TRACEABILITY IN AGRI-FOOD PRODUCTION AND SUPPLY CHAINS

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Abstract: *Enabling the traceability of food products is a must in developing markets. This is closely related not only to safety issues but also to food quality, regulations, and conditions that should be strictly checked and maintained in supply chains. Many new technologies can be of help in implementing traceability like automatic identification technology, blockchain technology, the Internet of Things, and global positioning systems. This paper provides an analysis of traceability systems and supporting technologies, their benefits and challenges, and the regulatory frameworks governing their implementation. The findings contribute to the understanding of traceability in the agri-food sector and provide valuable insights for policymakers, researchers, and industry stakeholders.*

Key words: automatic identification, Internet of Things; blockchain

1. INTRODUCTION

The production and supply chain is a complex system linking many stakeholders, including producers, distributors, retailers, and consumers. There are growing concerns about product quality, safety, and sustainability. Traceability is a key feature that enables verification of previous product stages, locations, and characteristics throughout the supply chain.

Traceability is particularly important in the agri-food sector as it helps to protect public health. It enables the rapid identification of spoiled and contaminated food, minimizing food recalls and protecting consumers. Traceability also contributes to product quality and authenticity. Information from the traceability system, filtered for consumer use, can help consumers in doubt to make an informed choice. In most cases, this information relates to food processing methods, standards, and special dietary requirements (Fanelli, V., et.al, 2021). Traceability helps to build consumer confidence in the product, production, and supply chain.

In order to achieve product traceability there is a need to establish efficient supply chain management. A supply chain management system with logistics planning, optimization of distribution, procurement, and profit analysis must be provided with real-time information about each transformation from raw material procurement to the final product in retail. In this way, production and distribution costs can be cut down thus reducing waste that is of special importance for food products with short shelf life.

Digital technologies that can improve traceability systems include automatic identification technologies such as barcodes (linear, 2D, 3D) and radio frequency identification (RFID), but also technologies such as global positioning system (GPS), blockchain, and the Internet of Things (IoT). These technologies offer increased data accuracy, real-time monitoring, and improved interoperability between supply chain participants.

When implementing traceability systems one must bear in mind numerous challenges like cost of implementation, diverse standardization protocols across different regions and industries, data privacy and security, etc. The cost of implementation must not overtake the benefits of having a traceability system.

This review paper aims to present key components of traceability systems, and technologies used for implementation, and analyze the challenges and standards governing traceability practices. The review will also highlight recent advancements and emerging trends in traceability, such as automatic identification technology, global positioning system, Internet of Things, and blockchain technology.

2. COMPONENTS OF TRACEABILITY SYSTEMS, TRACEABILITY TECHNOLOGIES AND CHALLENGES IMPLEMENTATION

Traceability systems are complex systems consisting of numerous interconnected components that enable tracing the movement of products and ingredients throughout the whole production processes and supply chain. These components acquire information in each phase of product transformation and also storing, and sharing information is enabled with the purpose to access and utilize these data effectively. The key components of traceability systems include data acquisition and storage, data accessibility and sharing, and traceability standards and protocols.

The fundamental components of traceability systems are labeling and identification. Every component of the product or final product, during the production process and throughout the whole supply chain needs to be uniquely labeled and identified. Different technologies can be used for this purpose like linear, 2D or 3D barcode, RFID (Radio Frequency Identification) tags, or other labeling techniques. Data related to labeled objects/products contain essential information, such as product name, substances, production date and expiration date, batch or lot number, origin, shelf-life, serial number, etc. Data acquisition, storing, and sharing at various stages of the supply chain in case of traceability is a must. Data can be acquired manually or automatically using technologies such as sensors (Zhang X., et.al, 2023), scanners, cameras, or IoT (Internet of Things) devices. These data are typically stored in databases or cloud-based systems for further sharing, processing, and analysis with the basic purpose of cutting costs of production, distribution, and waste. Data management systems, that include databases and cloud-based systems, should have thorough security measures in order to protect against unauthorized access (Prodanović R., 2020). When designing these systems, one must bear in mind the huge amount of data and that filtering and efficient data retrieval should be enabled.

Besides this information about the object/product, another essential information in the traceability system is its’ location throughout the whole supply chain. GPS (Global Positioning System) technology leverages satellite-based navigation systems to determine the precise location of objects/products. GPS-enabled tracking devices can be attached to containers, vehicles, or even livestock, enabling real-time monitoring of their movement and location (Min, H., et.al., 2019). GPS enhances traceability by providing accurate geospatial data, allowing stakeholders to track the movement of products throughout the supply chain. It facilitates logistics management, route optimization, and delivery tracking, contributing to improved supply chain efficiency and transparency.

During each product transformation, information about the product and its’ location can be corrupted. Blockchain technology enables the secure and transparent recording of transactions and data related to the movement of products (Mastilović J., et. al, 2023). Blockchain is a ledger system that is decentralized and distributed. It records and verifies transactions across multiple participants. Each transaction or event in the supply chain is recorded as a block, forming an immutable chain of information. Blockchain enhances traceability by providing a tamper-proof and auditable record of product provenance, certifications, and handling conditions. It enables stakeholders to verify the authenticity and integrity of data, increasing trust and transparency in the supply chain (Tegeltija S., et.al, 2022).

Since there can be numerous stakeholders requiring data from database management systems it is required to provide collaboration and communication among them. This implies the usage of communication protocols and interfaces for exchanging object/product data between different parties, which ensures continuous information flow.

Besides communication standards, basic parts of traceability systems are standards and protocols to ensure data consistency and harmonization across supply chains. These standards define the requirements for data formats, labeling, data exchange, and interoperability. International organizations, such as GS1, have developed standards for barcoding, labeling, and data synchronization. There are also standards implemented in the agri-food sector, such as the Safe Quality Food (SQF) standard or Organic certification, which provide guidelines for implementing traceability systems (Chen, H., & Prater, E., 2013).

As previously mentioned, product data can be acquired using sensors, scanners, cameras, or IoT devices. The IoT is the network of interconnected devices embedded with sensors, software, and connectivity capabilities. IoT devices collect and transmit data in real time, enabling continuous monitoring and tracking of products, environmental conditions, and processes. In traceability, IoT devices such as temperature sensors, humidity monitors, or RFID readers provide real-time data on product conditions and movements. This information is crucial for ensuring product quality, detecting anomalies, and enabling proactive decision-making throughout the supply chain. IoT enhances traceability by enabling seamless data collection, monitoring, and communication among supply chain stakeholders.

When implementing traceability systems in most cases there is a need for a combination of some of the previously described technologies to achieve optimal results, like product data accuracy and real-time product monitoring across the supply chain.

Traceability system implementation does not only bring benefits. Implementors must also be aware of potential problems and challenges in order to ensure successful traceability system implementation.

Some of the challenges can be the cost of implementation that can overtake benefits, the complexity of supply chains, the lack of standards, and legal challenges.

Implementation of traceability in production and product supply chain requires significant investments in software, hardware, infrastructure, and stakeholders' training. In most cases, stakeholders must adopt new procedures for which it takes time to achieve effectiveness, essentially in complex supply chains. Each stakeholder may have different systems (infrastructure, hardware, software, procedures), processes, and data requirements, making it challenging to achieve continuous traceability across the production and whole supply chain.

Another significant challenge is, in most cases, the lack of standardized systems. Each stakeholder may use diverse data formats, protocols, and coding schemes, which are difficult to integrate into the uniform information system. Also, data privacy and security are crucial in preventing unauthorized access. It has to be in compliance with regulations for data protection, such as the General Data Protection Regulation (GDPR). Balancing the need for traceability and transparency with data privacy concerns is an ongoing challenge.

Regulatory frameworks and standards play a crucial role in ensuring consistent and harmonized traceability practices across production and supply chains. In the agri-food sector, there are international bodies, such as the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), that have developed guidelines and recommendations for implementing traceability. These guidelines aim to enhance food safety, protect public health, and facilitate trade by providing a common understanding of traceability principles and best practices. International regulations, such as the Codex Alimentarius, also provide guidance on traceability requirements and the use of identification systems, labeling, and documentation in international trade. There are also industry-specific initiatives and certifications in promoting traceability often led by industry associations, certification bodies, or retailers. For instance, the Safe Quality Food (SQF) standard provides a framework for implementing traceability systems, risk assessments, and product recalls in the food industry. Organic certification programs also require traceability to ensure the integrity and authenticity of organic products. Additionally, sustainability certifications, such as Fairtrade or Rainforest Alliance, may include traceability as part of their standards.

Compliance with regulatory requirements not only ensures legal obligations are met but also enhances the effectiveness of traceability systems in improving food safety, quality assurance, and supply chain management.

3. CASE STUDIES AND INDUSTRY PRACTICES

Various case studies and industry practices demonstrate the successful implementation of traceability in agri-food production and supply chains. These advancements have brought about numerous benefits, including improved transparency, enhanced supply chain efficiency, and increased consumer trust. Here are some notable advances in traceability in agri-food sector:

- Farm-to-fork traceability systems: Farm-to-fork traceability systems provide end-to-end visibility of the supply chain. For instance, companies like HarvestMark and FoodLogiQ have developed traceability platforms that integrate data from multiple stakeholders, including farmers, processors, distributors, and retailers (Fang, L., & Ge, H., 2023). These platforms utilize technologies like barcoding, RFID, and blockchain to capture and share traceability information, allowing consumers to access detailed product information, such as production methods, certifications, and quality attributes.
- Supply chain transparency and visibility: Traceability systems have been instrumental in enhancing supply chain transparency and visibility. Walmart, for example, implemented a traceability initiative requiring its suppliers of leafy greens to use blockchain technology for traceability. By capturing data about the origin, handling, and transportation of leafy greens, Walmart achieved improved transparency, reduced response times during food recalls, and increased consumer confidence in the safety of their products (Hilten, M., et.al., 2020). Other retailers and food companies have also embraced similar initiatives to enhance visibility and build trust with consumers.
- Sustainability and ethical sourcing initiatives: Traceability systems are increasingly utilized to support sustainability and ethical sourcing practices. Companies like Nestlé and Mars have implemented traceability systems to ensure responsible sourcing of cocoa and palm oil. These

systems allow them to trace the origin of raw materials, assess environmental and social impacts, and verify compliance with sustainability certifications (Acierno, V., et.al, 2018). By integrating traceability into their sourcing strategies, these companies can promote transparency, support farmers' livelihoods, and address deforestation and human rights concerns in their supply chains.

- Consumer engagement and empowerment: Traceability systems are empowering consumers by providing them with access to information about the products they purchase. Apps and online platforms, such as OpenSC and Provenance, allow consumers to scan QR codes or product labels to access detailed information about the product's journey, sustainability credentials, and social impact (Obaid, T., 2016). This enables consumers to make informed choices aligned with their values, such as supporting fair trade, organic, or locally sourced products. By engaging consumers in the traceability process, these initiatives foster trust, accountability, and a stronger connection between consumers and producers.
- Improved recall management and crisis response: Traceability systems have proven instrumental in recall management and crisis response. During foodborne illness outbreaks or product recalls, traceability enables rapid identification of affected products, targeted recalls, and efficient communication with consumers. For example, in 2018, a romaine lettuce recall in the United States was traced back to a specific farm using blockchain technology, which facilitated quick removal of contaminated products from the market, protecting public health and minimizing economic losses for the industry (Jensen, A., et. al, 2013). Traceability enhances trace-back and trace-forward capabilities, reducing response times and the scope of recalls in the event of safety concerns.

These case studies and industry practices demonstrate the tangible benefits of traceability in the agri-food sector. By leveraging technology, enhancing transparency, supporting sustainability, and empowering consumers, traceability systems have improved supply chain efficiency, product safety, and consumer trust. These advancements serve as examples for other stakeholders in the industry, inspiring them to adopt and enhance traceability practices to meet the evolving demands of consumers and regulatory requirements.

4. TRENDS AND FUTURE DIRECTIONS

Emerging trends and future directions in traceability have great potential for further enhancing transparency, efficiency, and sustainability in the agri-food sector. It is noticed that there are some possibilities in key emerging trends, as follows:

- Implementation of artificial intelligence (AI) and machine learning (ML): AI and ML algorithms are being integrated into traceability systems to analyze and interpret large volumes of data since they can extract product information, real-time monitoring, anomaly detection, and predictive analytics, and thus can be used in risk assessment, and effective decision-making in areas such as inventory management, process downtime minimization, and quality control.
- Implementation of sensor technologies and real-time monitoring during product life cycle like temperature sensors, humidity monitors, and GPS trackers. Real-time monitoring helps make decisions on actions to maintain product integrity, optimize storage conditions, and prevent quality degradation.
- Blockchain-enabled supply chain traceability: Blockchain enables end-to-end traceability by creating an auditable record of every transaction and event in the supply chain. It offers benefits such as improved data integrity, enhanced security, and increased trust among supply chain participants.
- Enhancing interoperability and data exchange: by the development of standardized data formats, protocols, and interfaces that enable data exchange and interoperability.

As traceability technologies continue to advance, it is important to consider ethical and legal implications, including data privacy, security, and ownership. Addressing these concerns will be essential for maintaining consumer trust and ensuring the responsible use of traceability systems.

5. CONCLUSION

Traceability is one of the most important features of each production system, especially in agri-food production and supply chains, since it ensures the safety, quality, and sustainability of a product. The importance of traceability also can be in determining authenticity, and ethical practices, strengthening consumer trust and confidence, and enabling efficient supply chain management.

The components of traceability systems, such as identification and labeling, data acquisition, storage, sharing and accessibility, and traceability standards and protocols, work together to enable the effective tracking and tracing of products and ingredients throughout the whole supply chain.

However, implementing traceability systems is not without challenges. The cost of implementation, the complexity of supply chains, data privacy, and security concerns, lack of standardized systems, and legal challenges pose barriers to widespread adoption and effective implementation.

Regulatory frameworks and standards play a crucial role in ensuring consistent and harmonized traceability practices. International regulations, regional requirements, and industry-specific initiatives provide guidelines and requirements for traceability implementation, promoting transparency and accountability.

Case studies and industry practices have demonstrated the benefits of traceability in various areas, including farm-to-fork traceability systems, supply chain transparency, sustainability and ethical sourcing initiatives, consumer engagement, and improved recall management.

The future of traceability lies in using emerging technologies, promoting collaboration, and aligning traceability efforts with broader sustainability and circular economy initiatives. The integration of traceability with other digital technologies, such as AI, ML, IoT, and blockchain, has the potential to revolutionize supply chain management, product authenticity, and consumer trust. By embracing these emerging trends and driving continuous innovation, the agri-food sector can further enhance traceability practices, leading to safer, more sustainable, and transparent food systems.

In conclusion, traceability in agri-food production and supply chains is essential for ensuring food safety, quality, authenticity, and sustainability. By implementation of technological advancements, bearing in mind challenges, complying with regulatory and standard frameworks, and adopting best practices, stakeholders can foster transparency, efficiency, and consumer trust in the agri-food sector.

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