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IoT based climate smart agriculture succeeded by blockchain database—A bibliometric analysis

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Modern-day agriculture is vital for sustainable production, ensuring a consistent supply of food and fiber for humanity. The data proving its quality is economically significant, encompassing farm conditions, irrigation practices, inventories, contracts, and deals within the agro-food supply sector. To ensure transparent and secure data transfer and storage, a trustworthy interconnected databank is essential for all concerned authorities and contributors. The integration of Internet of Things (IoT) in agriculture with blockchain technology offers an unparalleled solution. This combination serves as a distributed ledger, ensuring transparent and secure management of critical environmental and supply chain data. The IoT-based blockchain infrastructure enhances agricultural sustainability and environmental monitoring. It is anticipated that this technology will become increasingly accurate and effective in addressing persistent challenges in the agro-food sector. This bibliometric analysis reviews and synthesizes relevant literature from the Scopus database, highlighting the growth and trends in IoT and blockchain research applied to precision agriculture. The study reveals a remarkable 47.58% annual growth rate in research within this field, starting with only three published documents in 2019 and peaking at 21 in 2022 and 20 in 2024. Globally, China and India lead in publication output, collectively accounting for 62% of the articles. In terms of citations, India ranks highest with 550 total citations, followed by Italy with 431 citations during 2019–2024. This comprehensive study serves as a valuable reference for understanding the research trends and growth in IoT and blockchain applications in agriculture, providing critical insights for future developments in this rapidly evolving field.

KEYWORDS

Scopus, IoT, agriculture, blockchain, bibliometric

1 Introduction

Humanity has always relied on the food, fiber, and other commodities produced by farmers. In modern times, human civilization has become multifaceted especially in recent millennia, due to factors such as the rising populace and its increasing demand for resources beyond its carrying capacity. The insufficient cultivable soil to meet food demands puts direct stress on natural capital (Jones et al., 2017; Sellami et al., 2019). These issues are exacerbated by universal environmental changes that will lead to several alterations globally. Feeding the global population, protecting natural resources and adopting active approaches to deal with the changing environment remain significant challenges (Calia et al., 2024).

Despite these challenges, modern agricultural practices leveraging computer-based technologies have markedly enhanced global agriculture. Technologies such as IoT, blockchain, and distributed ledger systems are instrumental in striving to accomplish the ambitious goals set by policymakers for the near future (Pranto et al., 2021). Recently, agricultural environment monitoring has been achieved using a wide array of IoT-built techniques, such as remote control observation of the farm environment and sensor-equipped devices facilitated by smartphone applications. IoT-based techniques have also been widely used to improve irrigation methods and agricultural water management schemes (Sylvester, 2019).

For instance, smartphone applications for estimating soil humidity and meteorological conditions via online evapotranspiration forecasting apparatus hold vital significance. Developing an IoT-based structure to detect soil humidity, pH and nutrients proves beneficial in modern agriculture (Van Wassenaer et al., 2021). Similarly, wireless sensor network algorithms with dynamic coverage-cast tree algorithms in orchid greenhouses are used for high-precision cultivation (Sajja et al., 2023). These agricultural environment monitoring systems provide standard data that decision-makers and resource managers can use for scheduling and planning (Paulchamy et al., 2021).

However, fraudulent activities by stakeholders, farmers, NGOs, customers, and policymakers, can manipulate actual data by inputting disproportionate information (Distor et al., 2023). By sharing database control with many players and constructing systems widely, data manipulation becomes challenging and impossible, thereby enhancing data reliability and accuracy (Kamilaris et al., 2019). To achieve this, IoT-based techniques coupled with blockchain frameworks are the next step. Blockchain technology, derived from the terms block and chain, involves blocks interlinked via encryption methods used for evidence storage and recovery (Singh et al., 2024). This technology improves data transparency and immutability making it resistant to manipulation and fraud.

Blockchain's competitiveness and cost effectiveness can also assist various transactions as a democratizing basis for a structure of distributed setups (Demestichas et al., 2020). Using IoT-blockchain integrated technology, observed data is deposited in a distributed cloud providing a foundation for democratized, programmed, and transparent data management (Linsner et al., 2019). This transparency, immutability and reliability allow for the verification and tracking of data from source to sink (Bermeo-Almeida et al., 2018). Blockchain technology provides security via decentralization, making data less susceptible to damage and alteration compared to centrally managed data (Lin et al., 2017). This immutable data can be used in large datasets, safeguarding the integrity of administrative services.

Blockchain databases are exceptionally useful in developing data-focused smartphone applications that support e-agriculture. Blockchain also addresses the challenge of creating a secure setup for various participating technologies in precision farming (Jothikumar et al., 2021). IoT-blockchain-based agricultural setups are absolute and distributed record management structures that support sustainable agricultural progress (Xiong et al., 2020). Today, numerous smart agricultural prototypes employing IoT and blockchain technology are projected and applied. A lightweight blockchain-centered design for a small greenhouse includes IoT sensors managed centrally by the greenhouse owner (Tran et al., 2021). Companies have developed smart hardware devices that can be used with existing apparatus via USB ports for secure blockchain transactions, linking physical items and networks through smart agriculture skills (Awan et al., 2020). Blockchain technology is also used by agricultural groups to streamline their farming activities. For example, irrigation organizations in Taiwan use blockchain to record and share information cooperatively within the community (Biswas et al., 2021).

The primary objective of this bibliometric analysis is to explore and examine existing literature related to the integration of blockchain applications in agronomic practices. This study aims to identify major trends, modern themes and leading contributors in the field, providing a comprehensive summary of the current state of knowledge. By analyzing publication productivity, citation trends and cooperation networks, the bibliometric analysis seeks to uncover aspects of the research landscape, highlight innovations and identify potential research gaps in the literature.

2 Materials and methods

A quantifiable bibliometric investigation on IoT and blockchain infrastructure for climate-smart agriculture coupled with the agro-food supply chain was carried out in 2024. This study aimed to synthesize existing literature related to this evolving theme and was structured around four key methodological steps: a comprehensive search scheme, inclusion and exclusion criteria, information extraction and data quantification (Sumarsono et al., 2024).

The initial phase involved an extensive search for published literature pertinent to the topic. To effectively navigate the vast and multidisciplinary nature of the research area, the Scopus database was chosen as the primary resource for locating relevant documents from 2016 to 2024. Scopus is recognized for its extensive and diverse collection of publications focusing on the integration of blockchain and agriculture, establishing it as an optimal choice for this study (Dasaklis et al., 2022).

This specific time frame, from 2016 to 2024, was selected to capture the significant advancements and implementations of blockchain technology across various sectors, particularly agriculture. By concentrating on this interval and leveraging the capabilities of the Scopus database, the present study aims to validate the latest and most impactful scholarly contributions related to blockchain utilization in agriculture. Consequently, research articles published in English during this period were retrieved using defined search terms and filters to ensure the relevance and quality of the data extracted.

TITLE-ABS-KEY ("IOT"* OR sensors OR devices OR instruments AND "AGRICULTURE"* OR precision farming or climate smart agriculture or cultivation or cropping or soil moisture or wind speed or irrigation or temperature or irrigation or fertil* or pH or crop diseases or productivity AND "BLOCKCHAIN"* OR agro-food traceability or supply chain or tracking or hash or smart contract) AND LANGUAGE (English)

AND PUBYEAR >2016 AND PUBYEAR <2025 AND DOCTYPE (ar or re)

This search string was meticulously constructed to capture the full scope of recent research at the intersection of these cutting edge technologies. As shown in Table 1, three components i.e., IoT, agriculture and blockchain were chosen for their unique contributions to advancing sustainable, technology-driven agricultural practices. To comprehensively address IoT applications, keywords such as sensors, devices and instruments were included to reflect the diverse technologies active within agricultural systems, particularly in data collection, automation, and system optimization.

TABLE 1 Components used for Scopus screening.

S#	Component	Abbr.	Explanation
1	Internet of Things	IoT	Kevin Ashton, in 1999, pioneered the term "Internet of Things" (IoT). IoT, often called the "smart internet" links physical objects to facilitate the exchange of information, enabling specific tasks and collective responsibilities through seamless data transmission (Son et al., 2019).
2	Agriculture	Agri.	Agriculture encompasses techniques for smart and sustainable production, providing food and fiber for humanity (Sarkar et al., 2020).
3	Blockchain	BLC	Blockchain is derived from "block" and "chain" where blocks are interconnected through encryption, serving as a secure method for data storage and retrieval. This technology enhances data transparency and immutability, preventing data loss (Saraji, 2023).

In parallel, expressions related to agriculture, such as soil moisture, irrigation, temperature etc. were selected to represent critical aspects of climate-smart and precision farming. This ensured the inclusion of research focused on IoT's role in monitoring environmental conditions and improving sustainable practices across various crops and agricultural settings.

For blockchain, terms like traceability, supply chain, hash etc. were chosen to emphasize blockchain's capacity to enhance transparency, traceability and automation through smart contracts. This selection captured blockchain's role in ensuring data reliability and strengthening agricultural value chains, thereby promoting sustainable agricultural practices. Overall, the combination of these search terms created a broad yet targeted review framework that aligns well with interdisciplinary studies integrating IoT, agriculture and blockchain, with a focus on impactful applications in sustainable agriculture.

Given the evolving nature of this field, we find out limited peer-reviewed literature. Primarily, 183 papers were retrieved from Scopus by using the search string stated above, however no articles from 2016, 2017 or 2018 fulfill our standards of methodological objectivity or relevance to the developing research landscape. This initial screening step was vital to check that only studies with a flawless and appropriate focus on IoT, blockchain, and agriculture integration moved to further stages of evaluation.

The filtering development began with a preliminary exclusion of 62 articles based on titles and abstracts that did not line up with the thematic scope of our study. These studies were excluded because they either lacked a significant focus on the integration of IoT, blockchain, and agriculture or offered an indirect approach that did not address the fundamental goals of climate-smart agriculture and agro-food supply chains. This stage refined our dataset to take account of the studies with direct relevance hence setting a robust foundation for succeeding quality valuations.

In the following quality assessment, we used rigorous criteria to keep stability, relevance and scholarly consistency within the remaining records. Papers were excluded if variations were found between the title, abstract and methodology, which often advocated misalignment or superficial engagement with the core themes (Braun and Clarke, 2023). This step led to the elimination of 17 papers that, even with a primary presence of relevance, lacked depth in addressing IoT, blockchain or agriculture integration. In addition, 10 papers were excluded due to their lack of alignment with the study's central theme, as they focused on blockchain or IoT applications not linked to agriculture or sustainability. For instance, some articles inspected blockchain in finance or IoT in industrial sites, which did not assist profoundly to our exploration of climate-smart agriculture. To further refine the dataset, identical records were recognized and eliminated using R version 2024, 4.4.1 (Hidayat et al., 2024), along with manual verification. This step facilitated remove redundancy, avoiding an over-representation of particular article and certifying the distinctiveness and genuineness of our dataset.

Finally, we attained a refined set of 84 high-grade documents, predominantly obtained from impact-factor journals, highlighting our commitment to precision and trustworthiness as shown in Figure 1. These selected studies indicate significant contributions to the field, proposing authenticated methodologies, important

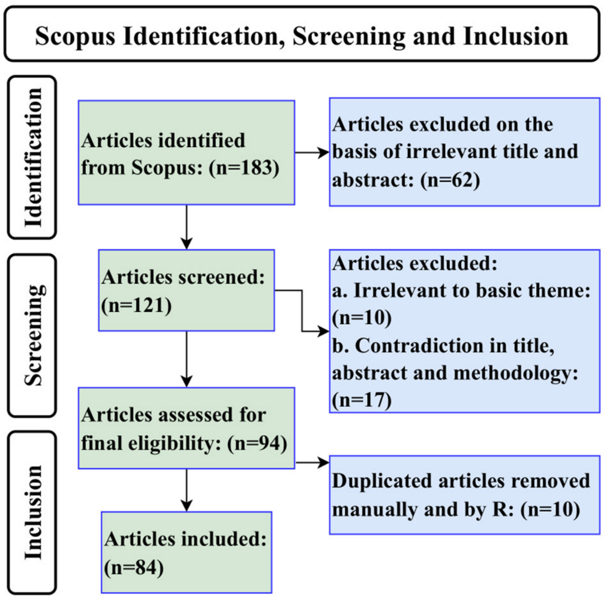

FIGURE 1
Flow chart representing Scopus identification, screening and article's inclusion.

TABLE 2 Overview of article's type and theme.

	Type		Theme		
	Research	Review	Precision agriculture	Food supply chain	Data security
Count	65	19	22	35	27

findings, and high relevance to our research theme. To enable a detailed investigation of these studies, we mined key metadata from each article, including authors' names, publication year, citation statistics, and keywords. This data allowed us to recognize developing patterns and trends, emphasizing major contributions within the field. For systematic numerical and scientific mapping, we used the bibliometric package in R, which presented an organized overview of the research landscape. Moreover, we engaged VOS viewer version 1.6.20 (Stea et al., 2023) for conceptual structure analysis, which shown thematic clusters and interconnections within the carefully chosen literature, providing deeper understandings into the developing scope of IoT and blockchain applications in climate-smart agriculture.

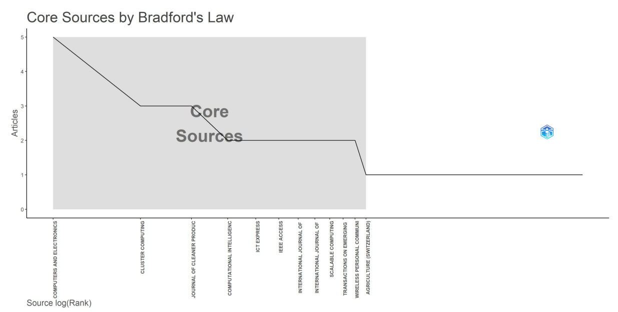

FIGURE 2
Articles source analysis by Bradford's Law (Ganjihal et al., 2022).

3 Results

3.1 Article's type, theme and source analysis

For this bibliometric analysis, a total of 84 significant documents focusing on "IoT-built blockchain practices utilized in agriculture" were identified from 68 different academic journals and related sources. This collection included 65 research articles and 19 review papers, offering a comprehensive view of the current state of research. The exploration of basic themes within these documents revealed that 35 articles pertained to the food supply chain, underscoring the critical role of blockchain and IoT technologies in enhancing transparency and efficiency within agricultural logistics. Additionally, 27 articles focused on data security, highlighting concerns and advancements related to safeguarding information in agricultural practices. The remaining 22 articles addressed precision farming, reflecting ongoing research into optimizing agricultural processes through advanced technologies (Table 2).

All selected documents met the eligibility criteria, including the inclusion and exclusion standards established for this study. Among the sources, "Computers and Electronics in Agriculture" emerged as the most prolific, with a total of five publications reflecting its significant role in disseminating research on the integration of IoT and blockchain in agriculture. This journal's focus on technology and its applications in agriculture has positioned it as a leading venue for relevant studies. It was followed by "Cluster Computing" and "Journal of Cleaner Production" each contributing three articles (Figure 2).

3.2 Annual scientific production

The annual scientific production in this research area during 2019–2024 exhibited an overall growth rate of 47.58%. Starting with only 3 research papers in 2019, the number of publications surged to a peak of 21 in 2022 and 20 in 2024 (Figure 3). This substantial increase reflects a growing interest and investment in the integration of IoT and blockchain technologies within agriculture. The sharp rise in publication volume, particularly in 2022 and 2024, suggests that these technologies have gained significant traction and relevance in addressing challenges related to agricultural sustainability and efficiency.

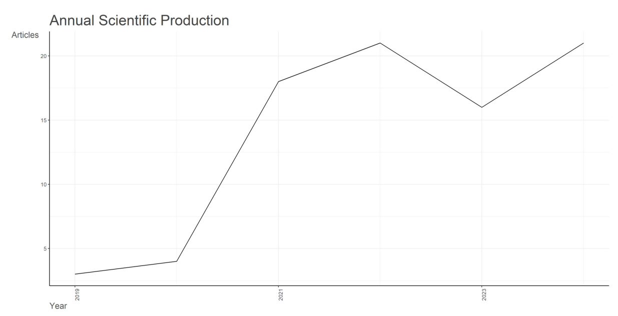

FIGURE 3
Annual scientific production (2019–2024).

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3.3 Most productive countries

The data reveals a strong concentration of research papers on IoT-based agriculture and blockchain technology, with China and India at the forefront, closely followed by Iraq, Pakistan and Saudi Arabia. Between 2019 and 2024, India and China together contribute 62% of global publications in this field, underscoring their central roles in advancing research and development in this area. India, in particular, stands out for its citation impact, with a total of 550 citations and an impressive average of 25 citations per article, highlighting its influential contributions to the research landscape.

Although Italy has produced fewer publications, it demonstrates a substantial impact with an impressive average of 215.50 citations per article, amounting to a total of 431 citations. This suggests that while Italy's research output in this field is smaller, its contributions are concentrated and highly influential. The accompanying visuals (Figures 4, 5) illustrate these trends, showcasing the citation impact and regional leadership of countries driving IoT and blockchain advancements in agriculture. Together, they also highlight the varying strengths of each region, with India and China leading in volume and Italy setting a benchmark for citation quality and influence in this emerging field.

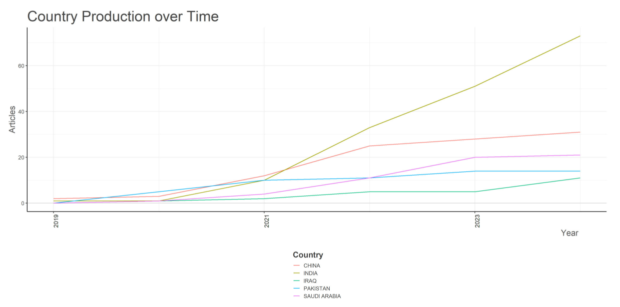

FIGURE 4
Country-wise total publications over time.

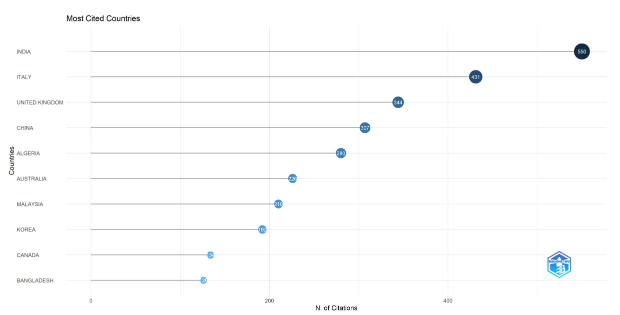

FIGURE 5
Country-wise total citations over time.

3.4 Author's contribution and productivity

Applying Lotka's law (Yılmaz and Yılmaz, 2022) to the dataset of 84 articles, we observe a total of 325 contributing authors, averaging 3.86 authors per paper. This distribution provides insight into the collaborative nature of research in IoT, agriculture and blockchain. Notably, 303 authors (93%) have contributed to only one article over the past five years, indicating a broad but relatively shallow pool of researchers in this area. Conversely, 19 authors (5.8%) have published two articles, demonstrating a moderate level of recurring involvement. Although no authors have published three articles, three authors (0.9%) have achieved four publications within the same time-frame (Figure 6).

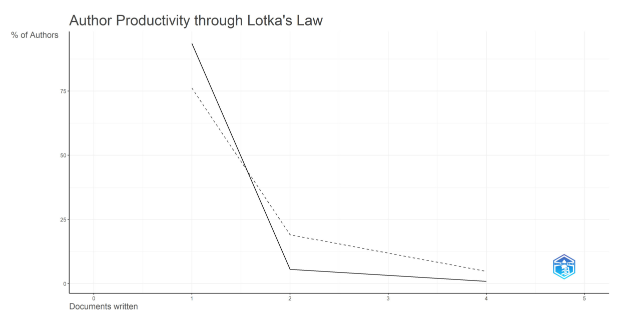

FIGURE 6
Research output analysis by Lotka's Law.

In terms of productivity, an analysis based on publication and citation metrics identified ten authors as the most productive contributors in this domain during the 2019–2024 period. Collectively, these top contributors have published 26 articles, garnering a total of 2,092 citations. Among them, Das AK, Sharma A, and Vangala A from the International Institute of Information Technology Hyderabad, India, stand out, each having published four articles. Their consistent contributions underscore their prominent roles in advancing IoT-based agriculture and blockchain research. Additionally, seven other authors have each published two articles, reflecting their active engagement in this evolving field (Table 3).

3.5 Most relevant affiliations

A total of 31 leading affiliations have been identified for their significant contributions to IoT-integrated blockchain applications in climate-smart agriculture. Nearly one-fourth of these institutions are based in Pakistan and the Kingdom of Saudi Arabia, underscoring the growing regional impact and investment in this emerging field. Among the top contributors, Iqra National University and King Saud University stand out, jointly producing nine articles. Other prominent institutions, such as Nanjing Agricultural University and Taif University, follow closely behind, indicating a diversified international effort.

TABLE 3 Top ten most productive authors over time.

Author	Year	Frequency	Total citations	Citations/ Year
Ahmed S.	2020	1	48	9.60
Ahmed S.	2021	1	65	16.2
Awan SH.	2020	1	48	9.60
Awan SH.	2021	1	15	3.75
Chatterjee K.	2023	2	36	18.0
Das AK.	2021	2	271	67.7
Das AK.	2022	1	77	25.7
Das AK.	2023	1	50	25.0
Ferrag MA.	2020	1	280	56.0
Ferrag MA.	2021	1	344	86.0
Frikha T.	2022	1	16	5.33
Frikha T.	2023	1	17	8.50
Gadekallu TR.	2021	1	134	33.5
Gadekallu TR.	2022	1	66	22.0
Ghorbel O.	2022	1	16	5.33
Ghorbel O.	2023	1	17	26.0
Sharma A.	2022	2	78	26.0
Sharma A.	2023	2	116	58.0
Vangala A.	2021	2	271	67.0
Vangala A.	2022	1	77	25.6
Vangala A.	2023	1	50	25.0
Total		26	2,092	603.2

The data (Figure 7) highlights the production trends of these affiliations over time, revealing a lack of publications in this field prior to 2019, followed by a rapid increase in interest and research output. Institutions such as King Saud University have maintained steady contributions since 2019, whereas others, like the University Institute of Engineering and Technology, exhibited a sharp rise only after 2021. This recent surge reflects an intensified global

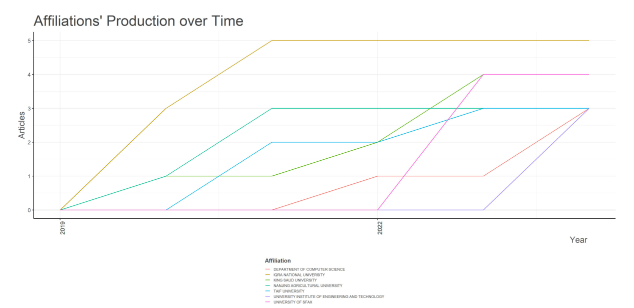

FIGURE 7
Leading affiliations during 2019–2024.

focus on integrating IoT and blockchain into agriculture, with most contributions emerging within the past 5 years. The trends underscore the steady growth and increasing influence of these affiliations in driving forward research on climate-smart agriculture using IoT and blockchain technologies.

3.6 Document citation analysis

Despite being an emerging field, the novelty and significance of IoT-based agriculture and blockchain technology are clearly reflected in the citation rates of related publications. Over time, as this research area has evolved, the average citation rates have improved, indicating growing recognition and impact. The ten most cited publications in this domain have collectively received a total of 2,005 citations, underscoring the substantial influence of key research contributions. These highly cited papers are published in reputable journals with varying impact factors, which play a crucial role in amplifying their visibility and scholarly influence.

For example, the article with the highest citation count, "IoT for the Future of Smart Agriculture: A Comprehensive Survey of Emerging Technologies," published in 2021 in "IEEE CAA Journal of Automatica Sinica" has garnered 344 citations. This journal's high impact factor contributes to the paper's wide dissemination and reflects its significant contribution to advancing the understanding of emerging technologies in smart agriculture. Similarly, other frequently cited articles, such as those in 'IEEE Access and Computers and Electronics in Agriculture' benefit from the high impact factors of these journals, enhancing their reach and impact within the academic community (Figure 8).

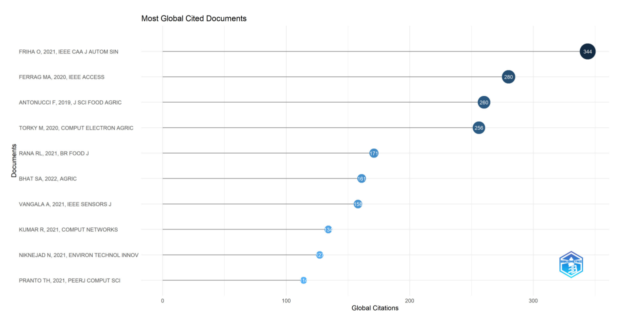

FIGURE 8
Top ten most cited articles over time.

At the lower end of the citation spectrum within these top ten, the article titled "Blockchain and smart contract for IoT enabled smart agriculture" with 114 citations, reflects a more specialized focus. The relatively lower citation count may be partly attributed to its niche subject matter, but it is also likely influenced by the lower impact factor of its publishing journal, "Peerj Computer Science" compared to higher-impact journals like "IEEE Access." This difference highlights the role of journal impact factors in determining citation rates and presents the significance of publishing in high-impact channels for extensive recognition.

3.7 Conceptual structure analysis by VOS Viewer

3.7.1 Detailed interpretation of the co-occurrence network

The VOS Viewer analysis of keywords discloses major thematic clusters that outline significant research areas and evolving trends in the application of IoT and blockchain in agriculture (Figure 9). This network arrangement proposes more than a simple visualization; it offers visions into the fundamental conceptual landscape, displaying how particular research areas are converging and developing over time. Each cluster in the network not only specifies an attentiveness of research interest but also reveals diverse technological and thematic developments that line up with the evolving significances and challenges in agriculture.

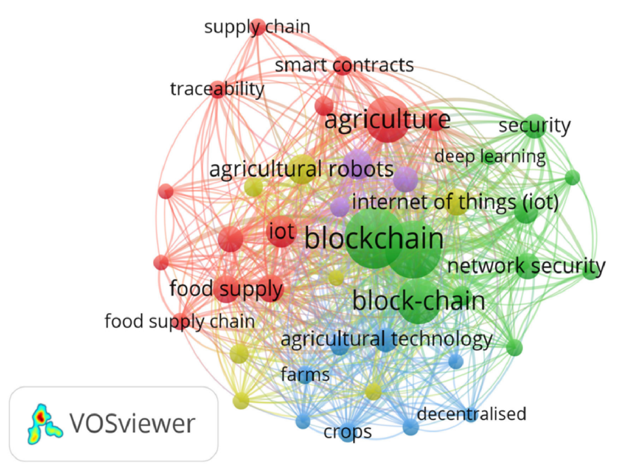

FIGURE 9
Co-occurrence network visualization by VOS Viewer.

3.7.1.1 Red cluster—Supply chain and traceability

This cluster, highlighted in red, includes terms such as "supply chain," "traceability," "food supply," and "smart contracts," indicating a strong research focus on the role of blockchain in enhancing agricultural supply chain management. The proximity of these terms suggests that improving traceability and transparency within supply chains is a central theme in the literature. The inclusion of "smart contracts" within this cluster underscores blockchain's capacity to automate transactions and provide real-time tracking information, facilitating seamless integration across various stages of the supply chain. Moreover, the link between "traceability" and "food supply" emphasizes blockchain's potential to strengthen food security and reduce fraud in the agri-food sector.

3.7.1.2 Green cluster—Blockchain security and IoT integration

The green cluster, marked by expressions like "network security," "deep learning," and "IoT" redirects a robust research attention on the intersection between blockchain security and IoT applications. This thematic assemblage signifies ongoing efforts to address the distinctive security challenges posed by integrating IoT devices with blockchain frameworks, predominantly in agriculture. IoT devices are crucial in agricultural systems for gathering huge amounts of data however they also lead network susceptibilities, making security a chief concern. The presence of "deep learning" in this cluster denotes the integration of AI for foretelling analytics and glitch recognition, which build up the security and trustworthiness of data exchanged across these networks. This cluster thus establishes the merging of blockchain and IoT with a mutual emphasis on security a vital feature for developing strong digital setups in agriculture.

3.7.1.3 Yellow cluster—Agricultural robotics and automation

The yellow cluster, characterized by terms such as "agricultural robots" and "agricultural technology" symbolizes research at the intersection of automation, blockchain and IoT in agriculture. The occurrence of "agricultural robots" in this cluster indicates a swing in the direction of technologically advanced precision farming way out where "blockchain" certifies secure data management and "IoT" devices enable actual data collection. Together, these technologies assist the trend of digital conversion in agriculture, highlighting the significance of competence, security and accuracy in the growing agricultural sector. In connection with preceding clusters, this cluster strengthens the role of blockchain and IoT not only in safeguarding supply chains and improving traceability but also in motivating automation and technological innovation within the agrarian sector.

3.7.1.4 Blue cluster—Decentralization and agricultural practices

Terms like "decentralized," "crops," and "agricultural technology" in this blue cluster highlighting importance of decentralized methods to manage agricultural data and practices. Decentralization is an essential feature of blockchain, which line up with the objectives of democratizing data access and improving resilience in agricultural systems. This cluster represents the role of blockchain in encouraging decentralized data structures, which permit farmers and stakeholders to share data fairly. The decentralization theme signifies a logical swing in agrarian data management, focusing on impartial data distribution and transparency. The inclusion of 'crops' specifies that particular agricultural approaches are increasingly depend on decentralized data bases, which assist sustainable resource management and data availability throughout the agricultural value chain.

3.7.1.5 Purple cluster—Emerging technologies in agriculture

This cluster's inclusion of expressions like "deep learning" and "IoT" indicates a robust emphasis on integrating cutting-edge technologies, such as artificial intelligence and IoT, to enhance agricultural systems. By leveraging these innovative tools, investigators are building upon blockchain's foundational abilities, targeting to enhance data accuracy, predictive analytics, and operating efficiencies in agriculture. The focus on "IoT" and "AI" within this cluster reveals an advancement, where these evolving skills support blockchain's role in transforming agrarian rehearses. Linked to the earlier clusters, this thematic emphasis represents how blockchain not only improves traceability and mechanization but also serves as a platform for integrating AI driven understandings and IoT empowered data gathering, further advancing the digital renovation of agriculture.

3.7.2 Temporal evolution and emerging trends

The temporal overlay visualization in Figure 10 traces the evolution of research topics related to blockchain and IoT within the agriculture sector, illustrating a clear chronological progression from 2021 to 2023. The color gradient, which moves from dark blue to yellow, reflects the flowing focus of research over time, start with an attention on IoT (denoted by dark blue nodes in early 2021) and moving toward blockchain applications in agriculture (green and yellow nodes appearing in late 2022). This timeline highlights a research route that primarily underscored data gathering and automation through IoT before steadily shifting toward secure data management and transaction automation using blockchain.

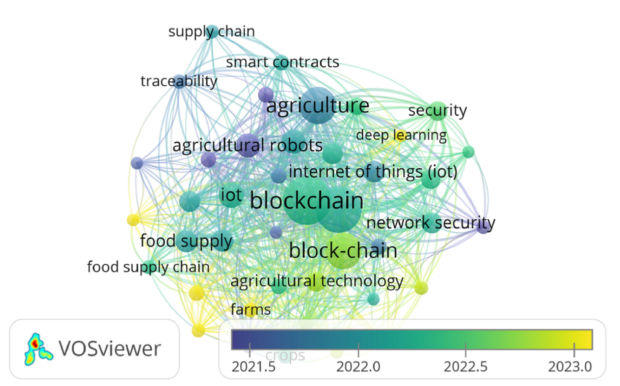

FIGURE 10
Co-occurrence overlay visualization by VOS Viewer.

3.7.2.1 Early focus on IoT (dark blue–early 2021)

In the beginning, research positioned on IoT and related terms like "food supply chain," "traceability," and "supply chain." These early associations highlight the foundational requirement for actual data gathering in agriculture, where IoT devices monitor critical factors such as soil moisture, crop health and weather conditions. This collected data serves as the source for refining decision making developments and improving traceability across supply chains.

3.7.2.2 Transition to blockchain and agriculture (green–late 2022)

As the timeline progresses into 2022, the concentration expands to blockchain, with expressions like "blockchain," "smart contracts," and "network security" evolving more prominently. This change reveals the research group's increasing awareness in leveraging blockchain to tackle challenges uncovered through IoT data, together with secure data management, transparency, and automation. The integration of blockchain certifies data reliability, which is crucial for building confidence within supply chains and mechanizing transactions via smart contracts.

3.7.2.3 Mature focus on integration and security (yellow-2023)

By 2023, the visualization demonstrates a growing emphasis on integration and security, denoted by terms like "agricultural robots," "deep learning," and "network security." This stage indicates a mature phase of research where the merging of IoT, AI and blockchain technologies is essential for attaining well-organized and secure agrarian systems. The occurrence of network security reveals keen thoughtfulness to protecting IoT networks against cyber threats, while deep learning supports in predictive analytics, glitch recognition and precision agriculture. This in depth highlighting on security and automation advocates that investigators are increasingly concerned with the practical execution of IoT and blockchain in agriculture, aiming for systems that are not only advanced but also resilient and secure.

4 Discussion

This bibliometric study provides an in-depth analysis of 84 research papers published between 2019 and 2024, focusing on IoT-based blockchain applications in agriculture. Using bibliometric tools such as R (Admoko et al., 2024) and VOS Viewer (Pooja and Upadhyaya, 2024), the study reveals a marked increase in scientific publications in this field, indicating growing interest and advancements in the integration of IoT and blockchain within agricultural practices. This expansion reflects a global response to the need for enhanced agricultural efficiency, transparency and sustainability through technological innovations.

From 2019 to 2024, the majority of publications emerged from China and India, accounting for 62% of the research output. India, with 550 citations, leads in scholarly impact, followed by Italy, which accumulated 431 citations. These numbers highlight the prominence and influence of research institutions and authors in these countries, contributing significantly to the academic understanding of IoT and blockchain applications in agriculture. This high citation impact suggests that the research outputs are well-regarded and have shaped the discourse in the field (Zhang and Wang, 2017).

A notable finding is the limited global collaboration in this area, which could hinder the development of a unified research landscape. Lack of international partnerships often leads to isolated research efforts, resulting in potential redundancies and missed opportunities for comprehensive insights (González-Mendes et al., 2024). Limited funding and divergent research priorities are likely barriers to collaboration, as national funding agencies tend to favor domestic projects (Kumari and Agarwal, 2024). Addressing these challenges could involve increasing support for transnational initiatives and establishing standardized research methodologies, which may foster more robust and impactful advancements in IoT and blockchain applications in agriculture.

In examining research journals, "Computers and Electronics in Agriculture" emerged as a leading source, publishing the majority of articles in this field. The presence of IoT, agriculture and blockchain research across journals with varying impact factors reflects a wide spectrum of perspectives and interests. High-impact journals provide authoritative insights, while lower-impact journals introduce emerging viewpoints and innovative approaches, enhancing the field's diversity (Safeer and Pulvento, 2024). Such a range of sources allows for a more holistic view of the evolving research landscape and fosters a balanced understanding of both established and nascent trends. Moreover by including impact factor considerations, this analysis offers a more nuanced understanding of the citation landscape in IoT-based agriculture and blockchain research, demonstrating how journal status and article relevance contribute to shaping scholarly inspiration (Baber et al., 2024).

The thematic evolution identified through co-occurrence analysis reveals shifts in research focus within IoT and blockchain applications in agriculture. Early studies (2019–2021) primarily explored IoT and blockchain integration, while recent research has expanded to include machine learning for climate-smart agriculture (Christian et al., 2024). This shift may be attributed to advancements in blockchain infrastructure, allowing for more complex applications. Climate change concerns have further driven interest in precision farming and resilient food supply chains, with IoT and blockchain applications increasingly tailored to address these challenges. This progression underscores the field's adaptability and its alignment with global priorities for sustainable agriculture (Doukas et al., 2023).

Despite progress, specific research gaps remain, particularly regarding IoT-blockchain integration for climate-smart agriculture. Few studies provide practical implementations and many lack in-depth analyses of scalability and cost-effectiveness in real-world settings. Future research should prioritize field-testing these technologies in diverse agricultural contexts, evaluating their feasibility, impact on productivity and environmental sustainability. Interoperability of IoT and blockchain systems also requires further exploration to establish seamless data-sharing networks, benefiting stakeholders across the agricultural supply chain. Creating standardized frameworks for data protocols could improve consistency, comparability and foster international collaboration.

The findings of this study have practical implications for agricultural stakeholders, including policymakers, farmers and agribusinesses. Policymakers are encouraged to support IoT and blockchain research through targeted funding and incentives, promoting global collaboration. For farmers and agribusinesses, integrating these technologies offers potential benefits in transparency, traceability and resource efficiency, aiding in informed decision-making and optimized production. Collaborations between stakeholders and technology developers can facilitate the adoption of IoT and blockchain for sustainable, traceable agricultural practices.

For future research, a focus on developing scalable, low-cost IoT-blockchain solutions tailored to the needs of small-scale farmers is essential. Additionally, integrating machine learning within these frameworks could enhance predictive analytics, making technology adoption more accessible. Given the rapid advancement in this field, interdisciplinary research that combines agronomy, computer and environmental science could address complex agricultural challenges. Establishing an open-access repository for data, methodologies and findings would support transparency, reproducibility and accelerate innovation across the sector.

5 Conclusion

This study offers a comprehensive overview of IoT and blockchain research in agriculture, highlighting key trends and identifying research gaps. Between 2019 and 2024, there has been notable growth in publications, reflecting increasing global interest and progress in this field. China and India lead in research output, with India achieving the highest citation impact, emphasizing the role of these countries in advancing IoT and blockchain applications in agriculture. "Computers and Electronics in Agriculture" stands out as the leading journal, with contributions across various journals reflecting diverse perspectives. Co-occurrence analysis indicates an initial research focus on IoT-blockchain integration, which has since evolved to encompass machine learning and climate-smart agriculture in response to emerging technological and environmental challenges. Despite advancements, significant gaps remain, especially in the practical application of IoT and blockchain for climate-smart agriculture. Addressing these gaps through field-based studies and enhancing system interoperability could substantially advance precision farming and food supply chain resilience. Overall, this study underscores the dynamic nature of IoT and blockchain research in agriculture, offering valuable insights for researchers, policymakers and practitioners. These findings provide a foundation for future innovations aimed at enhancing agricultural sustainability and addressing climate-related challenges, contributing to a more resilient agricultural sector.

Author contributions

SS: Writing – original draft, Writing – review & editing, Data curation, Formal analysis, Investigation, Software, Visualization. GM: Resources, Supervision, Validation, Writing – review & editing. CP: Conceptualization, Methodology, Funding acquisition, Project administration, Resources, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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