Scientific Papers. Series D. Animal Science. Vol. LXVIII, No. 1, 2025
ISSN 2285-5750; ISSN CD-ROM 2285-5769; ISSN Online 2393-2260; ISSN-L 2285-5750

HARNESSING BLOCKCHAIN FOR ENHANCED RISK MANAGEMENT IN THE FOOD SUPPLY CHAIN

Carmen Georgeta NICOLAE, George SCARLAT, Elena POGURSCHI

University of Agronomic Sciences and Veterinary Medicine of Bucharest,
59 Marasti Blvd, District 1, Bucharest, Romania

Corresponding author email: scarlatgeorgeag@yahoo.com

Abstract

The paper aimed to present the potential of blockchain technology in enhancing food safety and transparency across the global food supply chain. Blockchain's decentralized, immutable ledger enables end-to-end traceability of products, addressing critical issues of food fraud, contamination, and inefficiency. Through case studies, including IBM Food Trust initiatives at Walmart and Carrefour, this research demonstrates how blockchain can streamline traceability, improve operational efficiency, and bolster consumer trust by providing access to verified information on product origins. Despite these benefits, challenges such as high implementation costs, interoperability issues, and regulatory concerns remain barriers to widespread adoption. This paper offers insights and recommendations to facilitate blockchain's integration in the food industry, advancing toward a safer, more transparent, and sustainable food system.

Key words*: control, digital ledger, food safety, quality, traceability.*

INTRODUCTION

As the world faces rapid population growth, maintaining food safety has become a global priority.

The global population is projected to surge to 8.5 billion by 2030 and 9.7 billion by 2050 (United Nations, 2022).

This growth places immense pressure on the global food supply chain, which must maintain food quality, ensure safety, and minimize waste.

The food supply chain, a complex network of stakeholders, faces challenges like fraud, contamination, and inefficiencies, demanding innovative solutions for traceability and transparency. Blockchain technology, with its decentralized and immutable ledger system, offers potential for solving these issues. By enabling detailed and tamper-proof records from farm to table, blockchain enhances safety, trust, and operational efficiency, while addressing concerns of scalability, interoperability, and privacy (Crosby et al., 2016).

The purpose of this research is to explore how blockchain technology can be leveraged to mitigate risks in the food supply chain, with a particular focus on enhancing traceability to prevent biological, chemical, and mechanical contamination. This study aims to investigate the implementation and benefits of blockchain-based traceability systems in ensuring food safety, improving supply chain transparency, and fostering consumer trust.

MATERIALS AND METHODS

This study uses a mixed-methods approach, combining case studies with thematic analysis to assess blockchain's impact on food safety and traceability.

A digital traceability system enables farmers to monitor and record every stage of their produce lifecycle, from planting to delivery, ensuring transparency and data integrity.

Case studies, such as Walmart or Pietro Coricelli, take us behind the scenes of these digital transformations, uncovering the complexity and advantages of blockchain implementation.

Data sources include case studies from IBM Food Trust, Walmart, and Carrefour, along with industry reports, academic publications, and government regulations (International Business Machines Corporation, n.d.).

Primary data is gathered through interviews with stakeholders involved in blockchain implementations, while secondary data is drawn from existing reports and regulatory documents.

Thematic analysis will identify key trends, challenges, and best practices, providing a comprehensive understanding of blockchain's role in mitigating risks in the food supply chain.

RESULTS AND DISCUSSIONS

Blockchain technology has emerged as a transformative force in the food supply chain, enhancing traceability, transparency, and operational efficiency.

Blockchain revolutionizes data management by introducing distributed ledger systems (Casino et al., 2019).

While centralized systems (Figure 1, left) rely on a single point of failure, blockchain (Figure 1, right) creates a peer-to-peer network where data is replicated across multiple nodes. This decentralized architecture makes blockchain more resilient to attacks and more transparent.

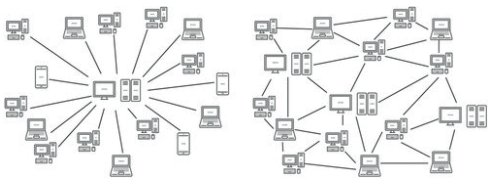

Figure 1. Difference between Centralized (left) and Distributed database (right) (Patelli & Mandrioli, 2020)

Traceability

In real-world scenarios, such as mango tracking at Walmart, blockchain turns a seven-day search into a process lasting only a few seconds (International Business Machines Corporation, n.d.).

This efficiency saves not just time but also resources, ensuring that potentially contaminated products are swiftly removed from circulation.

Such speed is critical in mitigating the impact of foodborne illnesses.

Transparency

For companies like Pietro Coricelli, blockchain authenticates the journey of olive oil from grove to shelf. Consumers can access verifiable details about the product's origin, production processes, and quality standards.

This level of transparency combats counterfeiting and builds trust.

Operational Efficiency

By using blockchain to monitor storage and transport conditions in real time, companies such as Antonello Produce significantly reduce waste while maintaining product freshness. This optimized logistics framework ultimately enhances customer satisfaction and cuts costs.

Stakeholder Impact

The benefits of blockchain adoption extend across the food supply chain, impacting various stakeholders (Hughes et al., 2019):

- ***Producers***: blockchain improves brand reputation and market differentiation by offering transparent product information. For example, Pietro Coricelli and Antonello Produce have strengthened consumer trust and brand value through blockchain-enabled traceability.
- ***Distributors***: enhanced tracking capabilities minimize product losses and streamline compliance with regulatory standards. Farmer Connect demonstrates how blockchain facilitates efficiency by ensuring direct connections between coffee farmers and consumers.
- ***Retailers***: reliable and transparent data builds consumer confidence. Walmart's use of blockchain to verify product origins has enhanced customer trust and reduced risks associated with counterfeit or unsafe goods.
- ***Consumers***: access to trustworthy, detailed product information empowers informed decision-making, improving consumer satisfaction and loyalty.

Companies like Walmart, Pietro Coricelli, Antonello Produce, and Farmer Connect illustrate the successful adoption of blockchain technology through IBM's Food Trust platform (Table 1).

Addressing Challenges

Despite its promise, blockchain is not without challenges (Ismail & Materwala, 2019).

The challenges in blockchain adoption for supply chains requires tackling high costs, scalability issues, data privacy concerns, and regulatory barriers:

- ***High costs***: The initial investment and ongoing maintenance expenses can deter smaller organizations from adopting blockchain solutions;

- ***Scalability issues***: Integrating blockchain with complex, high-volume supply chains present scalability challenges. Innovations in blockchain architecture, such as Layer 2 solutions, may mitigate these issues;
- ***Data privacy***: Sharing sensitive supply chain information on a blockchain network raises concerns about data privacy and confidentiality. Employing advanced encryption techniques and permissioned blockchains can address these concerns;
- ***Regulatory barriers***: The evolving nature of food safety regulations poses challenges for blockchain adoption. Industry-wide collaboration is crucial to establish standard protocols and ensure compliance with international guidelines.

By leveraging innovative solutions such as Layer 2 architectures, advanced encryption, permissioned blockchains, and fostering industry-wide collaboration, organizations can overcome these obstacles and unlock the transformative potential of blockchain technology (Cachin & Vukolic, 2017).

Table 1. Key Impacts of Blockchain Adoption

Company	Industry	Blockchain Application	Key Impacts	Source
Pietro Coricelli	Olive Oil	Traceability from grove to shelf	Increased consumer trust, brand differentiation	https://www.ibm.com/us-en
Antonello Produce	Fresh Produce	Tracking the journey of produce	Improved safety, reduced waste, enhanced reputation	https://www.ibm.com/us-en
Farmer Connect	Coffee	Connecting farmers and consumers	Promoted fair trade, increased transparency	https://www.ibm.com/us-en
Walmart	Retail	Tracking perishable goods like mangoes	Enhanced recall efficiency, consumer confidence	https://www.ibm.com/us-en

Practical Applications and Future Prospects

The ability of blockchain to integrate with complementary technologies such as the Internet of Things (IoT) and cloud computing makes it an invaluable tool for supply chain optimization through (Kim & Laskowski, 2018; Wang et al. 2019):

- ***Real-Time monitoring***: sensors linked to blockchain systems provide continuous updates on product conditions, enabling proactive decision-making;
- ***Predictive analytics***: blockchain-powered data analytics tools predict supply chain disruptions, enhancing resilience and efficiency.

Blockchain has the potential to greatly improve transparency and efficiency in global food supply chains. By enabling real-time tracking and providing immutable records, it offers a powerful tool to address fraud and contamination issues. Studies suggest that blockchain can significantly enhance transparency, ensuring that consumers and stakeholders have access to verified, traceable product information (Pandey et al., 2022).

Food traceability can be analyzed through both user interfaces and the underlying blockchain infrastructure. The process begins with a user-friendly dashboard that provides access to key traceability data. From there, the system relies on a decentralized network of nodes and an immutable digital ledger to securely record every transaction within the supply chain, ensuring transparency and food safety.

For example, in coffee supply chains, blockchain technology enables end-to-end traceability, allowing stakeholders to track the journey of coffee beans from their origin to the final consumer (Figure 2).

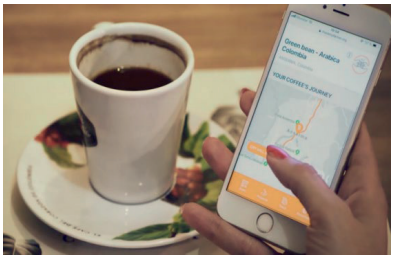

Figure 2. Traceability of coffee beans using Farmer Connect with IBM Food Trust Blockchain Network (https://www.ibm.com/us-en)

A Whole Grain Margherita Pizza consists of ingredients sourced from multiple locations across the global supply chain. Ensuring the authenticity and quality of these ingredients

requires a robust traceability system. Blockchain technology facilitates this process by providing transparent and verifiable data on the origin, production, and distribution of each component (Figure 3).

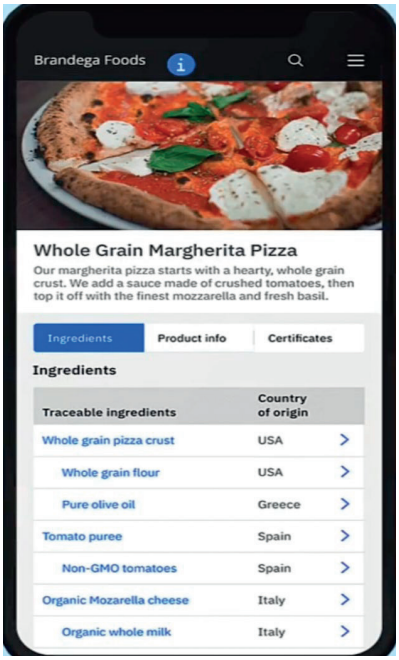

Figure 3. Traceability for Margherita Pizza from Brandega (https://www.ibm.com/us-en)

Exploring the Blockchain Architecture: Insights from MultiversX

Blockchain technology serves as the backbone of modern traceability solutions, transforming how we ensure transparency and trust in the food supply chain. Understanding the role of blockchain in traceability requires an examination of the MultiversX infrastructure - a blockchain that can be utilized to record every detail of a product's journey from origin to destination. Using data from the MultiversX testnet, this section explores how transactions are recorded, verified, and linked to create an immutable chain of information. Additionally, it highlights the critical function of nodes within the distributed network, ensuring data integrity and security.

The Blockchain's Role

Blockchain acts as an immutable digital ledger, documenting every transaction and movement of ingredients from farm to table. Each step in a product's journey is stored in a block, and these blocks are linked together, forming a secure and unalterable chain of information.

By enabling decentralized operations and secure data-sharing, blockchain allows companies to operate more collaboratively, reducing inefficiencies and fostering innovation. This shift in business models is particularly evident in industries like food supply chains, where blockchain's transparency and security are pivotal for building trust and improving operational practices (Scott et al., 2017).

Nodes: The Backbone of the Network

Unlike traditional databases, blockchain is not stored in a single location, it operates across a decentralized network of computers called nodes. Each node maintains a complete copy of the blockchain, contributing to its resilience and security.

Our TestNet wallet on the xSpotlight platform is a gateway to the exciting world of blockchain development. Built on the MultiversX blockchain, this platform empowers us to experiment and learn. This section examines the potential of decentralized applications and their role in supporting the growth of blockchain technology (Figure 4).

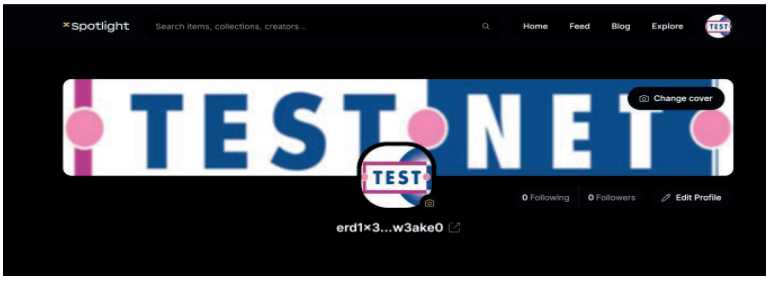

Figure 4. TestNet Traceability Blockchain Network thru xSpotlight using MultiversX Blockchain, made in Romania (Original)

Displayed is a transaction record from the MultiversX Testnet Explorer. It offers a glimpse into the underlying technology of blockchain, where every transaction is recorded and verified on a distributed ledger.

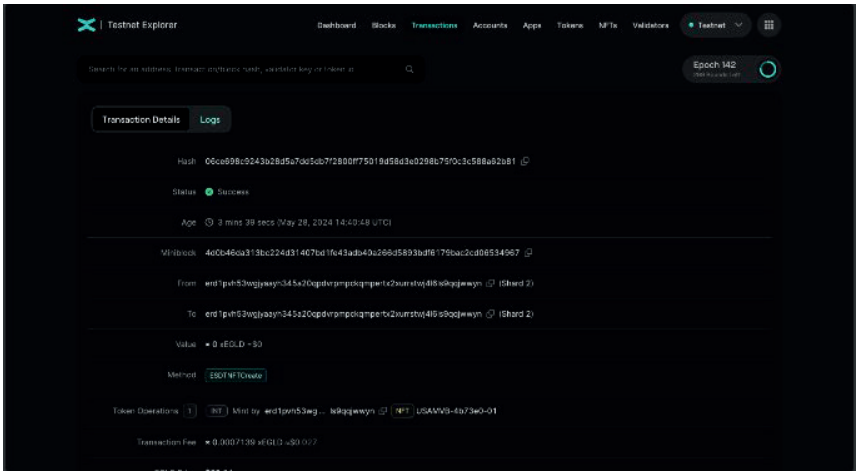

Figure 5. Transactions details on MultiversX Testnet Explorer (Original)

The provided data, such as the transaction hash, timestamp, and involved parties, demonstrates the transparency and security inherent in blockchain networks (Figure 5).

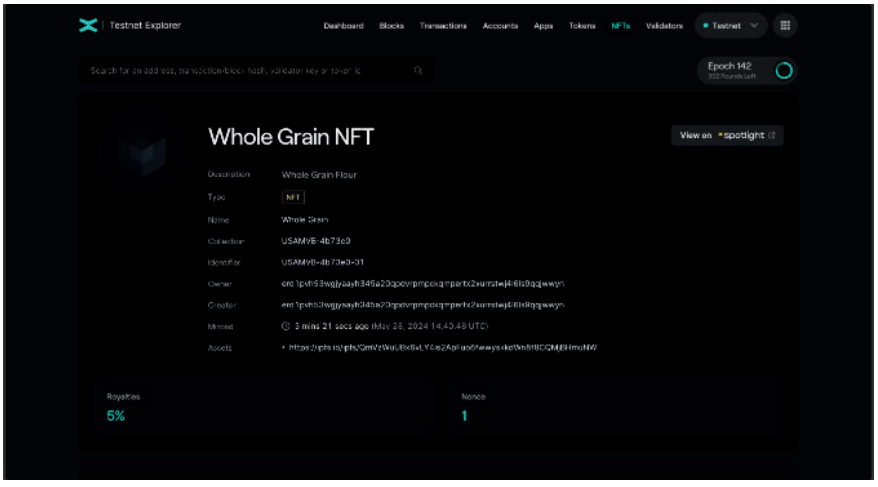

Figure 6. Information on its creator, the timestamp on Testnet Explorer (Original)

Figure 6 captures a snapshot of a Whole Grain on the MultiversX Testnet. The image provides detailed information about the product, including its creation timestamp, creator's wallet address, and associated metadata.

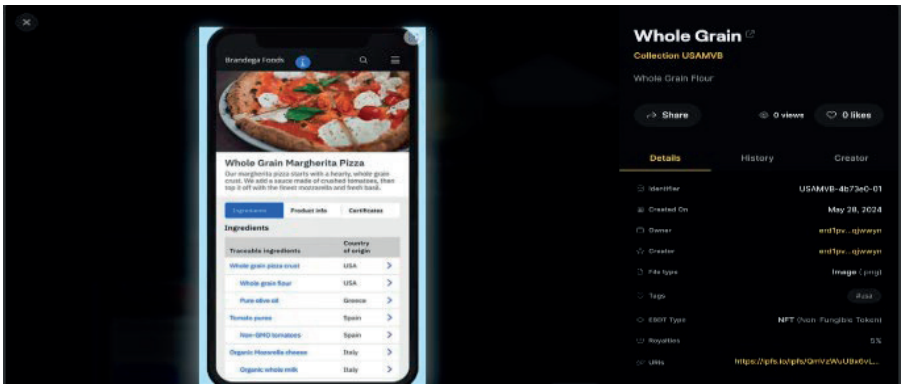

Figure 7. Margherita Pizza from Brandega Food in Blockchain on xSpotlight platform (Original)

Figure 7 depicts a digital representation of a Margherita Pizza on the xSpotlight platform. The Image associated with this pizza provides a detailed breakdown of its ingredients, their origin, and the entire production process. By utilizing blockchain technology, Brandega Food ensures the integrity and transparency of their products, allowing consumers to make informed choices about the food they consume.

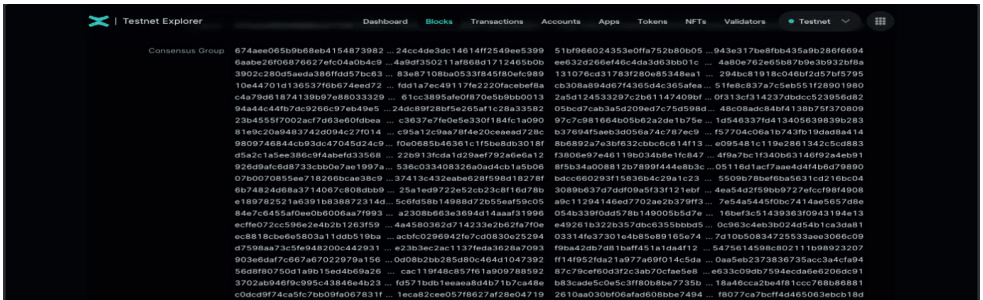

Figure 8. All validators “People” who add info to the block “Margherita Pizza” on Testnet Explorer MultiversX Blockchain (Original)

Figure 8 illustrates the collaborative effort of validators in securing the MultiversX Testnet. These validators, represented by their unique addresses, work together to verify and add new blocks to the chain, including the one containning the Margherita Pizza. This collective effort ensures the integrity and security of the network, making it a reliable platform for various applications, including food traceability. Behind the scenes, blockchain technology underpins the app's functionality. It records each step of the Margherita pizza's journey, from sourcing the fresh ingredients - such as tomatoes, mozzarella, and basil - to dough preparation, baking, and packaging. This data is stored in immutable blocks, creating a transparent and tamper-proof record. Each participant in the supply chain, such as farmers, processors, and distributors, acts as a node in the blockchain network. They contribute data about the movement and processing, which is verified and added to the blockchain. This ensures the information is accurate and trustworthy (Gipp et al., 2015).

Blockchain technology, along with its network of nodes and complex data structures, may initially appear sophisticated. The numerous technical terms and interconnected processes can create a perception of complexity. However, these elements represent the

underlying framework that ensures transparency, security, and traceability within the system.

From Complexity to Simplicity: Navigating Blockchain Through IBM Food Trust

The IBM Food Trust Platform serves as a user-friendly interface designed to enhance traceability within the supply chain. It simplifies the complexity of blockchain technology by offering an intuitive dashboard, where raw data is transformed into actionable insights. Through features such as visual analytics, real-time tracking, and automated data integration, the platform facilitates informed decision-making for businesses aiming to improve transparency and operational efficiency.

While blockchain provides the underlying infrastructure for secure data management, IBM Food Trust offers a structured environment where stakeholders can monitor and verify product traceability with ease. The following section explores the dashboard's functionalities and its role in streamlining supply chain oversight (Figure 9).

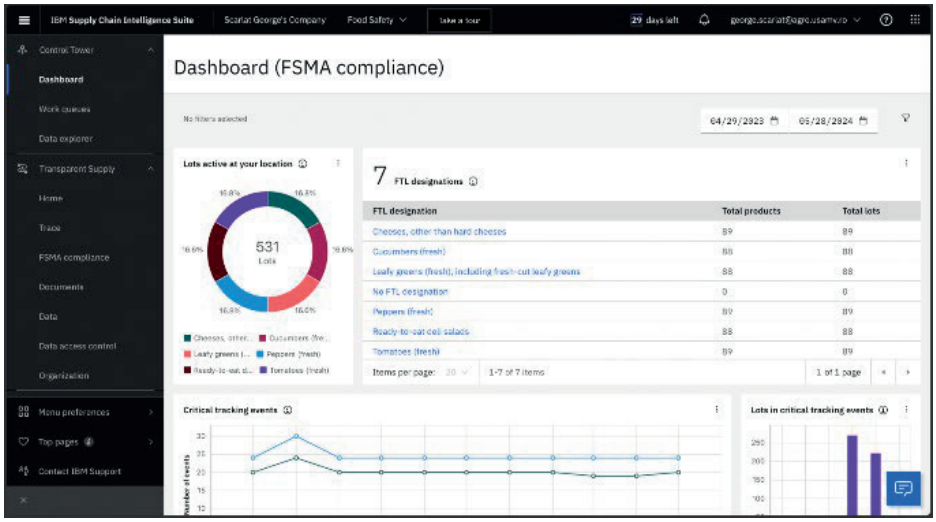

Figure 9. IBM Supply Chain Intelligence Suite Dashboard (Original)

Core components of the dashboard are represented by:

- Dashboard (FSMA compliance): The main title indicating the dashboard's focus.
- Work queues: A section likely for managing tasks and alerts related to food safety.
- Data explorer: A tool for exploring and analysing data within the system.
- Transparent Supply: A module that provides visibility into the supply chain.
- Lots active at your location: A counter showing 7 active lots.
- FTL designations: A table listing different food types and their corresponding FTL (Full Truckload) designations, along with total products and lots.
- Lots: A pie chart illustrating the distribution of lots across various food categories.
- Critical tracking events: A graph showing the trend of critical events over time.

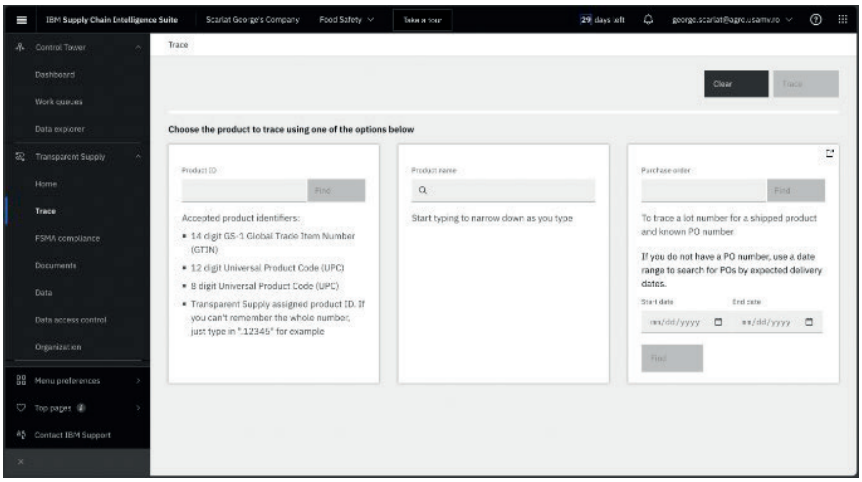

Figure 10. IBM Food Trust Platform: Simplifying Traceability with the Data Explorer (Original)

IBM Food Trust Platform's Data Explorer section, a prime example of how technology simplifies complexity. Here's how it translates the intricate blockchain data into an organized, user-friendly interface (Figure 10), like:

- ***Organized Data***: The platform neatly arranges information into columns: Lot Code (a unique identifier), Type (product category), Product Name, Product ID, Lot Code Creator, Lot Origin Location, and more. This clear structure makes it easy to locate specific products and track their journey through the supply chain.
- ***Searchable and Filterable***: The search bar at the top allows users to quickly find specific lot codes or products. Additionally, the platform likely offers filtering options to narrow down the results by type, location, or other relevant criteria.
- ***Transparency at a Glance***: Each row represents a single lot of a product. By clicking on a lot code, users can access detailed information about its origin, processing, and movement throughout the supply chain. This transparency empowers stakeholders to verify the authenticity and quality of products.
- ***Streamlined Collaboration***: The platform is designed for collaboration among different stakeholders in the supply chain. Suppliers, manufacturers, distributors, and retailers can share data securely, ensuring everyone has access to the most up-to-date information.

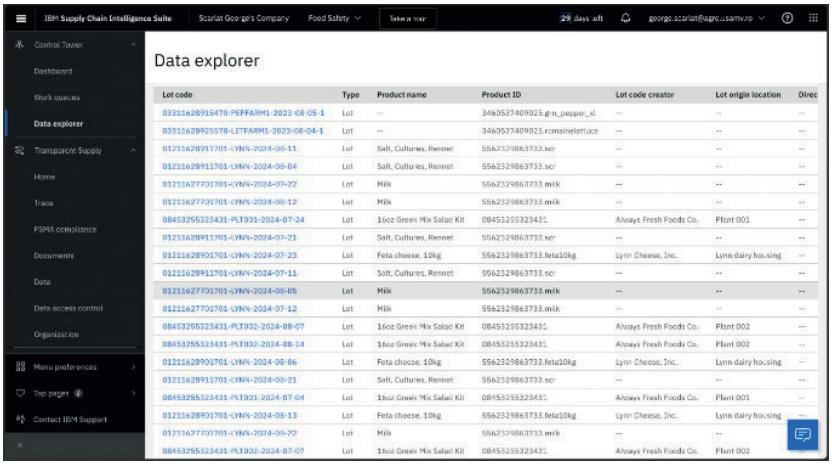

Figure 11. Trace feature on IBM Dashboard (Original)

This image displays the "Trace" feature within the IBM Supply Chain Intelligence Suite. This interface allows users to easily trace the journey of a product throughout the supply chain (Figure 11).

Here's how it simplifies the complexity of traceability:

Multiple Search Options: The platform provides three distinct search options, accommodating different ways users might identify a product:

- ***Product ID***: This could be an internal identifier assigned by the company or a universal code like a Global Trade Item Number (GTIN) or Universal Product Code (UPC);
- ***Product Name***: Users can search by the product's name, which is useful when the exact ID isn't known;
- ***Purchase Order (PO) Number and Date Range***: If the user knows the purchase order associated with the product, they can input that along with a date range to narrow down their search.

User-Friendly Search: The platform allows users to start typing and automatically narrows down the search results, similar to a search engine, making it easier to find the right product even with partial information.

Clear Instructions: Clear instructions are provided for each search option, explaining what information to enter and how to use the search effectively.

This helps even users unfamiliar with the platform to use it efficiently.

Traceability at Your Fingertips: Once a product is selected, the platform can likely display a detailed history of its journey through the supply chain. This includes information about its origin, processing, transportation, and any relevant certifications or inspections.

Empowering Transparency: By making traceability information easily accessible, the platform empowers businesses to ensure the quality and safety of their products. It also allows them to identify potential bottlenecks or disruptions in the supply chain.

Blockchain technology is revolutionizing supply chain management, offering unprecedented transparency and traceability. While the underlying technology may seem complex, platforms like IBM Food Trust and the IBM Supply Chain Intelligence Suite simplify the process, making it accessible and valuable for businesses of all sizes

CONCLUSIONS

This research highlights the transformative potential of blockchain technology in enhancing food safety and transparency within the supply chain. By offering immutable and decentralized record-keeping, blockchain ensures traceability from farm to fork. Initiatives such as IBM Food Trust validate blockchain's real-world applicability, demonstrating its ability to simplify processes, reduce fraud, and empower consumers with detailed, trustworthy information.

Blockchain's unique capacity to create tamper-proof ledgers aligns seamlessly with the needs of the food industry, revolutionizing safety protocols, mitigating counterfeit risks, and enabling swift responses to contamination issues.

However, blockchain is not a universal solution. Challenges such as scalability, interoperability, and evolving regulatory frameworks must be addressed. Successful adoption will require collaboration across all industry stakeholders to establish standards and overcome these barriers.

Despite these hurdles, blockchain holds huge promise for advancing food safety, transparency, and sustainability. Its ongoing evolution will pave the way for innovative applications that redefine global supply chains.

In conclusion, blockchain technology presents a pivotal opportunity to build safer, more transparent, and resilient food systems, fostering trust and security for future generations.

REFERENCES

Cachin, C., & Vukolić, M. (2017). Blockchain consensus protocols in the wild. *Leibniz International Proceedings in Informatics*, *91*, 1–16.

Casino, F., Dasaklis, T. K., & Patsakis, C. (2019). A systematic literature review of blockchain-based applications: Current status, classification and open issues. *Telematics and Informatics*, *36*, 55–81. DOI: 10.1016/j.tele.2018.11.006.

Crosby, M., Pattanayak, P., Verma, S., & Kalyanaraman, V. (2016). Blockchain technology: Beyond bitcoin. *Applied Innovation Review*, *2*, 71. Retrieved October

12, 2024, from https://scet.berkeley.edu/wp-content/uploads/AIR-2016-Blockchain.pdf.

Gipp, B., Meuschke, N., & Gernandt, A. (2015). Decentralized trusted timestamping using the crypto currency bitcoin. *iConference 2015 Proceedings*, 1-6. https://doi.org/10.5281/zenodo.3547488.

Hughes, A., Parl, A., Kietzmann, J., & Archer-Brown, C. (2019). Beyond Bitcoin: What blockchain and distributed ledger technologies mean for firms. *Business Horizons*, *62*(3), 273-281. https://doi.org/10.1016/j.bushor.2019.01.002.

International Business Machines Corporation (n.d.). Retrieved from https://www.ibm.com/us-en (28th May 2024)

Ismail, L., & Materwala, H. (2019). A review of blockchain architecture and consensus protocols: Use cases, challenges and solutions. *Symmetry, 11*(10), 1198. https://doi.org/10.3390/sym11101198.

Kim, H.M., & Laskowski, M. (2018). Toward an Ontology-Driven Blockchain Design for Supply-Chain Provenance. *Intelligent Systems in Accounting, Finance and Management*, *25*(1), 18-27.

Pandey, V., Pant, M., & Snasel, V. (2022). Blockchain technology in food supply chains: Review and bibliometric analysis. *Technology in Society*, 69, 101954. https://www.sciencedirect.com/science/article/pii/S0160791X22000951

Patelli, N., & Mandrioli, M. (2020). Blockchain technology and traceability in the agrifood industry. *Journal of food science*, *85*(11), 3670–3678. https://doi.org/10.1111/1750-3841.15477.

Scott, B., Loonam, J., & Kumar, V. (2017). Exploring the rise of blockchain technology: Towards distributed collaborative organizations. *Strategic Change*, *26*, 423–428. DOI: 10.1002/jsc.2142.

MultiversX Blockchain Testnet Explorer (n.d). Retrieved from https://testnet-explorer.multiversx.com/ (28th May 2024)

United Nations, Department of Economic and Social Affairs, Population Division (2022). World Population Prospects. Retrieved October 10, 2024, from https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf

Wang, Y., Han, J. H., & Beynon-Davies, P. (2019). Understanding Blockchain Technology for Future Supply Chains: A Systematic Literature Review and Research Agenda. *Supply Chain Management: An International Journal*, 169917106. DOI: 10.1108/SCM-03-2018-0148

xSpotlight platform on MultiversX blockchain (n.d). Retrieved from https://testnet.xspotlight.com/ (28th May 2024)