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Blockchain Application in Food Supply Chains: Bibliometric Analysis and Future Research

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ABSTRACT

This study aimed to organize and analyze studies on blockchain application in food supply chains and to discover emerging research themes and topics using cluster analysis to determine future research directions. Bibliometric analysis was used to organize and analyze the literature on blockchain application in food supply chains. The database consisted of 629 Scopus-indexed articles from 2016 to 2021. These were organized using bibliometric analysis (e.g., annual publication trends) and content analysis (e.g., research method applied). Themes and emerging research trends were then clustered based on keywords using the VOSviewer software. The analysis showed that manufacturing is the type of industry that most applies the blockchain. Trust is the most-cited benefit achieved by blockchain application, while traceability is the most-claimed function. Keyword classification resulted in seven main clusters (e.g., sustainability and transparency) and each cluster had emerging research trends (e.g., resilience toward sustainability and transparency). This research provides an overview of scientific development and emerging application trends related to blockchain application in food supply chains.

***Keywords**: Blockchain application; food supply chains; halal supply chains; bibliometric analysis; strategic diagram.*

1 Introduction

Food supply chains (FSC) require more sustainable efforts to increase end consumer trust in safe, high quality, and halal food products as proven by information tracking and authentication using a food traceability system (i.e., Bosona and Gebresenbet, 2013; Sun *et al*., 2017; Olsen and Borit, 2018; Galvez *et al*., 2018). In food supply chains, blockchain technology can be used to increase visibility and trust (e.g., Hastig and Sodhi, 2020; Kamble *et al*., 2020); transparency (Tan *et al*., 2020); Sunny *et al*., 2020); originality and traceability (Rejeb, 2018); Helo and Hao, 2019); company performance (Kamble *et al*., 2020; Hald and Kinra, 2019); and business models (Weking *et al*., 2020).

Although blockchain technology is still relatively new, its application has been reviewed extensively in the literature. Kshetri (2018) believes that blockchain technology can address all goals in supply chains, i.e., cost, speed, dependency, risk reduction, sustainability, and flexibility. Wang *et al*., (2019) have shown how blockchain technology will affect supply chain policies and practices in the future, as it can (a) increase system transparency and traceability, (b) implement supply chain digitization and disintermediation, (c) increase data security, and (d) apply smart contracts. According to Helo and Hao (2019), blockchain technology ensures the authenticity and accuracy of information, hence ensuring transaction security.

Like all food products, halal food products are processed along their path from the farm to the end consumer, except everything must be done according to Islamic Sharia law. The food's halalness must be ensured by all supply chain actors along the value chain. The application of blockchain technology is believed to be a promising way to increase trust, accountability, and transparency across business and halal supply chain networks (Tieman, 2011; Tan *et al*., 2020).

Systematic reviews on blockchain application in food supply chains have been conducted previously. For example, Zhao *et al*. (2019) looked for the standard application practices, main challenges, and future research directions in the agri-food supply chain. Citation network analysis was carried out based on author names. Duan *et al*. (2020) reviewed 26 articles using content analysis to discover the benefits and challenges of blockchain adoption. Feng *et al*. (2020) reviewed articles to anderstand how blockchain technology can enhance food traceability systems by identifying traceability issues and requirements, the performance dimensions of traceability objectives, and problem areas and challenges. Meanwhile, the current study aimed to review blockchain application in food supply chains and halal supply chains, using bibliometric and strategic diagram analysis. In particular, the contribution of this paper is:

- to organize and analyze articles on blockchain application in food supply chains and halal food supply chains,
- to determine research themes and emerging topics to inform future research.

The remainder of this paper is organized as follows. Section 2 explains the research design. Section 3 outlines the bibliometric analysis, i.e., annual publication trends, main journals, most cited papers, and content analysis. Section 4 maps author keywords using descriptive analysis, and research themes and emerging topics using cluster analysis and strategic diagram analysis. Finally, Section 5 gives the conclusions and discusses the limitations of this research.

2 Research Design

This study used bibliometric analysis and strategic diagram analysis to answer the research questions. Bibliometric analysis is a popular method for measuring scholarly quality and productivity as it uses objective criteria (Moed *et al*., 1995). According to Kamdem *et al*. (2019), bibliometrics analysis can effectively analyze and describe large numbers of publications and has been used in many fields. It can also analyze citation relationships, co-citations, and keywords to provide comprehensive information about a research field (Garcia-Buendia *et al*., 2020).

In this study, we adopted the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology. PRISMA is used to enhance the reliability and validity of the results when collecting articles on a specific topic (Moher *et al*., 2009). This methodology was applied on 11 June 2021 to retrieve papers on supply chain research from the Scopus database. PRISMA guides the researcher in conducting a systematic review or meta-analysis based on objective questions using a detailed and clear method. It allows to identify and evaluate the most appropriate and relevant studies (Rocha, 2021). The following is an explanation of the four stages of the search method used in this research.

Stage 1: Defining the search rules. Two research topics were determined to collect data from Scopus, i.e., 'blockchain and supply chain', and 'blockchain and halal'. Table 1 shows the keywords used for each topic.

Table 1.
Rule, topic, and keyword results.

Rule	Topic	Keywords	Number of Articles
1	Blockchain and Supply Chain	'blockchain' AND 'supply chain'	1,720
2	Blockchain and Halal	'halal' AND 'blockchain'	15
Total			1,735

Stage 2: Initial search. We used Rule 1 and Rule 2 separately in the search. The initial search results from Rule 1 using the 2016-2021 data consisted of 1,720 articles, while the initial result from Rule 2 using the 2018-2021 data consisted of 15 articles (see Table 2).

Stage 3: Second search. This stage resulted in 650 articles from Rule 1 and 8 from Rule 2 based on the document type (see Table 2).

Stage 4: Third search. This stage resulted in 622 articles from Rule 1 and 7 articles from Rule 2, narrowing the articles down to the subject area. Table 2 shows the search results in Stages 2, 3, and 4 from both Rule 1 and Rule 2 (see Table 2).

Table 2.
Search Results from Stages 2, 3 and 4.

Step	Combination	Refine	Number of Articles
1st	Rule 1	Year: 2016-present Doc. Type: All Source Type: All Language: All	1,720
	Rule 2	Year: 2018-present Doc. Type: All Source Type: All Language: All	15
2nd	Rule 1	Year: 2017-2021 Doc. Type: Article Source Type: Journal Language: English	650
	Rule 2	Year: 2019-2021 Doc. Type: Article Source Type: Journal Language: English	8
3rd	Rule 1 OR Rule 2	Subject area: Engineering, Com Science, Business Management and Accounting, Decision Science, Social Sciences, Materials Science, Agricultural, Economics, Mathematics.	629

Stage 5: Applying the PRISMA methodology. In this stage, the PRISMA methodology (Figure 1) was applied. The following are the steps of the PRISMA methodology.

Identification step: This step identified the articles foand from the search using 'blockchain' AND 'supply chain' and 'blockchain' AND 'halal' and whether there were duplicate articles. There were three duplicate articles among the results for the combinations of keywords used. Therefore, these three articles were excluded, bringing the total number of articles to 626 articles.

Screening step: This step screened the search result to remove incomplete articles, i.e., articles that did not contain an abstract, keywords, or a title. Five articles were removed, i.e., two articles without abstract, three articles that did not include keywords.

Eligibility step: This step determined the number of articles to be removed from the search result because they were not relevant to the research topic. Three articles that were insufficiently relevant to the research topic were removed.

Included step: The remaining number of articles to be included in the systematic review and meta-analysis was 618 articles.

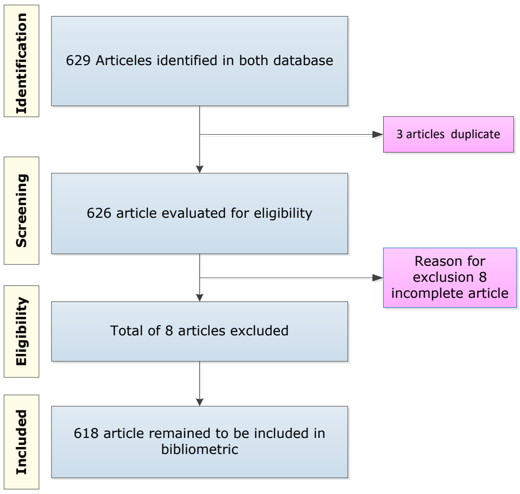

Figure 1. PRISMA steps to select articles for bibliometric review.

3 Basic bibliometric analysis

3.1 Annual publication trends and top 20 major journals

The final search result was 622 articles on supply chain blockchain and seven articles involving halal blockchain. The years of publication in the research period (2017-2021) are shown in Figure 2. The number of articles published increased yearly, showing that research interest in supply chain blockchain and halal blockchain has grown.

Table 3 shows the top-twenty papers that were published in the most significant journals from 2017 to 2021. The top-five major journals identified were: *Sustainability* (Switzerland) (26 articles), *International Journal of Production Research* (15 articles), *Supply Chain Management* (10 articles), *Electronics* (Switzerland) (8 articles), and *International Journal of Supply Chain Management* (8 articles). These accounted for 18% of the total publications on supply chain blockchains and halal blockchains.

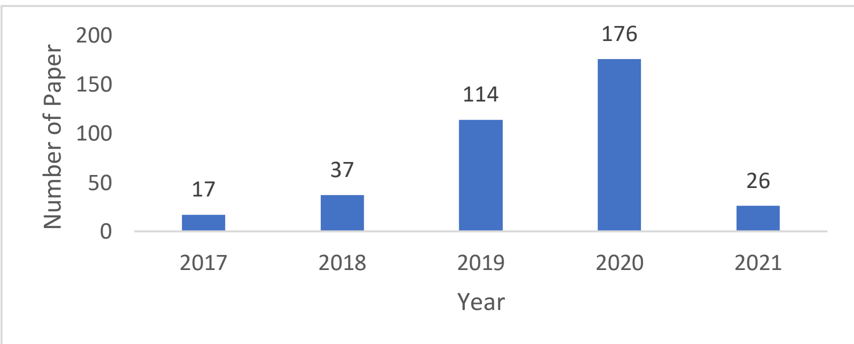

Figure 2. Year of publication of articles on blockchain application in supply chains and halal supply chains.

Table 3.
Top-twenty journals publishing articles on blockchain application in supply chains and halal supply chains

Rank	Journal Name	2017	2018	2019	2020	2021	TP
1	Sustainability (Switzerland)		5	4	13	4	26
2	International Journal of Production Research			3	12		15
3	Supply Chain Management		1	4	5		10
4	Electronics (Switzerland)			1	5	2	8
5	International Journal of Supply Chain Management				8		8
6	International Journal of Recent Technology and Engineering			7			7
7	IBM Journal of Research and Development			6			6
8	IEEE Transactions on Engineering Management				6		6
9	International Journal of Advanced Computer Science and Applications			4	1	1	6
10	IT Professional	2		3	1		6
11	IEEE Engineering Management Review		2	2	1		5
12	Sensors (Switzerland)		1		4		5
13	Applied Sciences (Switzerland)			2	2		4
14	Business Horizons			4			4
15	Future Internet			3	1		4
16	Information (Switzerland)	1			2	1	4
17	Intelligent Systems in Accounting, Finance and Management	1	2	1			4
18	International Journal of Scientific and Technology Research			1	3		4
19	ACM Computing Surveys			1	2		3
20	IEEE Network			1	2		3

3.2 Top 10 most-cited papers

Table 4 shows the top-10 most-cited articles from 2017 to 2021. The first most-cited publication was Kshetri (2018), which focuses on the effect of blockchain application on supply chain management's main objectives, such as quality, cost, speed, flexibility, etc. It had been cited 342 times in three years. The second most-cited publication was Mengelkamp *et al*. (2018), which discusses the concept of the blockchain-based microgrid energy market, with 342 citations. The third most-cited publication was Saberi *et al*. (2019), which examines blockchain applications such as smart contracts in supply chain management, with 307 citations.

Table 4.
Top 10 most-cited articles on blockchain application in supply chains and halal supply chains

Rank	Author	Year	Article title	TC	C/Y
1	Kshetri, 2018	2018	Blockchain's roles in meeting key supply chain management objectives	342	136.8
2	Mengelkamp et al., 2018	2018	A blockchain-based smart grid: towards sustainable local energy markets	342	136.8
3	Saberi et al., 2019	2019	Blockchain technology and its relationships to sustainable supply chain management	307	204.7
4	Casino et al., 2019	2019	A systematic literature review of blockchain-based applications: Current status, classification and open issues	243	162.0
5	Ivanov et al., 2019	2019	The impact of digital technology and Industry 4.0 on the ripple effect and supply chain risk analytics	221	147.3
6	Kim, 2018	2018	Toward an ontology-driven blockchain design for supply-chain provenance	177	70.8
7	Meng et al., 2018	2018	When intrusion detection meets blockchain technology: A review	168	67.2
8	Toyoda et al., 2017	2017	A novel blockchain-based Product Ownership Management System (POMS) for anti-counterfeits in the post supply chain	156	62.4
9	Lu and Xu, 2017	2018	Adaptable blockchain-based systems: A case study for product traceability	145	96.7
10	Queiroz and Wamba, 2019	2019	Blockchain adoption challenges in supply chain: An empirical investigation of the main drivers in India and the USA	141	94.0

3.3 Content analysis

The content analysis aimed to analyze the articles more deeply, based on a) the research method applied, b) the industry type, c) the benefits, and d) blockchain application in halal supply chains.

3.3.1 Applied research methods

The classification of the research methods was based on Lagorio *et al*. (2016), which divides them into six categories: 1) literature review, 2) empirical research, 3) conceptual research, 4) exploratory research, 5) modelling, and 6) survey. Table 5 presents the six methodologies. The results show that the most widely used method was literature review at 29%, followed by conceptual framework research at 18%, exploratory research at 17%, modeling at 13%, and survey at 8%. This is similar to the statement by Ali *et al*. (2021a) about the rarity of blockchain implementation and challenges. According to Tan *et al*. (2020), the existing studies were mostly theoretical and not based on real-life blockchain applications (Chandra *et al*., 2019; Tieman and Williams, 2019). This was confirmed by Rejeb *et al*. (2021), who state that theoretical and conceptual publications dominate new research fields such as the halal blockchain. Meanwhile, the exploratory research method accounted for 17% of the total, and empirical research methods mostly used modeling and surveying. Mathematical approaches, simulation modeling, and multi-criteria decision making were frequently used, although the rate was low for mathematical modeling, so this area is potentially rewarding for further exploration.

Table 5.
Applied research methods

Research Method		Amounts
1.	Conceptual framework	84
2.	Exploratory research	82
3.	Empirical research	65
4.	Modelling	62
Statistical techniques and tools		
	Partial Least Square	13
	Structural equation modelling	8
	Analysis of variance	3
	Bayesian network	2
	Principal component analysis	2
Decision making techniques and tools		
	Fuzzy logic	10
	ANP	8
	DEMATEL	8
	TOPSIS	7
	AHP	6
	ISM	20
	Best worst method (BWM)	4
	MICMAC	3
5.	Literature review	53
6.	Survey	35

3.3.2 Type of industry and type of benefit

Blockchain application in different industries addresses data integrity, lack of transparency, disruptions, and single points of failure. For example, blockchain application in manufacturing can increase organizational profitability and competitiveness by overcoming the bullwhip effect using the blockchain's real-time information. Table 6 shows the six types of industry where the blockchain has been studied, i.e., manufacturing with 75 articles, healthcare with 61 articles, agriculture with 44 articles, service with 40 articles, logistics industry with 7 articles, and energy industry with 5 articles.

According to Calvão and Archer (2021), manufacturing is the most promising area for industry adoption of blockchain technology. According to Karamchandani *et al*., (2021), the manufacturing industry has a high level of customization and low standardization—custom products are made according to the customers' needs. In this type of industry, the blockchain can improve customer services by evaluating customer expectations and satisfaction. Real-time customer feedback can provide immediate information about areas of improvement.

Meanwhile, in the food, medicine, jewelry, luxury goods, and logistics industries it is the opposite. They have a low level of customization and a high level of standardization. In these cases, the blockchain can provide accurate product quality and prevent counterfeiting, manipulation, and fraud (Kshetri, 2018). In other words, the blockchain can help achieve traceability and transparency in the manufacturing supply chain and ensure consumer confidence in product safety and authenticity.

Meanwhile, blockchain application in healthcare (Chukwu and Garg, 2016) aims to ensure transparency in the manufacture of drugs, track drug distribution, and ensure prescription authenticity. Blockchain technology can also be adopted to improve provider credentials, medical billing, contracts, medical record exchange, clinical trials, and prevent forgery. Additionally, blockchain-based healthcare systems can increase the security and reliability of patient data as patients will have control over their own healthcare records (Hölbl *et al*., 2018).

In terms of company size, according to Ali *et al*. (2021a) the blockchain is currently mostly used by large corporations. Small and medium enterprises (SMEs) are not keen on adopting blockchain technology. In general, adoption of technologies by SMEs is not as rapid as by large companies. Also, they may not have the human resources and infrastructure required (Lim, 2021).

Table 6

Blockchain application studied in various types of industry

Type of Industry		Amount
1.	Manufacturing	75
2.	Healthcare	61
3.	Agricultural	44
4.	Service industry	40
5.	Logistics industry	7
6.	Energy industry	5

Table 7 shows the benefits of blockchain application as summarized from the research. Trust, traceability, transparency, security, and efficiency are the top-five benefits of blockchain application. Trust is one of the most promising advantages of blockchain technology (Weber *et al*., 2016; Nakasumi, 2017), while other benefits are transparency, efficiency, traceability, security (Wang *et al*., 2019). In most research papers reviewed in the current study, trustworthiness, traceability, transparency, and security are the most claimed benefits, as shown in Table 8. This is in line with (Surjandari *et al*., 2021), who state that trust, traceability, and transparency in blockchain technology can improve the halal supply chain by integrating information among supply chain participants, which is open, yet confidential, immutable, and secure.

Table 7:

Benefits of blockchain application in supply chains

Type of benefit		Amount
1.	Increasing trust	157
2.	Enhancing traceability system	154
3.	Increasing transparency	136
4.	Increasing security	119
5.	Increasing efficiency	87
6.	Reducing fraud	38
7.	Increasing accuracy	17
8.	Increasing real time	11
9.	Increasing food assurance	11
10.	Increasing flexibility	10

With blockchain technology, halal certification bodies can improve the trust and authenticity of halal brands (Tieman and Williams, 2019). This is because the blockchain stores copies of all transactions permanently, which cannot be modified (Khan *et al*., 2020; Tian, 2017). In other words, the blockchain sees transactions in real time (Calvão and Archer, 2021) and all product information is stored in a shared and transparent system, establishing a trusted source of information for all (Galvez *et al*., 2018; Mao *et al*., 2019). As suggested by (Tieman and Darun, 2017), with accurate data, supply chain players' performances can be assessed accurately. Additionally, the blockchain can improve efficiency, which lowers operational costs (Lim, 2021). This is accomplished by eliminating the need for multiple verifications, as well as labor/administrative and physical costs (Mansfield-Devine, 2017). The digital documentation and high-speed data flow make the supply chain more efficient (Barnard, 2017).

3.3.3 *Blockchain application in halal supply chains*

This paper also identified previous research on blockchain application in halal supply chains. Table 8 shows the previous studies' purposes and the research methods used. Six articles were case studies, one involved simulation modeling, another one was a statistical study, and the last one was a systematic review. The two most recent papers on blockchain application in the halal food supply chain were by Surjandari *et al*. (2021) and Ali *et al*. (2021a). Surjandari *et al*. (2021) adopted the blockchain framework and determined the critical aspects of blockchain application in halal supply chains using simulation modeling. Ali *et al*. (2021a) proposed a halal food blockchain application framework for small, medium enterprises.

Table 8:
Blockchain application in halal supply chains

No	Author	Year	Purpose of research	Research Method
1	Surjandari et al., 2021	2021	To adopt a blockchain framework and determine key aspects of blockchain application for halal supply chains	Simulation modelling
2	Ali et al., 2021a	2021	To investigate blockchain opportunities and potential in a halal supply chain business model, as well as to investigate halal food practices of SMEs and challenges faced in adopting blockchain, and then to propose a halal food blockchain challenge framework for SMEs	Case study
3	Kirchner, 2020	2020	To describe the interrelationship of cryptocurrencies in sharia law	Case study
4	Calder, 2020	2020	To discuss financial and logistics halalization	Case study
5	Hew et al., 2020	2020	To participate in a blockchain-based halal traceability system through an integrated model consisting of a halal orientation strategy, institutional theory, and innovation diffusion theory	Survey
6	Tan et al., 2020	2020	To develop a conceptual framework for a halal food supply chain with an enhanced traceability system using blockchain technology with Internet of Things (IOT) integration	Case study
7	Katuk, 2019	2019	To review by identifying, evaluating, interpreting research and development relevant to the application of blockchain technology for halal product assurance	Literature review

The studies on blockchain application in halal supply chains are shown in Table 8. While four articles focused on halal supply chains, others discuss the blockchain in halal certification, halalization, and halal cryptocurrency. Most of them are theoretical, i.e., not based on a real-life application of blockchain technology, so they do not provide empirical evidence on how the proposed solution would play out in real life. On the other hand, Hew *et al*. (2020) examined the transparency and traceability systems of a real-life blockchain-based halal food supply chain. The systems enable end consumers to access complete supply chain information—from the origin to their hands. Likewise, Tan *et al*. (2020) did an empirical study involving three blockchain-based halal food companies, Haladinar (Haladinar.com), FoodChain (Food-chain.it), and WhatsHalal (WhatsHalal.com) to track and trace the movement, processing, and storage of halal food across the supply chain. Blockchain systems with smart contracts provide halal food traceability, hence improving the halal food supply chain's integrity. Surjandari *et al*. (2021) aimed to improve the halal supply chain using a simulation model approach, i.e., Hyperledger Fabric, in the halal meat industry. As tested in the simulation, blockchain application could secure the transaction data.

Blockchain technology is not only applicable in large-scale industries but can be implemented in SMEs as well. Ali *et al.*, (2021b), for example, investigated the opportunities, impacts, and challenges in adopting the blockchain in halal supply chains. They proposed a framework for the implementation of the blockchain in SMEs. Overall, the research showed that the blockchain can help achieve transparency in the food supply chain, including in SMEs. However, some challenges can hinder its implementation, i.e., complexity, capability, cost, competition, profitability, management of change and external pressures, halal sustainable production, and regulatory failure. These obstacles must be removed to improve the adoption rates of blockchain systems among SMEs. This is particularly important to enhance blockchain implementation in the food supply chain as a whole system.

4 Mapping blockchain application in supply chains

At this stage, the author keywords were mapped to determine research themes and emerging trends. Kim and Chen (2015) argue that this method can capture research themes, as keywords often represent the research concepts. The present research used a clustering method to construct keyword co-occurrence networks using the VOSviewer software. The research topics were also revealed based on the rate of keyword appearance in the last three years. Emerging issues were determined in Quadrant 3 of the strategic diagram based on keyword centrality and density. Cobo *et al*. (2011) divided the centrality and density results into four quadrants based on the keyword database. The following sub-section describes the keyword analysis before the clustered research themes and emerging topics are presented.

Table 9:
Top-thirty most frequently used keywords

No	Author Keyword	2016	2017	2018	2019	2020	2021	2022	Total
1	Blockchain	0	13	37	130	259	345	4	788
2	supply chain	0	3	17	42	115	148	1	326
3	smart contract	0	0	6	23	42	49	1	121
4	internet of things	0	4	8	12	37	49	1	111
5	Traceability	1	1	2	13	32	35	1	85
6	Sustainability	0	2	1	9	17	22	1	52
7	industry 4.0	0	2	3	7	8	22	1	43
8	Security	1	1	3	7	4	17	0	33
9	Transparency	0	0	3	5	7	15	0	30
10	food supply chain	0	1	0	4	13	11	0	29
11	Trust	0	0	0	5	9	14	0	28
12	Ethereum	0	1	0	5	6	15	0	27
13	Logistics	0	1	2	2	5	15	0	25
14	literature review	0	1	1	1	8	13	0	24
15	Hyperledger	0	1	1	1	10	8	0	21
16	Privacy	0	1	2	1	7	9	0	20
17	Technology	0	1	0	3	7	9	0	20
18	Healthcare	0	1	1	2	5	10	0	19
19	Bitcoin	0	1	1	3	5	8	0	18
20	covid-19	0	0	0	5	4	9	0	18
21	food safety	0	1	0	2	6	8	0	17
22	Digitalization	0	1	1	1	4	8	2	17
23	circular economy	0	1	0	3	5	7	1	17
24	supply chain finance	0	0	0	2	5	7	0	14
25	Cryptocurrency	0	1	2	2	5	4	0	14
26	machine learning	0	0	0	2	6	5	0	13
27	barriers	0	0	0	1	9	1	0	11
28	cloud computing	0	0	2	0	3	6	0	11
29	information sharing	0	0	0	2	4	5	0	11
30	artificial intelligence	0	0	0	3	2	6	0	11

4.1 Descriptive analysis of the author keywords

The author keywords analyzed in this study are those from papers published from 2016 to 2021. Keywords with the same meaning were combined. For example, ‘supply chain’ and ‘supply chains’; ‘supply chain management’ and ‘management with blockchain technology’, ‘distributed ledger’, and ‘distributed ledger technology’. There were 2,159 keywords listed, with ‘blockchain’ being the most used keyword (788 times), followed by ‘supply chain’ (326 times), ‘smart contract’ (121 times), ‘Internet of things’ (IoT) (111 times), ‘traceability’ (85 times), and ‘sustainability’ (52 times). Table 9 summarizes the thirty most frequently used keywords, which increased significantly from 2017 to 2021. This is in line with the study by Moosavi *et al*. (2021), in which the most occurring keywords were ‘blockchain’, ‘supply chain’, ‘internet of things’, ‘smart contract’, and ‘traceability’.

4.2 Research themes

The clustering aimed to group articles based on the keywords (Nobanee *et al*., 2021). A co-occurrence network was used to map the keywords as shown in Figure 3. With VOSviewer and a threshold of at least five occurrences for each keyword, the keywords were classified into seven significant clusters. The most prominent nodes were on ‘blockchain’ and ‘supply chain’ because they were the terms used to search the Scopus database. The second and third largest nodes were ‘smart contracts’ and ‘Internet of Things,’ referred to as Cluster 2, which indicates that they can contribute individually or be integrated with the blockchain in supply chains. Meanwhile, ‘traceability’ was captured by the fifth largest node, which suggests that it can be implemented in supply chains using blockchain technology (Feng *et al*., 2020).

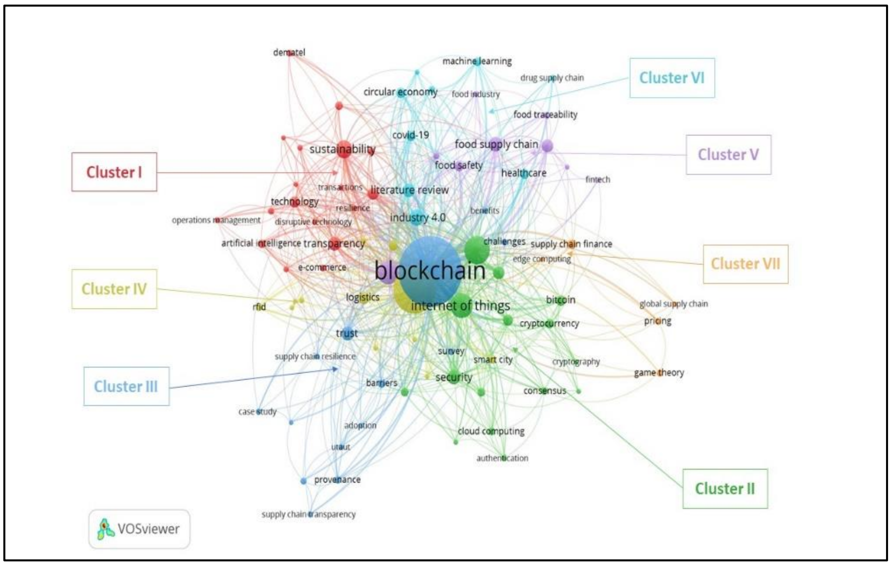

Figure 3. Main clusters of the keywords based on co-occurrence mapping.

Cluster 1 focuses primarily on sustainability and transparency, with the most used keywords being ‘sustainability’, ‘transparency’, and ‘technology’. These three keywords are interconnected. Transparency can increase sustainability (Badzar, 2016; Tian, 2017), and achieving both sustainability and transparency requires the application of new technologies such as blockchain (Park and Li, 2021) and artificial intelligence (Ebinger and Omondi, 2020). The application of advanced technologies in supply chains that can integrate actors will increase transparency, sustainability (Bai and Sarkis, 2020), and boost competitive advantage (Mugurusi *et al*., 2021).

Cluster 2 is concerned chiefly with smart contracts and IoT. A smart contract can be carried out using applications to reach a consensus among supply chain partners (Khanfar *et al*., 2021). It can be integrated with blockchain technology individually or combined with IoT to allow access, to share and verify information securely, as the data is protected by advanced cryptography (Chen and Bellavitis, 2020). Cloud computing can also improve blockchain application by strengthening cyber security and protecting privacy (Chen and Bellavitis, 2020).

In Cluster 3, the keywords were linked to 'blockchain' without exception. Keywords close to 'blockchain' were 'trust', 'benefits', 'surveys', and 'challenges'. The keyword 'trust' was the second most occurring keyword after 'blockchain'. This is similar to the findings of Bai and Sarkis (2020), who state that the blockchain can increase trust and transparency among supply chain partners.

Cluster 4 represents 'supply chain', 'logistics', and 'big data'. The use of big data in supply chains and logistics can solve challenges and problems (Sandarakani *et al*., 2021) as it makes various aspects of the supply chain responsive (Zhang *et al*., 2020) and achieves greater transparency (Talwar *et al*., 2021). In the agri-food supply chain sector, the use of big data has been increasing (Kamble *et al*., 2020) to reduce food waste, monitor products in real time, and minimize scalability problems.

Cluster 5 describes the relationship between 'traceability' and 'food supply chain'. Traceability is a critical factor in ensuring food safety throughout the supply chain (Yu *et al*., 2020) and also food security (Scholten *et al*., 2016). In the food industry, ensuring food safety requires accurate and reliable data storage (Iftekhar and Cui, 2021). Blockchain application with a consortium system can track the communication between participants and require data storage improvement (Bragadeesh and Umamakeswari, (2020).

Cluster 6 represents the correlation between 'Industry 4.0' and 'circular economy'. In recent years, the development of Industry 4.0 and the circular economy has increased significantly along with the rising digital transformation (Rosa *et al*., 2020). Industry 4.0 automates the sector by combining artificial intelligence and machine learning capabilities repeatedly and systematically (Tavera Romero *et al*., 2021).

Cluster 7 focuses on supply chain finance, which includes 'pricing', 'edge computing', 'global supply chain', and 'game theory'. The keywords 'edge computing' and 'pricing' dominate this cluster. 'Game theory' and 'global chain' did not show a strong link, but 'pricing' had a strong correlation with 'game theory' because it is often synonymous with pricing.

Research trends were also determined based on increasing occurrences of the keywords in the 629 articles. Figure 4 shows the trends of the top-thirty keywords each year from 2016 to 2021. Five keywords that showed a significant increase in the last three years were 'IoT', 'smart contract', 'traceability', 'sustainability', and 'Industry 4.0'.

4.3 Strategic diagram analysis and emerging topics

4.3.1 Strategic diagram analysis

Strategic diagram analysis can identify research topics based on the centrality and density of keywords (Callon *et al*., 1991). Cobo *et al*. (2011) visualized the centrality and density in a two-dimensional strategic diagram with four quadrants. Research topics in Quadrant 1 (Q1) represent the specialty's motor themes with strong centrality and high density. Quadrant 2 (Q2) represents specialized and peripheral topics with well-developed internal links and irrelevant external links. Research topics in Quadrant 3 (Q3) represent emerging or declining themes with low density and low centrality. Research topics in Quadrant 4 (Q4) represent general and basic topics in the research field.

Four metrics are used to represent the centrality and density to determine the types of quadrants in the strategic diagram, such as total link strength (TLS), occurrence (OCC), average publication year, the logarithmic value of TLS (Log TLS), and logarithmic value of OCC (Log OCC). Based on the density and centrality calculation, the values of average publication year, log TLS and log OCC were 2020.118, 1.462, and 1.044, respectively. Figure 5 shows the strategic diagram with the X-axis as the centrality measure, represented by the values of Log TLS, and the Y-axis as the density measures, denoted by the Log OCC value.

In Quadrant 1 (the specialty's motor themes), the centrality and density values are high, indicating that the research topics in this quadrant are well defined and developed over a long period of time by the research community (Kastrin *et al*., 2021; López-Robles *et al*., 2019). In Quadrant 1, there are 21 keywords located in all clusters (Cluster 1 to Cluster 6), such as 'sustainability' in Cluster 1, 'IoT' and 'smart contracts' in Cluster 2, 'trust' and 'blockchain' in Cluster 3, 'logistics' and 'big data' in Cluster 4, 'traceability' and 'food safety' in Cluster 5, 'Industry 4.0' and 'COVID-19' in Cluster 6. Five keywords out of 21 in the specialty's motor themes group are well-developed and form the foandation of blockchain studies, i.e., 'smart contracts', 'IoT', 'traceability', 'blockchain', and 'Industry 4.0'.

In Quadrant 2 (specialized and peripheral topics), the centrality value is low, while the density is high, representing research topics that have relevant keywords but are not important enough to be considered in the research field (López-Robles *et al*., 2019). In Quadrant 2, keywords are located in Clusters 4, 6, and 7, such as 'bibliometric analysis' in Cluster 4, 'machine learning' in Cluster 6, and 'supply chain finance' in Cluster 7. Two keywords out of thirty are specialized and peripheral, i.e., 'supply chain finance' and 'machine learning'.

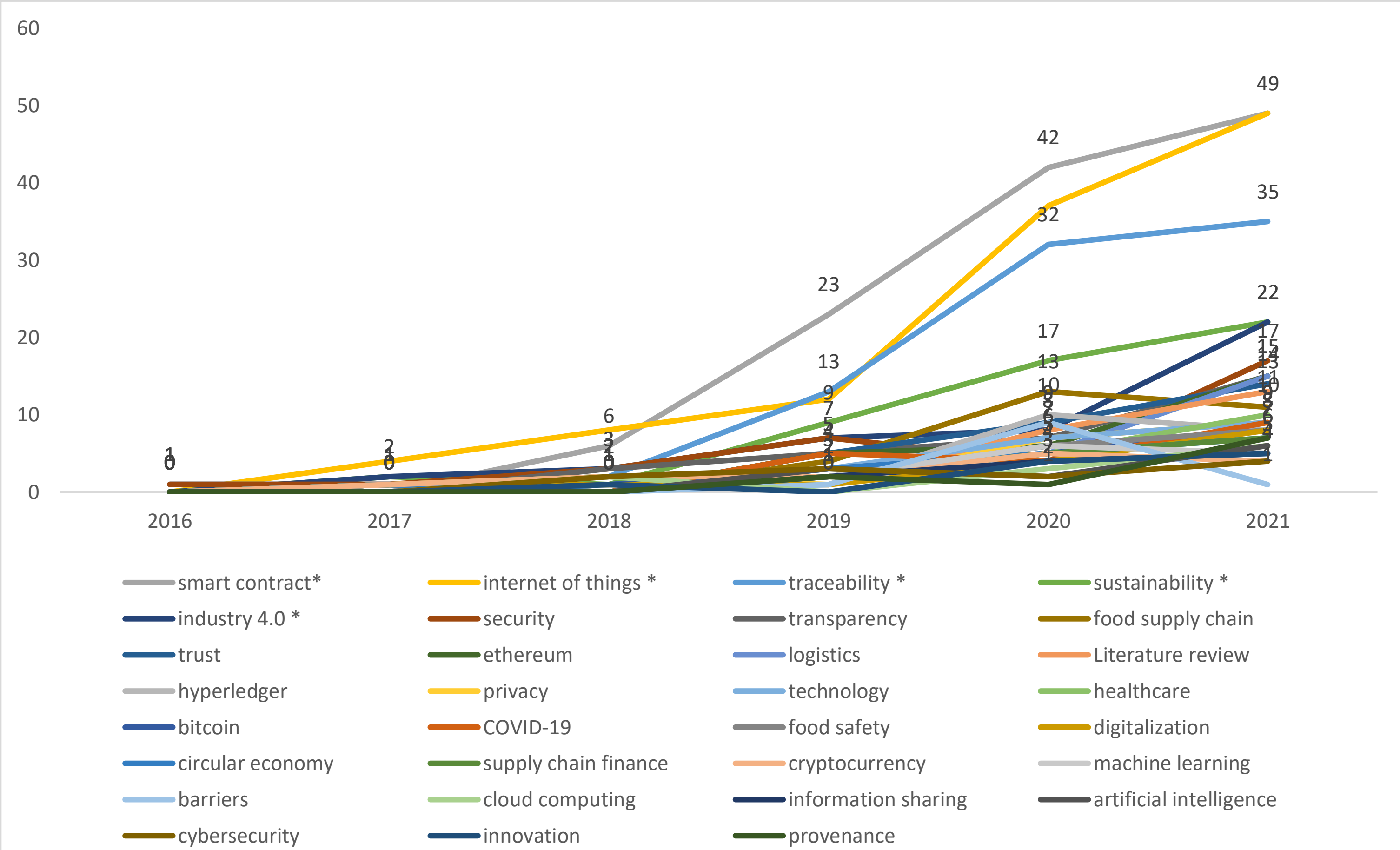

Figure 4. Research topic trends in blockchain application research based on author keywords.

In Quadrant 3 (emerging or declining topics), the centrality value is low, while the density is not centralized but well-developed and related to new research topics (Jafari Roodbandi *et al.*, 2021; Kim and Chen, 2015; López-Robles *et al.*, 2019). There are eighteen keywords located in Clusters 1, 2, 3, 5, 6, and 7, i.e., 'additive manufacturing' and 'transparency' in Cluster 1, 'decentralization' and 'information sharing' in Cluster 2, 'benefits' and 'technology adoption' in Cluster 3, 'food industry', and 'food security' in Cluster 5, 'agricultural supply chain' and 'digital transformation' in Cluster 6, 'edge computing' and 'pricing' in Cluster 7.

In Quadrant 4 (general and basic topics), the density value is low, while the centrality value is high, which means that keywords in this quadrant are general and basic (Della Corte *et al.*, 2019), have been widely used by the research community, but could be difficult to develop (Nasir *et al.*, 2020). There are five keywords in Clusters 1, 2, 4, and 5, i.e., 'artificial intelligence' in Cluster 1, 'cyber security' and 'cloud computing' in Cluster 2, 'smart city' in Cluster 4, 'scalability' in Cluster 5.

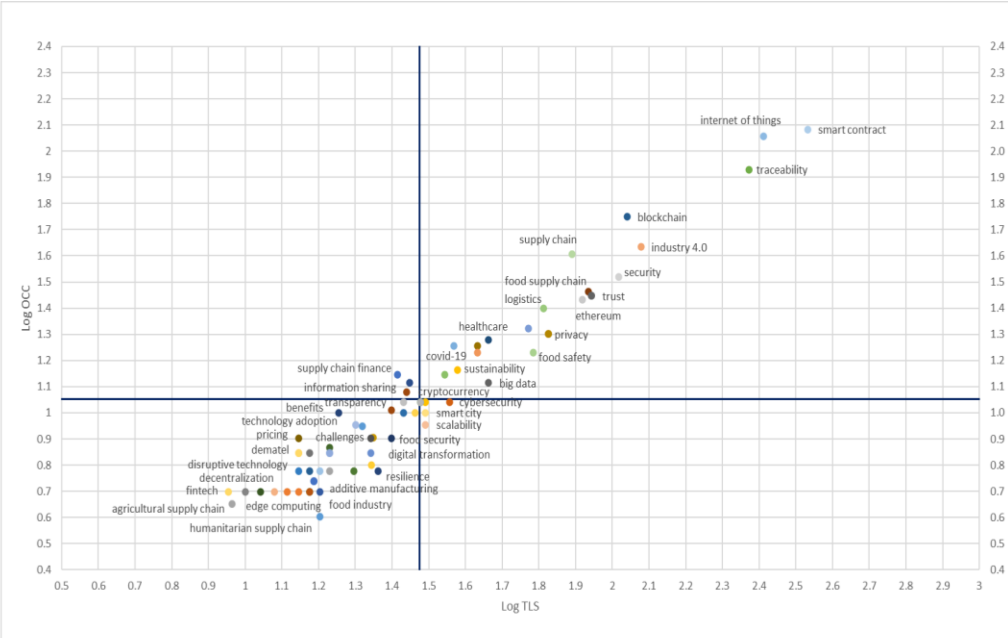

Figure 5: Strategic diagram.

4.3.2 *Emerging research trends*

We focused on Quadrant 3 in the strategic diagram to determine emerging and declining research topics. Table 10 shows the emerging and declining research topics from the 35 keywords in Quadrant 3. The results show that there were 18 (51%) emerging research topics of blockchain application in food supply chains, and 17 (49%) declining research topics.

5 Concluding remarks and limitations

This paper reviewed previous studies on blockchain application in food supply chains as reported in Scopus-indexed articles published from 2016 to 2021. In total, 629 academic papers and 2,322 keywords were analyzed using bibliometric analysis (VOSviewer software) and strategic diagram analysis. The annual number of publications grew significantly from 2016 to 2021. The leading journal was *Sustainability* (Switzerland). Kshetri's (2018) articles had the most frequent citations, while Saberi *et al.* (2019) had the highest citation rates per year. The visualization of the research themes based on the keywords showed that there were seven main clusters, i.e., (1) sustainability and transparency, (2) smart contract and IoT, (3) blockchain, (4) supply chain, logistics and big data, (5) traceability and food supply chain, (6) Industry 4.0 and circular economy, and (7) supply chain finance. The emerging research trends in each cluster were determined, e.g., in the sustainability and transparency clusters, the keywords were 'resilience', 'digital supply chain', and 'transparency'.

Table 10:
Emerging and declining research topics in Quadrant 3 of the strategic diagram

No	Keyword	TLS	OCC	Avg. pub (Year)	Log TLS	Log OCC	Q3 Emerging (>2020.118)	Q3 Declining (<2020.118)
1	Additive Manufacturing	16	11	2020.320	1.18830	0.73860	√	
2	Adoption	14	5	2019.800	1.14613	0.69897		√
3	Agricultural Supply Chain	11	9	2020.500	0.96471	0.65051	√	
4	Authentication	16	4	2019.833	1.20412	0.60206		√
5	Benefits	18	6	2020.500	1.25527	0.77815	√	
6	Case Study	18	15	2019.938	1.22970	0.86620		√
7	Challenges	22	7	2020.429	1.34242	0.84510	√	
8	Consensus Algorithm	23	13	2019.989	1.34332	0.80103		√
9	Cryptography	16	5	2019.400	1.20412	0.69897		√
10	Decentralization	10	5	2020.600	1.00000	0.69897	√	
11	DEMATEL	14	7	2020.429	1.14613	0.84510	√	
12	Digital Transformation	27	36	2020.278	1.34926	0.90490	√	
13	Disruptive Technology	14	6	2020.500	1.14613	0.77815	√	
14	Drug Supply Chain	15	5	2020.000	1.17609	0.69897		√
15	E-Commerce	17	7	2019.571	1.23045	0.84510		√
16	Edge Computing	12	5	2021.400	1.07918	0.69897	√	
17	Fintech	9	5	2020.200	0.95424	0.69897	√	
18	Food Industry	16	6	2020.333	1.20412	0.77815	√	
19	Food Security	25	8	2020.250	1.39794	0.90309	√	
20	Food Traceability	22	8	2019.750	1.34242	0.90309		√
21	Game Theory	14	8	2020.000	1.14613	0.90309		√
22	Humanitarian SC	11	5	2020.400	1.04139	0.69897	√	
23	Information Sharing	27	11	2020.182	1.43136	1.04139	√	
24	Innovation	29	10	2019.889	1.46240	1.00000		√
25	Operations Management	15	5	2020.000	1.17609	0.69897		√
26	Pricing	15	7	2020.750	1.17609	0.84510	√	
27	Provenance	27	10	2019.800	1.43136	1.00000		√
28	Resilience	21	12	2020.500	1.29553	0.77815	√	
29	RFID	20	9	2019.889	1.30103	0.95424		√
30	Supply Chain Integration	13	5	2019.200	1.11394	0.69897		√
31	SC Performance	17	6	2019.667	1.23045	0.77815		√
32	Technology Adoption	25	44	2020.210	1.31847	0.94837	√	
33	Transactions	23	6	2019.833	1.36173	0.77815		√
34	Transparency	39	42	2020.160	1.39830	1.01110	√	
35	Utaut	15	6	2019.830	1.17610	0.77820		√

The limitation of this review was that it involved only articles published between 2016 and 2021, collected from a single database. With the growing trend over the past five years, research on supply chain blockchain and halal blockchain will likely continue to grow. Therefore, we recommend that this research will be repeated in the future. Future research will also benefit from including other academic publications such as proceedings, conferences, books, and trade magazines.

New models based on decision-making and mathematical approaches are needed in the future to ensure that blockchain application in the food supply chain can improve sustainability, transparency, and business resilience. Future research could focus on the role of blockchain application in supporting supply chain digitalization, IoT, and Industry 4.0. Meanwhile, halal supply chains involve unique critical points and operations because they need to be guided by a halal assurance system. The challenges, adoptions, benefits, and barriers of blockchain application in halal supply chains could be another direction for future research.

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