A review and bibliometric analysis of traceability system development in the agricultural and food sector in Indonesia

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ABSTRACT

Several technologies and methods for traceability systems in the agriculture and food sectors have developed rapidly in recent decades. There has been an increase in traceability system research in many developing countries, including Indonesia. Our review collects data from the Scopus database to study the development and dynamics of research on traceability systems and to identify emerging technological trends in the field. This paper uses bibliometric analysis by VOSviewer to find out studies regarding traceability. Our findings reveal traceability system research in Indonesia encompasses 1,264 documents within the Scopus database from 1998 to 2022. The number of studies on traceability systems has increased significantly after 2016. Most scholarly articles on traceability technology are disseminated as conference proceedings. These traceability systems have been established and are widely adopted to ensure the quality and safety of agricultural and food products, monitor species diversity, and oversee environmental parameters. The objective of the user influences the development of the traceability system. Technologies such as deoxyribonucleic acid (DNA) barcoding, unmanned aerial vehicles (UAVs), satellites, wireless sensor networks (WSNs), blockchain, product tagging, spectroscopy, and smart packaging rapidly advance to enhance traceability capabilities.

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1. INTRODUCTION

Technological developments have encouraged society to create innovations in the agricultural and food sectors. The traceability system is a topic that has developed rapidly over the past decade because it is related to public health and safety. The traceability system can integrate the entire production process from upstream to downstream in the food supply chain, providing detailed data related to production, shipping, processing, storage, quality control, and product distribution [1], [2].

Bosona and Gebresenbet [3] stated that the traceability system provides essential information to stakeholders about the origin and type of raw materials, the origin and kind of feed ingredients, production stages, and the resources used (tools and machines). The availability of this data is critical to address possible food risks. Opara [4] has explained various technological approaches to developing and implementing traceability systems in the agricultural and food sectors. These methods include integrated software development, geospatial data analysis, data exchange, product identification, food safety and quality evaluation, environmental monitoring, and genetic analysis technology.

However, research on the development of traceability technology in Indonesia still needs to be completed. As a developing country, Indonesia is attempting to establish an effective traceability system in the agriculture and food industries to assure product quality and safety. Traceability systems are critical for increasing transparency, reducing food safety hazards, and meeting international standards required to access the global market. A bibliometric approach can be used to examine the development and evolution of science in this field. Borregan-Alvarado *et al.* [5] stated that bibliometric analysis can use databases from scientific databases to evaluate emerging research trends. Cobo *et al.* [6] added that this analysis can help determine the quality of research results, productivity, influence, mapping of scientific fields, and interactions between relevant topics [7], [8].

With current technological developments, the scope of the traceability system is comprehensive because it can apply various technologies depending on the objectives of the system being developed. Indonesia is a developing country that is still trying to establish research on traceability systems. Several researchers have conducted studies related to traceability systems. Borregan-Alvarado *et al.* [5] performed a bibliometric investigation on the advancement of Industry 4.0, and Kuzior and Sira [9] examined the development of blockchain technology using bibliometric analysis. However, there has yet to be research that specifically examines the development of traceability technology in Indonesia's agricultural and food sectors using a bibliometric approach.

This paper aims to perform a bibliometric analysis to discern trends and attributes of technological advancements within traceability systems. Using bibliometric analysis, researchers and stakeholders in Indonesia can better understand the global research landscape in traceability technology. This method allows the identification of strengths and weaknesses in domestic research, as well as opportunities for international collaboration and further development. This approach can contribute to developing a more effective and efficient traceability system, supporting Indonesia's efforts to achieve better food security and improve the competitiveness of its agricultural products in the global market.

2. METHOD

Bibliometric analysis is one method widely used in conducting systematic reviews to obtain information about research gaps [10]. Therefore, systematic review research requires structured steps to identify keywords to collect the relevant scientific literature and complete the analysis. This research examines developing and implementing various traceability technologies in Indonesia's agricultural and food sectors. This study adopts the method from Fahimnia *et al.* [11], which has been modified according to needs and consists of four main stages presented in Figure 1.

Figure 1. Research stages for bibliometric analysis

– Stage 1: determining literature keywords

The first step in this study is to determine relevant literature keywords. The Scopus database is used to search for relevant literature. Traceability technologies in the agricultural and food sectors are diverse, and stakeholders can use them according to their intended use. This study adopts technological keywords from the traceability system proposed by Bosona and Gebresenbet (2013) [3]. Some keywords related to traceability system technology used include traceability system, near-infrared, unmanned aerial vehicles (UAV), deoxyribonucleic acid (DNA) barcoding, wireless sensor networks (WSNs), environmental monitoring, chemometrics, blockchain, and smart packaging. The keywords used to search for data through the Scopus database are as follows:

TITLE-ABS-KEY (traceability AND system; AND food) OR TITLE-ABS-KEY ("near infrared"; AND agriculture) OR TITLE-ABS-KEY ("near infrared"; AND food) OR TITLE-ABS-KEY ("non destructive"; AND agriculture) OR TITLE-ABS-KEY ("non destructive"; AND food) OR TITLE-ABS-KEY (ftir; AND agriculture) OR TITLE-ABS-KEY (ftir; AND food) OR TITLE-ABS-KEY (dna AND barcoding)

OR TITLE-ABS-KEY (uav; AND agriculture) OR TITLE-ABS-KEY (chemometric; AND agriculture) OR TITLE-ABS-KEY (chemometric; AND food) OR TITLE-ABS-KEY (geospatial; AND agriculture) OR TITLE-ABS-KEY (smart AND packaging; AND food) OR TITLE-ABS-KEY (wireless AND sensor AND network; AND agriculture) OR TITLE-ABS-KEY (satellite; AND food) OR TITLE-ABS-KEY (satellite; AND agriculture) OR TITLE-ABS-KEY (blockchain; AND food) OR TITLE-ABS-KEY (blockchain; AND agriculture) OR TITLE-ABS-KEY (geospatial; AND food) OR TITLE-ABS-KEY ("intelligent packaging"; AND food) OR TITLE-ABS-KEY ("environmental monitoring"; AND agriculture; AND indonesia) OR TITLE-ABS-KEY ("environmental monitoring"; AND food; AND indonesia) OR TITLE-ABS-KEY (traceability AND system; AND agriculture)) AND PUBYEAR >1997 AND PUBYEAR <2023 AND (LIMIT-TO (AFFILCOUNTRY, "Indonesia")) AND (LIMIT-TO (LANGUAGE, "English").

– Stage 2: literature screening and keyword search

Literature screening and keyword searches were conducted several times to ensure the data obtained followed this study's objectives. The technology keyword was filtered by adding the scope of agriculture and food. Furthermore, database screening was carried out for articles published in Indonesia, using English, and published from 1998 to 2022. The results of document screening obtained 1,264 publications in the Scopus database. Data from Scopus, such as bibliography, abstract and keywords, funding details, and others, were downloaded in CSV format for analysis.

– Stage 3: data analysis

The data analysis features provided by the Scopus database were utilized for statistical data analysis. The review's findings on the development of traceability system technology in Indonesia are supported by annual publication trend data and institutions that publish the most scientific articles. This analysis provides an overview of how traceability technology has developed and been adopted in Indonesia's agriculture and food sector.

– Stage 4: data mapping and synthesis analysis

Data mapping was conducted using VOSviewer software based on the keyword data obtained. Mapping aims to determine trends in technology development and research related to traceability systems in agriculture and food. Gong *et al.* [12] explained that VOSviewer can be used to map publications, authors, and journals based on the citation network and keywords of the paper. The author intends to perform a synthesis study to elucidate diverse technologies on the advancement of traceability systems in Indonesia and their potential for future research.

3. RESULTS AND DISCUSSION

3.1. Research trends

Recently, there has been a significant increase in the number of scientific papers covering traceability systems. A total of 1,264 publications were identified from 1998 to 2022. The initial study of the traceability system in Indonesia began in 1998. In the following decade, the development of research on the traceability system has not occurred significantly. During this period, research on traceability systems mainly focused on environmental monitoring and land management. In 2010, research on traceability systems had a broader scope of the study. Several studies on using satellites to determine changes in land cover and spectroscopy for evaluating food ingredients are starting to develop. With the development of technology, research on traceability systems began to increase in 2011. Increasing public awareness regarding food commodities that are good quality and safe for consumption has increased research on traceability systems in 2017 by producing 105 publications.

The growth of digital technology in Indonesia, powered by the internet of things (IoT), actively promotes the advancement of traceability technology, focusing on its application in the agriculture and food sectors. Research on the traceability system continues to increase until 2019. The development of traceability system technologies varies widely according to desired objectives. Based on the data in Figure 1, most research on traceability systems was developed in 2021 by producing 239 scientific publications. However, in 2022, research on the traceability system will experience a significant decline by producing 180 scientific publications. The development of research and publications for traceability systems implemented in the agricultural and food sectors in Indonesia is presented in Figure 2.

Table 1 presents a brief overview of the primary sources of publications concerning the advancement of traceability systems within Indonesia's agricultural and food industry. This research found ten publication sources from the Scopus database that published the most papers. Based on this data, the IOP Earth and Environmental Science made the highest number of publications, reaching 326 papers. The publications produced in the IOP Conference Series have the widest variety of topics in technology development for traceability systems, such as chemometrics, UAV, information technology (IT), and other technologies. The second journal that produces the highest number of publications is Biodiversity, with publications that discuss the diversity of plant, animal, and microbial diversity from the gene to ecosystem level and the interaction of a species with the environment. The Biodiversity Journal has produced 57 papers on traceability systems in agriculture and food. In third place, most publications regarding traceability systems are found in the IOP Materials Science and Engineering with 44 papers. In fourth and fifth place, the most publications are in the AIP Conference Proceedings, with 38 articles, and the Journal of Physics Conference Series, with 31 papers. Traceability publications are also produced in journals such as Food Research, Aacl Bioflux, PLoS One, Ecology Environment and Conservation, and Marine Pollution Bulletin. Based on these data, publications in the form of proceedings are very much produced in research on the development of traceability systems.

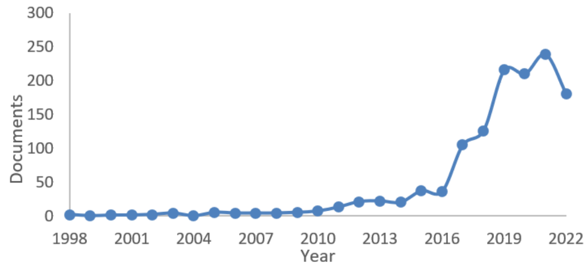

Figure 2. The progression of research on traceability systems in Indonesia

Table 1. Top 10 journals producing traceability research in Indonesia

No	Publication sources	Documents	Research area
1	IOP Conference Series: Earth and Environmental Science	326	Agricultural and environmental science
2	Biodiversitas	57	Agricultural and biological science
3	IOP Conference Series: Materials Science and Engineering	44	Materials and engineering
4	AIP Conference Proceedings	38	Natural science and engineering
5	Journal of Physics: Conference Series	31	Physics and astronomy
6	Food Research	18	Food science
7	AACL Bioflux	14	Agricultural, biological, and environmental
8	Plos One	11	Multidisciplinary
9	Ecology Environment and Conservation	10	Agricultural, biological, and environmental
10	Marine Pollution Bulletin	10	Aquatic science

3.2. Research topic visualization

An analysis using VOSviewer is needed to determine the research development on traceability systems in Indonesia. Gong *et al.* [12] and Roxas and Recario [13], keyword analysis can help understand the main objectives of the research, thus providing a broader picture of the overall development of the study. Figure 3 shows keywords related to the study on the advancement of traceability systems in Indonesia. Zakaria *et al.* [14] explained that the node size in the co-occurrence analysis shows the frequency of keywords that researchers often study. Based on Figure 3, Indonesia's most frequently discussed research topic is the development of traceability systems using DNA barcoding technology because its nodes are the most prominent. DNA barcoding technology is widely used to accurately identify and authenticate living things based on existing gene sequences. Modern research often applies this technology to study biodiversity and species identification [15], [16].

Several other technologies are also widely used to develop traceability systems, including IoT, WSNs, remote sensing, blockchain, and chemometrics. These technologies offer a variety of innovative solutions to improve the accuracy and efficiency of traceability systems. For example, WSNs and remote sensing can monitor environmental conditions in real time, while IoT and blockchain can ensure supply chain visibility and data security. One of the strategies that are utilized to guarantee the quality and safety of food products is the utilization of smart packaging devices that are equipped with labelling technology. This technology facilitates information about product conditions, which can be updated regularly and monitored throughout the distribution chain so that consumers can better understand the product's status. By understanding the various technologies used and the objectives of these studies, we can get a clearer picture of the development of traceability systems in Indonesia and the potential innovation that can be developed.

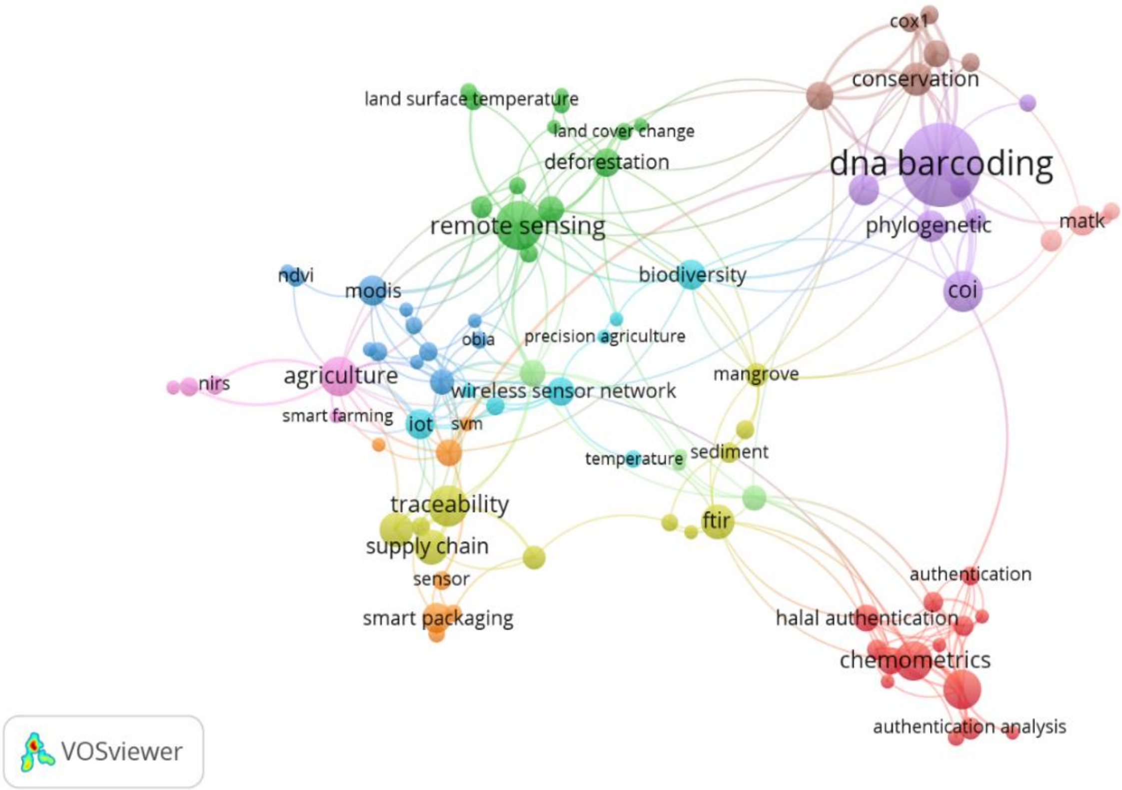

Figure 3. Research keyword networks for a traceability system

3.3. Traceability system technology trends

The traceability system positively impacts all stakeholders in the supply chain. This system facilitates communication between stakeholders, such as producers, distributors, and consumers, and creates information transparency. Transparency is required to develop confidence among the many supply chain stakeholders to increase the efficiency and reliability of the manufacturing and distribution processes. With an effective traceability system, each stage in the supply chain can be properly monitored and controlled, allowing the cause of a problem to be recognized and handled quickly. In addition, this system also helps meet food safety regulations and standards set by the government and related institutions, ensuring that the products that reach consumers are safe and high-quality products [17].

Purwandoko *et al.* [18] there are two primary functions of the traceability system, namely: (i) tracing, which involves the capability to acquire information regarding the production of raw materials, and (ii) tracking, which is the ability to find information about the product after the production process is complete. This traceability system can be a tool for production control and realizing transparency in the supply chain, providing stakeholders with information about the production process. The traceability system is an integral component of supply chain management. This system allows data acquisition, storage, and dissemination of information about food, feed, and other ingredients at every production stage, from upstream to downstream. As a result, this approach assures quality control and product safety across the whole supply chain [19]. As shown in Figure 4, a system that can track products both internally and externally across the supply chain can be included in a traceability system.

Developing and implementing a traceability system will positively impact all stakeholders, starting from farmers, industry, consumers, and the government. Some of the benefits of a traceability system are (i) increasing customer satisfaction, (ii) improving food crisis management, (iii) increasing supply chain management efficiency, (iv) realizing sustainable agriculture, (v) increasing product added value, (vi) minimizing product recall costs, (vii) protecting consumers, (viii) providing information related to product identity, and (ix) to identify production problems [20]-[22]. Through a traceability system, the food and agricultural industries can improve the quality of raw materials and expand market segmentation so that the products produced have high competitiveness [23]. Furthermore, the traceability system can monitor product halalness and certify organic products [24].

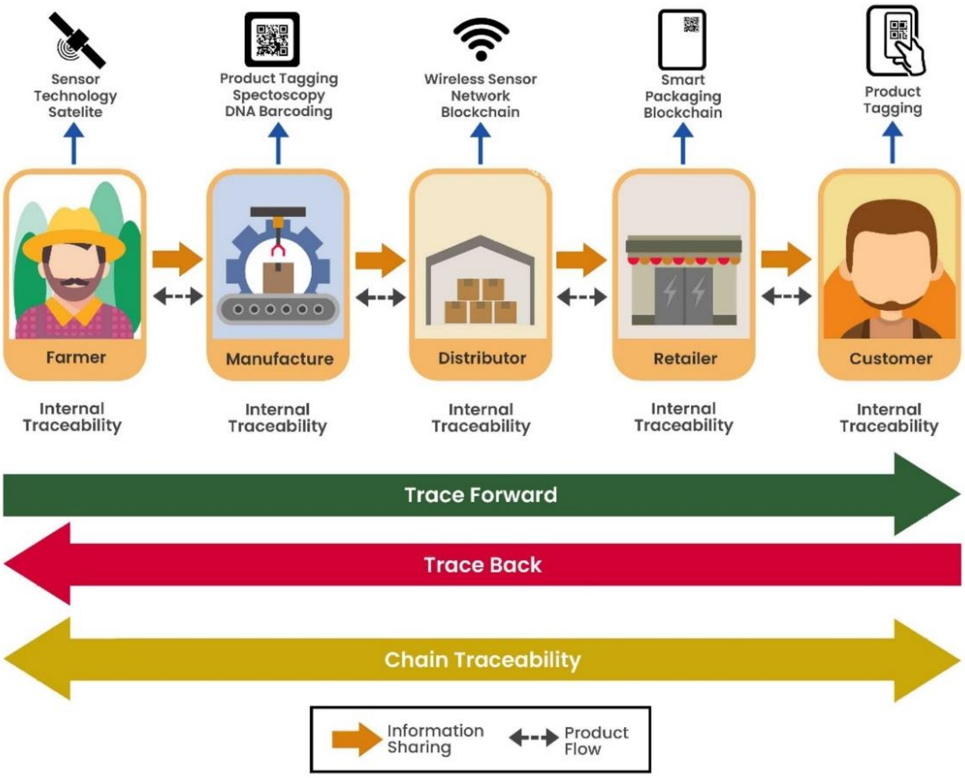

Figure 4. Traceability concept

Opara [4] stated that traceability systems require several technologies to identify products, capture information, store and transmit data, and integrate systems. Various technologies have been developed to facilitate traceability of agricultural and food products. Each technology has a specific role in ensuring transparency and security of the supply chain. One molecular tool that has been used extensively in the food and agricultural industries is DNA barcode technology. DNA barcoding is used to genetically authenticate plants or animals, ensuring that the species grown or bred follow the claims [25]. Research by Sarmiento-Camacho *et al.* [26] showed that DNA barcoding effectively identifies plant species and varieties and detects cross-contamination in food products.

Spectroscopy is another technology used to determine the quality and origin of agricultural commodities such as coffee, meat, and essential oils [27]. This method allows rapid and non-destructive analysis of the chemical composition of products, helping in determining quality and preventing counterfeiting [28]. Product identification technologies such as barcodes and QR codes are also crucial in traceability systems. These codes can track production history along the supply chain, from farmers to consumers. Studies have shown that QR codes increase transparency and allow consumers to access detailed information about the product's origin [29].

Satellite imagery can monitor land conditions, drainage, and soil structure, especially useful for food crops or horticultural products. This technology provides a broad overview of land conditions and potential yields. Satellite imagery can help farmers manage land efficiently [30]. In addition, a collection of environmental sensors, such as temperature and humidity sensors, are usually integrated with a wireless network to monitor agricultural ecological conditions [31]. This WSN consists of several sensor nodes that can capture environmental parameter data, which are then transmitted to a central node on a server for further data processing. Studies have shown that WSN improve land management efficiency and real-time monitoring of agricultural conditions [32]. Therefore, these technologies work together to create a comprehensive traceability system, ensuring that every step in the supply chain can be appropriately monitored and supervised, improving the quality and safety of products reaching consumers. Some technologies developed for traceability systems in Indonesia's agriculture and food sector include product identification technology, remote sensing, environmental monitoring, genetic analysis, smart packaging, and spectroscopy Figure 5.

Figure 5. Traceability technology in the agriculture and food industry

The development of wireless technology supports the current traceability system through the IoT. Qureshi *et al.* [33] explain that IoT technology does not require human and machine interaction because it can transfer data and information through wireless networks via computing devices. IoT technology has seen extensive adoption in the agricultural and food sectors, where its implementation is often combined with other technologies. As a result, the traceability system technology ecosystem incorporates multiple elements, including data acquisition sensors, internet networks, cloud or server infrastructure, computers, and other necessary devices for field data retrieval, as shown in Figure 6. Figure 6 shows how sensors collect data, which is subsequently stored in the cloud. Any user with a computer or mobile phone can view this data. In addition, data stored on a server or in the cloud can be analyzed with the help of artificial intelligence (AI) and machine learning (ML) to analyze useful information and make decisions easier.

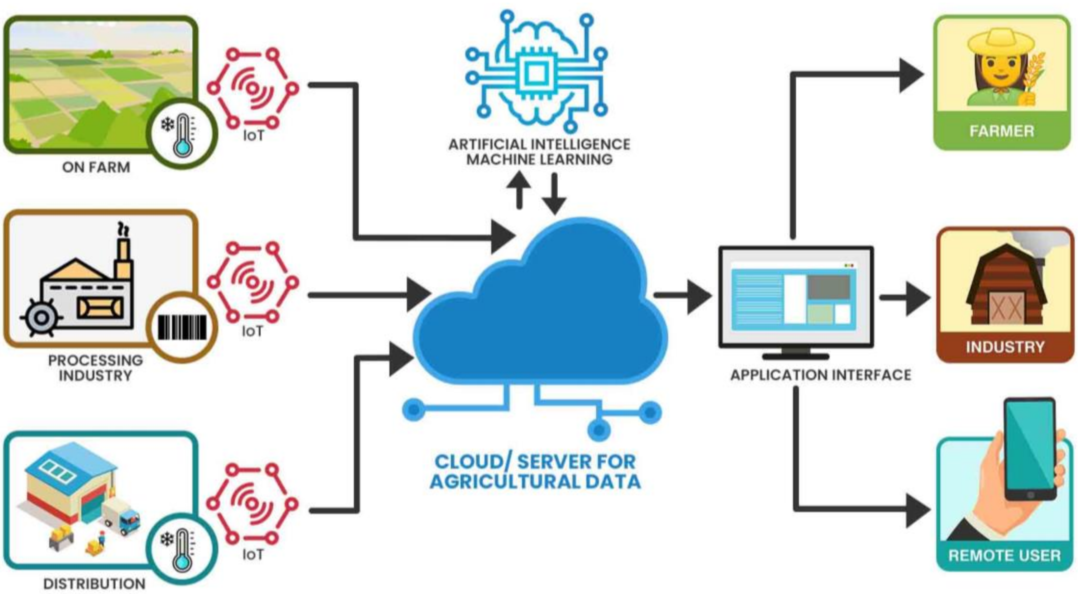

Figure 6. The IoT-enabled traceability system environment technology

Xu *et al.* [34], the traceability system relies on data acquired from sensors linked to the IoT, which is then recorded in a database. Sensors are usually used to collect data for environmental monitoring, knowing plant and animal perceptions, food quality, and safety. Some sensors used are temperature, humidity, optical, acoustic, and laser sensors [33]. Besides that, remote sensing technology using satellites and drones (UAV) can also be used by stakeholders for data acquisition to monitor agricultural cultivation in real time [35]. All data acquisition tools will support collecting agricultural production data to support traceability systems. The application of wireless technology using the IoT can positively impact agricultural productivity, guaranteeing food quality and safety, optimizing agricultural resources, and decision-making [33]. Technology for developing traceability systems is very varied and adapted to user requirements. Therefore, stakeholders' selection of traceability technology must be adjusted to the user requirements and objectives. Table 2 describes the purpose of various technological innovations developed for traceability systems in Indonesia's agricultural and food sectors.

3.4. Discussion

This study shows that the development of traceability system technology in Indonesia's agricultural and food sectors has reached a reasonably advanced level. However, further improvements are needed to improve the quality of technology. Modern technologies such as blockchain, DNA barcoding, and WSNs have improved food and agricultural traceability from production to distribution [36]. This study shows that effective implementation of IT in traceability systems can improve operational efficiency, transparency, and customer satisfaction and assist in making more informed decisions and better managing risks. Ekawati *et al.* [37] and Susanty *et al.* [38] also emphasize integrating various technologies to ensure effective traceability in the agricultural and food supply chain.

IT facilitates the integration of various traceability components such as satellite technology, RFID, barcodes, sensors, and other technologies to enable real-time data capture and processing. This technology allows product identification and tracking from upstream to consumer. Furthermore, IT contributes to effective data management by ensuring the accuracy, consistency, and accessibility of information and also integrating data from various sources, such as suppliers, industries, and distributors. This integration drives real-time transparency and visibility into the supply chain [39]. IT also facilitates the application of advanced analytics to traceability data to gain insights into process efficiency, quality control, and supply chain optimization. Predictive modeling helps identify patterns and potential issues in the supply chain, enabling proactive decision-making and risk management [40]. It allows stakeholders to achieve a reliable and efficient traceability system, improving operational performance and customer satisfaction.

Table 2. Technology innovation for a traceability system

No	Technology	Purpose	Source
1	DNA Barcoding	Species identification, food safety authentication, food fraud detection, taxonomy, and phylogenetic analysis.	[41]-[43]
2	Unmanned aerial vehicle (UAV)	Crop monitoring, mapping, irrigation management, pest and disease diagnosis.	[44]-[46]
3	Satellite	Agricultural land monitoring, cropping pattern identification, detecting agricultural production anomalies, early warning systems, and monitoring the performance of agricultural seasons.	[47]-[49]
4	Blockchain	Supply chain integrity, record product history, monitor production steps, and record product transactions.	[50]-[52]
5	Product tagging (QR code, RFID)	Traceability unit identification, transferring information about the product, and data collection.	[53]-[55]
6	Wireless sensor network (WSN)	Crops monitoring, agricultural environment monitoring, irrigation management, pest control, and fertilizer application.	[32], [56], [57]
7	Spectroscopy (NIR, FTIR)	Food quality evaluation, halal authentication, animal feed and feedstuff evaluation, fraud detection, adulteration identification, and rapid microbial identification.	[58]-[62]
8	Smart packaging	Food quality indicator, monitoring food freshness, monitoring food safety and quality	[63], [64]

This study highlights the development of traceability technology and analyses publication trends related to traceability in Indonesia, which have yet to be widely discussed in international literature. For example, DNA barcoding technology can identify genetic diversity, WSNs are used for environmental monitoring, satellites are used to monitor land cover, and blockchain is used to monitor products along the supply chain. Thus, the developed traceability system technology must be adjusted to the selected objectives. Table 2 describes technological innovations for traceability systems in the Indonesian agriculture and food sector. This study also shows that IoT and AI technologies have great potential to be applied more widely. However, this technology is still in the early stages of development in Indonesia. Chandrashekarappa *et al.* [65] explain that IoT technology allows real-time monitoring of agricultural conditions to optimize resources through precision agriculture.

The study results show that Indonesia has adopted various modern technologies to improve traceability in the agriculture and food sectors. However, the development of traceability systems has limitations, such as high initial costs for adopting modern technology and IT infrastructure that can be a barrier for many farmers and small businesses in Indonesia. Integrating multiple technologies also requires specialized expertise and ongoing maintenance, which may be difficult for some stakeholders. In addition, the lack of consistent standards and regulations may hinder the widespread adoption of traceability technologies.

The main objective of this study is to evaluate the development of traceability system technology in Indonesia's agricultural and food sector and identify trends, advantages, and limitations of the technology used. This study is critical because it provides a comprehensive view of the development of traceability technology in Indonesia, which can be used as a reference for further improvements in this sector. An effective traceability system can improve the quality and safety of food products and increase consumer confidence and market competitiveness.

Future research should focus on implementing AI for predictive analysis to improve decision-making and supply chain efficiency. AI technology can improve decision-making, manage risks, and improve supply chain efficiency. Furthermore, the use of the IoT for real-time monitoring should be improved so that all stakeholders can benefit from it. The creation of consistent standards and laws to support the wider implementation of traceability technology must also be improved. Studies on how to reduce the cost of implementing modern technology should also be developed in the future so that more farmers and small businesses can adopt it.

4. CONCLUSION

This is the first report that provide an overview of the development of traceability systems in Indonesia's agriculture and food sectors. The findings can be used as an essential reference for further research and development and also as a guide for policymakers in improving traceability systems in Indonesia. This study identifies various technologies used for traceability, including DNA barcoding, UAVs, satellites, blockchain, product tagging, WSN, spectroscopy, and smart packaging.

A comprehensive review of 1,264 articles published in Scopus between 1998 and 2022 reveals a notable increase in publications in 2016, which may be attributed to the growing concern over the safety and quality of food. According to the research, traceability technologies are used in a very diverse and user-specific manner in Indonesia. A more transparent, efficient, and risk-managed agriculture and food supply chain is possible with the use of these technologies, which also assist in tracking the origin and product movement. Effective IT integration allows for real-time data collection, storage, and analysis, which significantly benefits all stakeholders. This study demonstrates that deploying proper traceability technologies may strengthen the supply chain system and provide better food safety guarantees to customers.

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