# Unfolding the role of metaverse in agri-food supply chain security: current scenario and future perspectives

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**Summary**

Since its inception, the metaverse has evolved drastically and opened up many opportunities for many stakeholders, including individuals and businesses. The agri-food supply chain is currently starting to incorporate metaverse technology. Retailers and prominent companies use this technology to achieve particular goals, such as ensuring traceability or boosting sales and reputation. Concurrently, there is an opportunity for the metaverse to affect food chain performance more broadly. Even so, the literature provides little evidence for this effect and primarily focuses on specific indicators, leaving little knowledge about it. By exploring the rapidly evolving field of metaverse technologies and their potential impacts on the security of agri-food supply chains, this study aims to fill this knowledge gap. The study aims to improve collaboration and communication throughout the agri-food supply chain by providing a structured framework covering a variety of metaverse technologies, from the development of immersive virtual worlds to the deployment of blockchain for traceability. The findings offer valuable insights, particularly for researchers, decision makers, and industry partners who aim to better comprehend the potential benefits and challenges related to integrating metaverse solutions into the agri-food industry. The study concludes with recommendations for future research directions and strategic factors that could assist in ensuring the effective adoption of metaverse technologies and the security and resilience of agri-food supply chains.

**Keywords:** Agri-food supply chain, metaverse, immersive virtual environments, security, agri-food industry

## Introduction

The agricultural sector faces several challenges, including food safety, digitization, sustainability, and the urgent need for an enhanced agri-food supply chain (AFSC) (Kumar et al., 2022; Vinay Surendra Yadav et al., 2022). Assuring food security is one of these concerns that cannot be overstated, particularly considering that there will be 9.8 billion people on Earth by 2050. Estimates suggest a demand increase ranging from 59 to 98% to meet the growing population's increasing food demands (Nations et al., 2022). Disturbing figures from the World Health Organization (WHO) reveal an annual toll of more than 420,000 lives globally due to food contamination, with children under the age of five facing the most significant vulnerability, experiencing more than 125,000 deaths annually from foodborne illnesses[1]. Moreover, a 2016 PwC report underscores the substantial economic impact of food fraud, estimating global losses exceeding $40 billion annually within the food industry[2]. In light of these challenges, AFSCs are essential for addressing food security-related challenges. The AFSC encompasses diverse stages, from initial farm processes to eventual consumption by end-users. The conventional perspective involves decision-making processes governing physical and informational flows across production, processing, storage, and distribution (see Figure 1).

Industry 4.0 represents a technological initiative geared toward the comprehensive digital transformation of manufacturing processes and products (Abbasi et al., 2022). This initiative envisions a radical evolution of the entire industrial supply chain characterized by enhanced autonomy and intelligence (Belaud et al., 2019). Similarly, AFSCs are confronted with similar imperatives for technological integration, potentially involving the application of technologies such as blockchain, big data and analytics, artificial intelligence (AI), the Internet of Things (IoT), and augmented reality (AR) (V.S. Yadav et al., 2022). However, amid these pivotal cross-industry technologies, the metaverse stands out as needing more market readiness (Bordegoni and Ferrise, 2023). The challenges associated with the pursuit of more innovative agri-food systems are

[1] https://www.who.int/news-room/fact-sheets/detail/food-safety
[2] https://www.pwc.com/my/en/press/160127-fighting-40bn-food-fraud-to-protect-food-supply.html

substantial and encompass issues such as difficulty identifying a universally applicable standard solution, bridging the gap between farmers and metaverse researchers, tackling issues with distributed secure machine learning and negotiating the social and technological challenges of big data (Bian et al., 2022).

Given the novelty of the metaverse as a solution, a significant portion of the existing discourse surrounding this technology revolves around the technical intricacies associated with its implementation (Bibri et al., 2022; Bitas, 2022; Bordegoni and Ferrise, 2023). Within the agri-food literature, certain business studies have examined the potential benefits of this emerging technology, although empirical studies validating these advantages are still limited (Büyükakin and Soylu, 2023; Kang et al., 2023). These benefits encompass aspects related to supply chain management, food quality attributes, and the economic outcomes of firms. (Bian et al., 2022) emphasize the role of the metaverse in reducing food waste, expediting logistic operations, and enhancing information accessibility for consumers. (Abou El-Magd et al., 2023a) explore the possibility of linking product information to the metaverse to effectively manage food safety and quality issues within the dairy supply chain. Furthermore, (Kshetri, 2022) explains how Coca-Cola avoids forced labor in the sugarcane industry by utilizing the metaverse. Regarding the impact of the metaverse on firms' economic outcomes, (Nakano et al., 2022) underscore its significance in generating value added for exported food products. Additionally, (Büyükakin and Soylu, 2023) argue that the metaverse can assist food firms in mitigating instances of food fraud and safeguarding their reputations.

Despite the advantages outlined above, (Abou El-Magd et al., 2023a) contend that a paradigm shift toward a metaverse-ready food chain faces resistance from most stakeholders. This resistance primarily stems from a limited awareness and understanding of the technology and its economic implications (Bibri et al., 2022). Furthermore, (Cha, 2022) argues that retailers exhibit a low level of engagement with the metaverse, primarily due to a need for more comprehension of the actual economic benefits of its adoption.

To the best of our knowledge, this paper is among the first attempts to conceptualize the metaverse in relation to AFSCs and lays the groundwork for a future research agenda. Our investigation demonstrated that the

metaverse holds substantial potential to significantly enhance the evolution of AFSCs. However, realizing this potential requires further technological advancements and the synergistic integration of multiple technologies. Specifically, our focus in this paper is to delve into the role of the metaverse in enhancing AFSC security. While individual studies have explored topics related to AFSCs (Kumar et al., 2022; V.S. Yadav et al., 2022) and the metaverse (Bibri et al., 2022; Kshetri, 2022), the concurrent examination of these subjects, as well as the exploration of intrinsic features, emerging opportunities, and potential challenges of metaverse technology, as presented in this survey, represents a unique contribution. The critical contributions of our work are outlined below:

• We outline the components of the metaverse and explain the critical enabling technologies that make this possible while also highlighting the revolutionary role of the metaverse in AFSC security.

• We conduct an in-depth examination and research into the potential benefits and prospects offered by the metaverse for enhancing the security of AFSCs.

• Research challenges related to introducing the metaverse in AFSCs are systematically identified and discussed. Finally, the future prospects of this evolving technological paradigm are explained.

While metaverse research is still in its infancy, several academics are curious about how the metaverse could guarantee AFSC security (Abou El-Magd et al., 2023a; Bian et al., 2022; Büyükakin and Soylu, 2023). The reason behind the present research is the outcome of (Chen et al., 2023; Huang and Chen, 2023), who highlight how supply chains can be made more resilient and secure by using the metaverse. Given the importance of the agri-food sector to the global economy and the dynamic nature of issues such as food safety and traceability, it is imperative to comprehend how metaverse technologies can aid in addressing these concerns (Aamer et al., 2021; Moysiadis et al., 2022). By examining this unexplored area, this study hopes to yield insightful information that will guide subsequent studies and strategic decisions regarding the effective deployment of metaverse solutions for improving the security of AFSCs. Many industries, including real estate, education, and the economy, could undergo radical change as a result of the metaverse, but its

specific contribution to improving AFSC safety has not received enough attention. Thus, the decision to carry out an exploratory study on the role of the metaverse in AFSC security was motivated by the need to close a significant gap in the body of the current literature.

The structure of the paper is as follows: by delving into the metaverse present extent in section 2, the research paper allows for the introduction and explanation of metaverse technologies, helping readers grasp the significance and relevance of the study within the broader landscape of technological advancements. The transformative role of the metaverse in AFSC security in section 3 seeks to elucidate how virtual environments can revolutionize traditional AFSC practices. Potential opportunities and benefits emerging in the metaverse for AFSC security in section 4 contribute to a comprehensive understanding of the positive impacts that metaverse technologies can have on AFSC security, providing valuable insights for researchers, practitioners, and policymakers. By presenting future perspectives for implementing and developing metaverses in AFSCs, section 5 contributes to guiding future research agendas in the field. This entails determining knowledge gaps, potential areas for study, and open research challenges that can stimulate more in-depth scholarly investigation. Finally, the conclusions are presented in section 6. The selected subheadings collectively contribute to a systematic and comprehensive exploration of the multifaceted relationship between the metaverse and AFSC security.

## Recognizing the present extent of the metaverse

### Tracing progression

The term "metaverse" refers to an immersive virtual environment where users can communicate with computer-generated objects and other users through avatars in a virtual reality (VR)-enabled space (Bordegoni and Ferrise, 2023; Büyükakin and Soylu, 2023). This shared area is open to all users, and any

changes made to the metaverse map will be visible to all users worldwide (El jaouhari et al., 2023). Building an ideal metaverse means constructing a digital space where individuals can interact digitally in a way that is similar to real-world interaction (Dincelli and Yayla, 2022). The metaverse offers a seamless, immersive, and safe user experience by utilizing revolutionary technologies such as blockchain, IoT, AI, and AR.

The metaverse paradigm shifts in three major ways: (i) from a narrow single-world perspective to a broader framework that links several virtual worlds; (ii) from a virtual persona to a blended reality perspective that includes experiences throughout the extended reality (XR) spectrum—VR, AR, MR, and the fusion of many other technologies; and (iii) from an avatar to an avatar-centric perspective that highlights the immersive and socially interactive aspects of its surroundings. A brief summary of the evolution of the metaverse concept over time is given in Table 1.

## Enablers of metaverse technology

### VR, AR, MR, and XR

Virtual reality (VR), augmented reality (AR), mixed reality (MR), and extended reality (XR) are key technologies that drive metaverse forward by providing users with completely immersive experiences. Virtual reality (VR) is a three-dimensional computer-generated environment that simulates reality and allows for user interaction (Farshid et al., 2018). Fully immersive, semi-immersive, and nonimmersive are the three primary categories of VR systems (Dincelli and Yayla, 2022). AR presents real-time information from the outside world using text, audio, video, and virtual objects (Farshid et al., 2018). AI, processing power, lenses, AR software, and sensors are the five essential components of AR. VR and AR can be seamlessly combined with MR to enable real-time interaction between digital and physical objects (Maas and Hughes, 2020). Compared to VR or AR, this integration requires more processing power. Three key elements for real-world MR

experiences are improved input techniques, cloud computing, and environmental detection. Immersion technologies such as VR, AR, and MR are all included in XRs (Farshid et al., 2018).

**Blockchain**

A blockchain is a decentralized, open, verifiable, readable, safe, and reliable digital transaction ledger that safeguards digital assets in the metaverse (Bian et al., 2022; Huynh-The et al., 2023a). The metaverse can operate as a single virtual world owing to a decentralized blockchain ecosystem that enables independent nodes to synchronize (Lin et al., 2022). Participants in this ecosystem can efficiently manage their social, legal, and economic relationships through the use of smart contracts, which in turn establishes the basic rules governing the metaverse (Mourtzis et al., 2023). Blockchain appears to have the ability to completely eradicate centralized decision-making processes throughout the metaverse and lower the risks related to malware and attacks (Bian et al., 2022).

**Artificial intelligence**

Artificial intelligence (AI), which combines computer vision and natural language processing (NLP) methods, powers the metaverse (Huynh-The et al., 2022). Improving the processing and understanding of natural language and visual information is one of the main goals of computer vision and NLP. NLP and computer vision are automatically made possible by machine learning (ML) algorithms. Moreover, they enable systems to independently analyse data and spot trends and make predictions (Abbas et al., 2020). AI stimulates creativity by presenting novel ideas and scenarios in the metaverse based on historical data (Bordegoni and Ferrise, 2023). Conversely, AI enables data processing, protection, and user interaction. Moreover, it enables the development of chatbots and avatars, among other functions that enhance the authentic nature of the user experience (Huynh-The et al., 2023b).

**5G technology, edge computing, and the Internet of Things**

The integration of 5G technology, which provides essential features such as dependability, throughput, and low latency, is necessary to enable metaverse and relevant apps (Huang et al., 2023). Compared with most wired broadband connections, 5G networks substantially decrease energy use while boosting data rates by nearly 90%, effectively meeting the essential requirements of the metaverse (Ding et al., 2022). These 5G technological advancements have great metaverse benefits since they meet certain application needs within their domain. Concurrently, edge computing appears to be another essential technology that underpins the metaverse. Rapid reaction times resulting from edge computing provide users with a metaverse immersion experience (Wang and Zhao, 2022a, 2022b).

Interaction between virtual and real-world environments is made easier by the Internet of Things (IoT) (Wang et al., 2023). Conversely, metaverse technology makes it possible for IoT device collections to have 3D user interfaces and promotes the creation of user-centered IoT and metaverse experiences (Ning et al., 2023). The combination of these technologies makes data-driven decision-making easier to understand and requires less training and effort. Moreover, the IoT must retrieve and incorporate current, reliable, and secure data from the outside world into the metaverse (Wang et al., 2023).

**3D rebuilding**

The inclusion of a three-dimensional environment is necessary for the metaverse to remain sustainable (Abou El-Magd et al., 2023a). The creation of lifelike 3D human avatars is necessary for the metaverse to fully materialize as a virtual domain. This calls for the application of 3D rebuilding technology to construct virtual environments with 3D objects (Dionisio et al., 2013). Building a real 3D environment with 3D cameras and

reconstruction technologies that collect data from the real world is the main prerequisite for metaverse systems (Hou et al., 2023). The data are subsequently used by computers to create metaverse simulations. In essence, by precisely translating physical objects into 3D models, 3D rebuilding technology significantly contributes to the increased realism of the metaverse. This facilitates the metaverse's transition into an actual virtual environment (Goel et al., 2023).

**AFSC security: The transformative role of the metaverse**

The agricultural production of food is referred to as "agri-food," and agri-food supply chains encompass all farm-related activities, processing, distribution, retailing, and end-user consumption (V.S. Yadav et al., 2022). Beyond these practical concerns, AFSCs involve a complex web of stakeholders who share objectives such as guaranteeing food sustainability, safety, and quality (Kumar et al., 2022). Farmers, the food industry, wholesalers, retailers, and consumers are the main parties directly involved in the AFSC logistics process. The diverse network of AFSC stakeholders is further enhanced by indirect partners such as financial institutions, food and manufacturing firms, governmental organizations, and nonprofit organizations.

The metaverse revolution is currently having a significant effect on AFSCs. Developing a virtual supply chain representation in a metaverse gives stakeholders a thorough and current understanding of the agri-food ecosystem (Cha, 2022).

Blockchain creates a transparent and secure ledger that helps track the origin, processing, and distribution of food products, which benefits global food supply chains (Bhat et al., 2022). Scanning QR codes on tangible product packaging allows customers to access virtual displays in the metaverse that depict the entire product journey (Bian et al., 2022). IoT sensors and devices in the metaverse region mimic their AFSC counterparts in the real world (Abou El-Magd et al., 2023a). These virtual sensors furnish real-time temperature, humidity, and product condition data. Stakeholders leverage the metaverse to monitor and analyse these data, ensuring

the quality and safety of food products. (Büyükakin and Soylu, 2023) underscore the significance of AR features, describing their application in crafting digital authentication tags for food products. Consumers can use smartphones or AR devices to authenticate products by interacting with these digital tags, mitigating the risk of counterfeiting (Xi et al., 2018).

Furthermore, as depicted in Figure 2, we extend the conventional understanding of AFSCs from being "a coordinating and integrating of financial, material, and information flows between departments and businesses to optimize the use of supply chain resources throughout the whole value chain, from suppliers of raw materials to customers" (Bhat et al., 2022) towards a triple-AFSC perspective, where physical, metaverse, and physical-metaversion AFSCs coexist. Figure 2 illustrates the connection between the physical and metaverse realms using AI, big data analytics, blockchain, edge computing, the IoT, 5G, enterprise resource planning (ERP), and simulation (Abou El-Magd et al., 2023a; Huynh-The et al., 2022; Mourtzis et al., 2023). 3D printers, smart devices, and sensors integrated into tangible goods are examples of data sources in the metaverse. In virtual marketplaces, virtual consumers, represented by avatars, are offered and sold digital food products using digital currency. Digital collaboration spaces are used by managers to coordinate sourcing, production, and logistics.

**Potential opportunities and benefits associated with AFSC security**

Among the applications of the metaverse to supply chain management, AFSCs offer the best chance for enhancing security (Büyükakin and Soylu, 2023; Cha, 2022). From a legal perspective, according to the European Union General Food Law EC 178/2002[3], food security encompasses a multidimensional framework of strategies, policies, and technologies to safeguard the entire agricultural and food production network from potential threats, risks, and vulnerabilities. The complexity of security in AFSCs is increasing given the

[3] https://www.fao.org/faolex/results/details/en/c/LEX-FAOC163008/

increasing length of these chains due to expanding globalization and intensifying competition (Nations et al., 2022).

More recently, scholars and practitioners have underscored the potential for the metaverse to act as a disruptive force, adding value to AFSCs by enhancing product security (Cha, 2022). Putting security measures in place can enhance the quality of the information stored and provide actors with the most recent information about things occurring within the AFSC (Abou El-Magd et al., 2023a). Moreover, a metaverse-based blockchain—which depends on transparent, reliable, and auditable data—supports fraud detection and counterfeiting preventative measures (George and Al-Ansari, 2023; Mourtzis et al., 2023). Furthermore, metaverse-integrated IoT devices and sensors allow real-time environmental condition tracking, including humidity and temperature (Abou El-Magd et al., 2023a). With this capacity, stakeholders can act quickly to ensure the safety and quality of agricultural products when real-world conditions differ from ideal conditions (Mourtzis et al., 2023).

Every supply chain transaction is tracked and recorded using transparent, secure ledgers made possible by the integration of blockchain technology into the metaverse (George and Al-Ansari, 2023). Establishing an unchangeable record describing the location, production, handling, and distribution of agricultural products enhances traceability and reduces the likelihood of fraud (Bhat et al., 2022). Agricultural products can have digital authentication tags created and visualized using AR components from the metaverse. This application aids in verifying product authenticity, reducing the risk of counterfeiting, and ensuring supply chain security (Xi et al., 2018). Thus, the metaverse may be able to assist agri-food businesses in boosting their marketing efforts and refining their customer targeting skills, which would enhance their ability to respond to customer demands, comply with legal requirements, and uphold moral principles (Abou El-Magd et al., 2023a; Bian et al., 2022; Cha, 2022). From the consumer standpoint, having access to transparent and traceable agri-food products via the metaverse guarantees accurate information regarding the origin and dissemination of food. Thus, the metaverse helps consumers make informed choices about the products and companies they support

by addressing issues with food product safety, quality, authenticity, and sustainability (Abou El-Magd et al., 2023b; Cha, 2022).

While metaverse-based security offers numerous advantages for agri-food companies and consumers, it is essential to recognize that AFSCs will encounter a number of technological, legal, managerial, and financial challenges in implementing this technology.

**Agri-food supply chain security: Challenges and future perspectives**

The metaverse is a technology poised to revolutionize global supply chains, yet several critical challenges must be addressed for widespread adoption. Primarily, as a nascent technology, the metaverse is surrounded by uncertainties and unresolved questions, leading to a slow increase in enterprise acceptance (El jaouhari et al., 2023). Despite significant research attention, adopting metaverse technology in supply chains could be more active globally (Dincelli and Yayla, 2022). Furthermore, in the current early stage of metaverse development, decision makers in supply chains lack clear guidelines to adequately account for unintended consequences and minimize risks (Queiroz et al., 2023). This uncertainty parallels the initial phases of other disruptive innovations in the past 25 years, such as smartphones, the Internet, smart and ambient infrastructure, and smart agriculture (Ning et al., 2023). The adoption of metaverse technology faces a variety of challenges, including those related to technology, the economy, the user experience, ethics, and regulations.

Technological challenges arise because the metaverse is primarily conceptual and needs to be fully functional. Organizations are cautiously experimenting with their virtual presence, as platforms are still in the early phases of production. The lack of established blueprints or examples of best practices, in addition to the high cost and risk involved in platforms and solutions, presents difficulties (Wang and Zhao, 2022a). AFSCs need to take risks, work with entrepreneurs from different sectors, and use a digital twin to create a virtual presence.

This project is an investment in unknown territory that calls for imagination, ingenuity, sufficient capital, and a risk-taking attitude.

Currently, the majority of economic and managerial research in the metaverse domain is experimental in character (Steiner et al., 2023). The possible effects of integrating the metaverse into supply chain dynamics are still uncertain (Abou El-Magd et al., 2023b; Queiroz et al., 2023). Notably, more use cases that methodically evaluate the effects of metaverse integration are needed, especially with regard to customer experience (Esen et al., 2023; Giang Barrera and Shah, 2023). Furthermore, the majority of stakeholders must prepare for a possible paradigm change in favor of the metaverse. The reason for this lack of readiness is a lack of understanding of the metaverse and its claimed advantages for all users and participants in the context of AFSCs (Abou El-Magd et al., 2023b; Büyükakin and Soylu, 2023). Furthermore, actors in AFSCs are generally skeptical about embracing the metaverse, and many of them continue to use traditional paper-based procedures. Furthermore, AFSC businesses frequently struggle with the task of choosing wisely in regard to metaverse investments. Moreover, many people are unsure about how to establish a metaverse-based network and work with partners and stakeholders in an efficient manner (El Jaouhari et al., 2023).

Agri-food businesses and platforms must implement extensive preventive and protective measures to minimize any potential negative effects. For instance, users now have more control over how they engage with the metaverse because of Meta's addition of the personal boundary feature. Consequently, it is imperative to address intellectual property issues and copyrighted content infringement within the virtual realm to counteract potential food fraud. However, security issues and privacy concerns persist in the metaverse. Within the agri-food sector, businesses must confront and manage these privacy and security risks. To illustrate, questions arise regarding the connection between virtual identities in the metaverse and users' real-world identities. Moreover, there is a pressing consideration of whether agricultural businesses and platforms should be permitted to retain and store the substantial data generated during extensive interactions within the

metaverse. A critical question emerges: in scenarios where multiple businesses, organizations, and platforms contribute to a user's metaverse experience, who bears liability for the associated security and privacy issues?

The AFSC has not yet developed regulations pertaining to the security of the metaverse for methodical application (Büyükakin and Soylu, 2023). Particularly noteworthy is the lack of uniform terminology for regulating metaverse, which poses significant obstacles to developing a suitable legal framework and formulating policies. Such terms must undergo elucidation, clarification, and subsequent standardization. Global national regulators have made a variety of occasionally contradictory demands that further complicate matters. These demands cover everything from food fraud and market substitution to allergies, pesticides, and trace elements. To effectively address these challenges, it is recommended that governments and stakeholders involved in relevant use cases collaborate with one another (Giang Barrera and Shah, 2023; Steiner et al., 2023). Moreover, white papers are useful instruments for synthesizing research results and opinions on complex topics such as the metaverse. They provide a forum for suggesting ways to strengthen regulators' authority and involve stakeholders in regulatory procedures.

## Conclusions

Metaverse technology appears to be an important driving force behind the increasing digitalization of the agri-food industry. In addition to increasing pressure from global ecosystems, AFSCs are constantly battling issues within industrial and economic structures. In the face of these challenges, it works to satisfy a range of needs, maintain a competitive edge, bolster capabilities, and resolve security issues. Given this, metaverse adoption patterns are examined in this study, with a focus on the implications for AFSC security. Figure 3 displays an overview of the entire work.

The potential of the metaverse could lead to significant changes in the AFSC, which encompasses the production, distribution, processing, and consumption of agricultural products. The analysis demonstrates

how metaverse technology can fully realize its potential within AFSCs by highlighting its enabling technologies and benefits. The paper also highlights and analyses important research challenges that prevent the metaverse from being widely used. Although widespread acceptance of the metaverse is still in its infancy, its importance has already been established in a number of fields. However, a number of challenges, including data management, network capabilities, security and privacy, interoperability, and ecological effects, need to be resolved before the metaverse can fully materialize.

In summary, the agri-food sector has a revolutionary opportunity to benefit greatly from the metaverse in terms of productivity, food safety, security, and transparency. Future developments in focused metaverse technologies, such as blockchain, VR, AR, 3D printing, XR, and AR, have great potential to expand AFSC functionalities.

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**Author contributions**

**Asmae El jaouhari:** Conceptualization; investigation; writing–original draft**. Jabir Arif:** writing–review and editing; project administration. **Fouad Jawab:** Conceptualization; supervision; writing–review and editing. **Ashutosh Samadhiya:** Conceptualization; project administration. **Anil Kumar:** Conceptualization; investigation.

**Ethical approval**

This study does not require ethics approval.

**Conflict of interest statement**

The authors declare no conflicts of interest.

**Data availability statement**

There are no related data.

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The paper offers a conceptual framework that aligns with our research focus on the transformative potential of the metaverse in the context of agri-food supply chain security.

Abou El-Magd, L.M., Abdelnapi, N.M.M., Darwish, A., Hassanien, A.E., 2023b. A Proposed Metaverse Framework for Food Security Based-IoT Network and Machine Learning, in: Hassanien, A.E., Darwish, A., Torky, M. (Eds.), The Future of Metaverse in the Virtual Era and Physical World, Studies in Big Data. Springer International Publishing, Cham, pp. 137–153. https://doi.org/10.1007/978-3-031-29132-6_8

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The work contributes a narrative on enterprise blockchain interoperability, aligning with our research focus on the metaverse's role in agri-food supply chain security. By citing this source, we aim to enrich our paper with perspectives on technological synergies, fostering a comprehensive understanding of potential integrations that could complement metaverse advancements in enhancing security and efficiency throughout the agri-food supply chain.

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This work elucidates the integration of blockchain technology for establishing food traceability within virtual environments. By citing this work, our research aims to draw parallels between blockchain-enabled traceability systems and the potential applications of the metaverse in enhancing transparency, security, and traceability within the agri-food supply chain.

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This source contributes perspectives on the broader implications of metaverse technologies beyond supply chain security. By referencing this work, our research aims to contextualize the role of the metaverse within the larger landscape of the food and retail industry, providing a holistic understanding of potential disruptions, innovations, and opportunities that may influence the dynamics of agri-food supply chains.

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