food system

The agri-food system, in general, can be strengthened using the application of BCT. This opens an arena for balancing demand and supply in a more efficient manner. The possibility of finding out the surplus and procuring the same would reduce wastage and also enhance the stability of the system. With mobile-based applications, the transmission of stock and demand data through blockchain will become more efficient. There will be commendable increase in food quality and global food security with data capture through censor-based BCT. Forecasting and getting prepared for crop loss due to changing weather variables is an example for this. Commendable improvement can be ensured in the logistics of products from production to final consumption. Tracking of products would ensure reduced frauds and malpractices. With these benefits, it cannot be ignored that the stakeholders involved are not fully aware of how to use and make the best of the technology. Thus, policies, rules and regulations pertaining to BCT application in agriculture are to be framed such that no stakeholder is exploited, or deprived of any rights (Suthar *et al.*, 2019). Crop insurance efficiency, damage calculation and reporting, and thus, payout of claims can be made relatively transparent and faster using the BCT (FAO, 2019), thereby, resolving the issue of farmer's dissatisfaction regarding delayed claim settlement and inadequate payment. Hence, upscaling the technology is suggested to help the farmers to adopt better practices and encourage crop diversification, enhancing food security and price stability.

6.2 Society

The decentralized system in the blockchain is both a boon and a curse at the same time. Since the data are stored in various servers, the amount of control in a decentralized system is very low, and it might even be impossible to remove unwanted or offensive information once added to the public domain (Gabison, 2016). This makes it essential to bring all the nodes or servers in a decentralized system under the control of federal/state. There have been reports of using personal data for commercial benefits. Such actions might become rampant and out of legal jurisdiction with the advent of new technology. The technocrats and the lawmakers should focus sharply on these issues parallel to the increased usage of the new technology. The circulation of articles with copyright could become more complicated to solve when blockchain is used for carrying out the same (Vogel, 2016). With the new technology, it becomes relevant to have stringent regulations that would allow the copyright owner to enjoy all its benefits and legally sue any kind of infringement.

BCT is comparatively newer in the technology domain. When such a technology is being introduced in sensitive sectors like agriculture and in developing countries, where illiteracy is rampant among the farmers and technology intrusion is limited, emphasis should be given to the capacity building of stakeholders. Training should be given in using devices, legal and technological aspects. With farmers, who are less literate and technology aware on one side, this should not open new arenas of exploitation. Implementation should be seriously monitored by agencies and departments. Investments in technology and education must be made in order to further produce and demonstrate evidence considering the benefits of the BCT.

6.3 Consumers

Blockchain systems would allow the consumer to have a better awareness of the product and enhance traceability (Shew *et al.*, 2021). This would have an impact on trustworthiness. With widespread use of the technology, quality and variety of products reaching the consumer would also increase. The high degree of traceability would provide incentives to farmers adopting good practices and penalize those involved in malpractices, making improvements in product quality (FAO, 2019). Consumers are directly or indirectly benefited, whenever there is an improvement in the whole system from production to final retail outlet, including those improvements in product quality. Clearly, to avail the benefits of the BCT, consumers should be made aware of its usefulness and associated advantages.

7. Limitations and scope for future research

This research provides a review of the application and opportunity of BCT in agri-food supply chains for traceability and transparency management. It also contributes to the enhancement of knowledge on BCT-based applications, framing the agenda for further research and practical implications for sustainable food systems. However, this study also consists of certain limitations as it is completely based on the review of literature and the underlying theory is conceptual-based. Therefore, the proposed frameworks should be empirically validated. There are certain limitations regarding the functionalities of BCT, its implementations, as well as challenges faced by various stakeholders during the operations of BCT. The limitations provide opportunities to the practitioners and researchers for future research in case of the operational framework, designing and multipurpose applications of BCT. Future research can focus on the application of BCT in different agri-food supply chains to enhance the performance and sustainability of the entire agri-food system.

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Further reading

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Crosby, M., Pattanayak, P., Verma, S. and Kalyanaraman, V. (2015), "Blockchain technology: beyond bitcoin", Nachiappan, available at: BlockchainPaper.pdf

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