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Integration and Analysis of Data in Grain Quality and Safety Traceability Using Blockchain Technology

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Abstract. As the complexity of the global food supply chain continues to grow, ensuring food quality and safety has become an important challenge for the global food industry. Food quality and safety traceability is a key methodology that can be used to track the origin and quality of food to ensure food safety. Meanwhile, blockchain technology, as a distributed ledger technology, provides new opportunities for food traceability. This study aims to explore how to integrate blockchain technology and data fusion analysis to improve the efficiency and accuracy of food quality and safety traceability. This paper first reviews the advantages of blockchain technology in food traceability and introduce the key concepts of data fusion analysis. Then, this paper proposes a blockchain-based framework for food quality and safety traceability, describing in detail the process of data collection, cleaning, fusion and analysis. Through practical case studies, this paper demonstrates the application of the framework in the field of grain quality and safety, and presents the fusion analysis results. Finally, the paper discusses future directions, including technical challenges, regulatory implications, and sustainability considerations. This study provides strong support for the integration of food quality and safety traceability and blockchain technology, which is expected to contribute to the further development of global food security and quality management.

Keywords: Food quality and safety, traceability, blockchain technology, data fusion analysis, food safety

1. Introduction

The management of the global food supply chain has always been a complex and important challenge. As population growth and urbanization accelerate, the demand for food is increasing, while food production, distribution and quality management are becoming more complex (Salah et al., 2019). At the same time, food quality and safety issues have attracted widespread attention. In the global marketplace, the supply chain for food typically spans multiple countries and regions and involves a multitude of players, including farmers, producers, wholesalers, retailers, and government regulators. This decentralized supply chain structure complicates the regulation of food quality and safety, and can easily lead to information asymmetry, fraudulent practices, and food safety problems.

Traditional methods of food quality and safety monitoring often rely on manual records and reports, which are vulnerable to tampering and errors (Zhang et al., 2020). Moreover, when a quality problem arises, it usually takes a lot of time to trace the root cause of the problem, which may have caused serious losses. Therefore, there is an urgent need to introduce advanced technologies and methods to enhance the regulation and traceability of food quality and safety.

Blockchain is a distributed ledger technology that is decentralized, untamperable and transparent, as shown in Figure 1. It makes it possible to trace food quality and safety back to the source, with every step of the record securely stored on the blockchain and available for verification by all parties. Blockchain can also provide traceability and transparency to all parts of the food supply chain, helping to quickly identify and solve problems (Sharma et al., 2020). Therefore, combining blockchain technology with food quality and safety regulation has great potential.

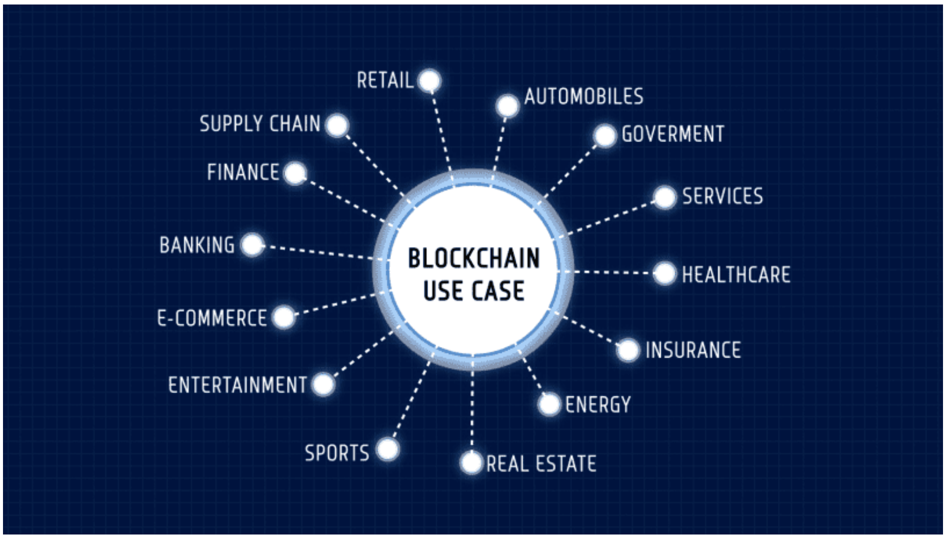

Fig.1: Blockchain Applications

The combination of food quality and safety traceability and blockchain technology is a highly regarded research field, attracting the attention and research of many scholars and research institutions at home and abroad (Xu et al., 2022).

Application of blockchain technology in the field of food safety: foreign scholars began to study the application of blockchain technology in the field of food safety several years ago. Studies show that blockchain technology can improve the transparency and traceability of the food supply chain and reduce the occurrence of food safety incidents (Zhang et al., 2023). For example, a well-known foreign supermarket chain introduced blockchain technology, allowing consumers to scan product labels to view the origin and production information of the products, which improves the credibility of food products. Domestic researchers have also actively explored the application of blockchain technology in food traceability. They have proposed a series of blockchain-based food quality and safety traceability systems and conducted practical case studies. These systems can track the origin, production conditions and transportation history of food, improving the efficiency of food safety management.

Application of data fusion analysis methods: foreign researchers have also made significant progress in the field of data fusion analysis. They have developed various data fusion techniques, including multi-source data integration, data cleansing and data mining methods, for improving the processing efficiency and analyzing accuracy of food safety data (Cocco et al., 2021). These methods provide strong support for food quality and safety traceability. Domestic researchers have also carried out a lot of work in the field of data fusion analysis. They have proposed multi-source data fusion methods, including the integration of sensor data, remote monitoring data and traditional data, to improve the accuracy of food quality regulation. These methods have already achieved some success in practical applications.

Practical case studies: some foreign companies have begun to adopt blockchain technology for grain quality and safety traceability in actual production. These case studies show that blockchain technology can improve the credibility of the supply chain and reduce the occurrence of food quality problems (Cocco & Mannaro, 2021). For example, a large foreign food company uses blockchain technology to track the transportation and storage conditions of food to ensure its freshness and safety. Domestic governments have also stepped up regulation and standardization of food quality and safety. Some local governments have begun to promote the application of blockchain technology in the field of food quality and safety, establishing a series of relevant policies and standards to ensure the legal and compliant application of blockchain technology.

In summary, domestic and international researchers and organizations have made significant progress in the study of food quality and safety traceability and blockchain technology (Gupta & Shankar, 2023). Although some challenges remain, such as data privacy protection, development of technical standards and cross-border cooperation, research in this area will continue to contribute to the continuous improvement of global food quality and safety management to ensure food safety and quality for consumers.

Blockchain is a decentralized distributed ledger that is tamper-proof, transparent and secure. It consists of a series of blocks, each of which contains a certain amount of transaction data and is linked to the previous block by cryptography to form a chain (Yakubu et al., 2022). This structure makes it virtually impossible to modify information once it has been written into the blockchain, ensuring the trustworthiness of the data.

Blockchain technology makes it possible to record and trace information throughout the food supply chain. Every step from farm to fork can be accurately recorded, ensuring that the origin and history of the food can be traced. Data on the blockchain is encrypted and cannot be easily tampered with. This means it is difficult for malicious actors to forge or tamper with food information. Blockchain can provide almost real-time data updates, helping to quickly identify and resolve potential problems, reducing the spread and impact of food safety incidents (Li et al., 2022).

Some enterprises and organizations at home and abroad have already begun to try to apply blockchain technology to food safety traceability. For example, Walmart, an internationally renowned supermarket chain, uses blockchain technology to track the supply chain of some commodities and is able to identify the source of food within seconds, greatly improving the management of food safety. In addition, some domestic agricultural product traceability platforms are also exploring the application of blockchain technology to ensure the safety of domestic food quality.

Data fusion analysis is the process of integrating, cleaning and analyzing data from multiple sources. It can combine multiple data types, such as sensor data, remote monitoring data and traditional data, to obtain more comprehensive information (Hu et al., 2019). This approach can help regulatory agencies and businesses better understand the state of food quality and safety.

Data fusion analysis brings together data from different sources to help regulators build a more comprehensive picture of food quality and safety. For example, combining weather data and farmland sensor data can better predict the growth and quality of produce. Fusion analytics can also help clean inaccurate or erroneous data, improving the quality and accuracy of the data and reducing the risk of poor decision-making.

Some domestic regulatory agencies have begun to use data fusion analytics to monitor food quality and safety. They have combined sensor data, inspection data and remote monitoring data to achieve more comprehensive regulation of food quality and safety (Lee, 2021). These methods have already played an active role in the early identification of and rapid response to food safety incidents.

The main objective of this study is to explore how blockchain technology as well as data fusion analysis methods can be utilized to enhance the regulation and traceability of food quality and safety. Specifically, this study aims to achieve the following objectives:

Developing a fusion methodology for blockchain technology and grain quality data: this paper will explore how to combine blockchain technology with grain quality data to establish a secure and trustworthy grain quality and safety information system (Nie & Liu, 2021). This will include key steps such as data collection, cleansing, storage and analysis.

Validating the application value of blockchain technology in grain quality and safety traceability: through actual case studies, this paper will validate the effectiveness and feasibility of the proposed blockchain framework in grain quality and safety traceability. This paper will collect actual market data and perform data fusion analysis to demonstrate how blockchain technology can improve the regulation of grain quality and safety.

Exploring Future Directions and Challenges: finally, this paper will discuss the future directions of blockchain technology in the field of grain quality and safety regulation, as well as identifying and exploring possible challenges, such as data privacy, regulatory compliance, and technical standards.

This research has important theoretical and practical implications. First, it helps to improve global food quality and safety management and reduce the occurrence of food safety problems. Second, it provides practical cases and experiences for the application of blockchain technology in the food supply chain, which provides strong support for future research and practice. Finally, by exploring data fusion analysis methods, this study also helps to improve the efficiency of data management and analysis, which is also relevant for data management in other fields.

2. Methods

2.1. Theoretical foundations of food quality and safety traceability

Food is one of the basic needs of human life and is vital to people's survival and health. Therefore, the quality and safety of food is of great concern. The quality and safety of food refers to the fact that food products are free from pollution, adulteration, pests, mold and other factors during production, processing, transportation, storage and sale, ensuring that food products meet the requirements of hygiene, nutrition, standards and laws and regulations, and that they do not pose a hazard to human health, so as to safeguard the quality and safety of the food that people consume.

Grain products must meet hygiene standards and not contain harmful microorganisms, toxic substances or chemical contaminants. Hygiene and safety are related to human health and are one of the basic elements of food quality and safety. Grain must provide sufficient nutrition, including protein, carbohydrates, fat, vitamins and minerals, to meet the growth and health needs of the human body. It is important not only to provide adequate nutrition, but also to ensure the balance and diversity of nutrients in food. Food products must meet international and national quality standards as well as legal and regulatory requirements. These standards and regulations include provisions for all aspects of the production, processing, transportation, storage and marketing of food products. Food products must be traceable, i.e. they can be traced back to all stages of their production and distribution. This facilitates the rapid identification and resolution of quality problems and reduces the spread and impact of food safety incidents.

Food quality and safety is of paramount importance to both individuals and society:

Individual health: Consumption of unsafe food products may lead to foodborne illnesses, which can seriously jeopardize an individual's health and even endanger his or her life. Therefore, food quality and safety is directly related to the quality and longevity of everyone's life.

Social stability: Food security is an important part of the state and society and is directly related to social stability and economic development. Food safety incidents may lead to social unrest and economic losses.

International trade: Food products in international trade must comply with international trade regulations and standards. Food quality and safety is critical to competitiveness in international markets.Sustainable development: Food quality and safety is also closely linked to sustainable agricultural development. By ensuring food quality and safety, the market competitiveness of agricultural products can be improved, farmers' incomes can be increased and sustainable agricultural development can be promoted.

In summary, food quality and safety is a complex and multidimensional issue, involving multiple links such as production, processing, transportation, storage, marketing and supervision. Ensuring food quality and safety is of great significance in safeguarding individual health, maintaining social stability, promoting international trade and realizing sustainable development. In the ever-changing global food market, food quality and safety will continue to be an important topic of concern and research.

Food quality and safety cannot be ensured without traceability technologies, which allow the tracing and verification of the origin and history of food products, thus helping regulators and consumers to better understand the food supply chain. This section explores the fundamentals of traceability technology, including its definition, components and key concepts.

Traceability technology is a technique for tracking and recording information about a product's supply chain to ensure quality, safety and compliance, as shown in Figure 2. It covers all aspects of a product from production to distribution, including information on the origin of raw materials, the production process, transportation, storage and distribution. The purpose of traceability technology is to track the flow of products in order to quickly identify and resolve quality issues, protect the rights of consumers and maintain the transparency of the food supply chain.

Fig.2: Traceability analyzes the entire supply chain

Components of traceability technology: Information Recording System: Each link in the supply chain will need to record information about the product, including time, place, manufacturer, and transporter. This information will be recorded in an information system. Data storage and management: The recorded information will be stored in a data storage system such as a database or blockchain to ensure data security and accessibility.

Key Concepts of Traceability Technology: Lot Tracing: Lot tracing is the tracking of a specific batch or lot of products. It allows for the rapid identification of affected products when a problem is detected. Timestamping: Timestamping is the recording of when an event occurs. It is key to ensuring that information is accurate and current. Geographic Location Information: Records the geographic location of the product, including the place of manufacture, transit point, and point of sale, to determine the flow and origin of the product. Traceability Chain: The traceability chain is the entire supply chain path of a product from production to distribution. It includes all participants and links.

In traceability technology, there are some basic formulas and concepts used to describe and calculate the flow of products and information transfer. Here are some common formulas:

Product tracking is accomplished by looking up the identifier of a specific product. The formula is as follows:

$$Product\_ID = Barcode\_or\_RFID\_Tag \tag{1}$$

Recording the timing of events is key to tracking the flow of product. The formula is as follows:

$$Timestamp = Date\_and\_Time \tag{2}$$

Record the geographic location of the product to determine its flow. The formula is as follows:

$$Location = GPS\_Coordinates \tag{3}$$

These formulas and concepts are the basis of traceability technology, through which accurate tracking of product flow and information transfer can be realized.

In summary, traceability technology is one of the key tools for ensuring food quality and safety, allowing the tracing and verification of the origin and history of a product to ensure that it meets hygiene, nutritional, standards and legal and regulatory requirements. Through identifiers, information recording systems and data storage management, traceability technology can track the flow of products throughout the supply chain, safeguard the rights and interests of consumers, and improve the transparency of the food supply chain.

Blockchain is a decentralized distributed ledger technology for recording and verifying transactions or events, ensuring data immutability and transparency. A blockchain consists of a series of blocks, each containing multiple transaction records and linked to the previous block to form a continuous chain.

Components of blockchain technology: block (Block): block is the basic unit of blockchain, containing multiple transaction records. Each block has a unique identifier, called a hash value, which is used to connect to the previous block. Distributed network: a blockchain network consists of multiple nodes, each with a complete copy of the blockchain. These nodes share and verify transactions through peer-to-peer communication. Consensus Algorithms: In order to ensure the security and consistency of the blockchain, nodes in the network need to reach a consensus, i.e., agree on the validity of transactions. Common consensus algorithms include Proof of Work (PoW) and Proof of Stake (PoS). Encryption: Blockchain uses encryption to protect the confidentiality and integrity of data. Transaction records are encrypted and stored on the blockchain, and only authorized users can decrypt and view them.

Core Mechanism of Blockchain Technology: Decentralization: Blockchain is decentralized and there is no single central authority controlling it. Transactions are verified by multiple nodes in the network, rather than relying on a centralized body. Immutability: Once a transaction is recorded on the blockchain, it is virtually impossible to modify or delete it. This ensures trustworthiness and historical traceability of data. Transparency: Transaction records on the blockchain are publicly visible and can be viewed by anyone. This increases the transparency and verifiability of transactions. Smart Contracts: Smart contracts are self-executing codes that automatically execute transactions based on predetermined conditions. They extend the functionality of the blockchain and enable it to support more complex business logic.

A Hashing function maps input data of arbitrary length to a fixed-length output, which is unique and irreversible. The formula is as follows:

$$Hash = H(Input) \tag{4}$$

PoW is a consensus algorithm that requires nodes to solve complex mathematical problems to prove their contribution to the block. The formula is as follows:

$$PoW(Nonce, Previous\_Hash, Transcation\_Data = Hash \tag{5}$$

Proof of Stake (PoS) is a consensus algorithm where nodes validate transactions based on the amount of cryptocurrency they hold. The formula is as follows:

$$PoS(Stake_{Amount}) = Probability\_of\_Validation \tag{6}$$

In summary, blockchain technology is a decentralized, tamper-proof and transparent distributed ledger technology that ensures data security and consistency through hash functions, consensus algorithms and encryption. Its basic principles and components provide a reliable foundation for food quality and safety traceability.

2.2. Integration of blockchain technology with food quality and safety traceability

Grain traceability is a key part of ensuring food quality and safety, and blockchain technology shows a series of significant advantages in grain traceability. Blockchain technology provides a highly transparent solution for grain traceability. Every transaction and record is stored on the blockchain and any participant with access can view these records. This transparency means that consumers, regulators and producers all have real-time access to information about the food supply chain. This verifiability helps ensure product authenticity and compliance, reducing the potential for misinformation and fraud. Once recorded, data on a blockchain is virtually impossible to tamper with or delete. This non-tamperability ensures the integrity of grain quality and traceability information and prevents data counterfeiting and tampering.

Blockchain technology has the ability to update data in real time, making food traceability more timely and efficient. As soon as new transactions or information are added to the blockchain, they are immediately propagated throughout the network and supply chain participants have immediate access to the most up-to-date information. This is critical for quickly identifying and resolving potential risks or issues, especially in the face of emergencies or recalls.

Blockchain technology allows every step in the food supply chain to be traced. By viewing transaction records and timestamps on the blockchain, it is possible to trace back details such as the origin of the food, date of production, production batch, and more. This traceability is important for understanding each link in the food supply chain and quickly pinpointing problems, helping to strengthen regulation and improve food quality management.

Blockchain is decentralized technology with no single governing body or control point. This means that information and records in the food supply chain are not controlled by any single entity, reducing the potential for manipulation or undue interference. Decentralization also increases the resilience of the system, allowing the network to function even if one node goes down.

Blockchain technology uses advanced encryption algorithms to secure data. Transaction data is encrypted and stored on the blockchain so that only authorized users can decrypt and view it. This security protects sensitive information from unauthorized access and data leakage.

Overall, blockchain technology has significant advantages in food traceability, including transparency, immutability, real-time, traceability, decentralization, and security. These advantages help improve the management efficiency of the food supply chain, ensure product quality and safety, and enhance the trust of regulators and consumers in the origin of food. Therefore, blockchain technology has great potential and application prospects in food quality and safety traceability.

The application of blockchain technology requires a well-developed architecture to enable the integration of food quality data. Blockchain architectures typically include the following key components: Nodes: nodes are participants in the blockchain network and they can be individuals, organizations or institutions. Each node has a complete copy of the blockchain and participates in transaction verification and block generation. Blocks: Blocks are the basic units of the blockchain, which contain a certain number of transaction records. Each block has a unique identifier (hash value) that is used to connect to the previous block to form a chain. Consensus Algorithms: Consensus algorithms are used to ensure that all nodes in the network agree on the validity of a transaction.

The following key steps are required to integrate blockchain with food quality data: Data collection: first, data is collected from all parts of the grain supply chain, including production, processing, transportation, and storage. These data can include temperature, humidity, production date, quality test results, etc. Data uploading: the collected data needs to be uploaded to the blockchain network. This can be achieved through smart contracts to ensure data security and consistency. The data is recorded in blocks with timestamps and hash values. Data validation: once the data is uploaded, nodes in the network will validate it. The consensus algorithm ensures the validity and consistency of the data. If the data does not meet the specified conditions, it will be rejected. Data Access and Sharing: Fused data can be accessed and shared by various participants in the food supply chain, including producers, transportation companies, testing organizations, and regulatory authorities. This increases data transparency and traceability. Data analysis and applications: Fused data can be used to analyze the performance of the food supply chain, identify problems and improve processes. Smart contracts can also automate certain actions, such as triggering quality inspections or issuing alerts. Privacy protection: Since data on the blockchain is publicly visible, sensitive information needs to be encrypted to protect privacy. Only authorized users can decrypt and view the details of the data.

Integrating blockchain with grain quality data brings multiple advantages: Data immutability: once the data is on the chain, it is virtually impossible for it to be tampered with. This ensures the integrity and credibility of grain quality data. Real-time: Blockchain technology supports real-time data updates, keeping food quality information up-to-date and helping to respond to issues in a timely manner. Transparency: All participants have access to the same data, increasing transparency and trust. Traceability: Once data is on the chain, it can be easily traced back to the source and history of the grain, helping to quickly resolve issues. Automated execution: Smart contracts can automate certain operations, such as triggering quality checks or issuing alerts, increasing operational efficiency.

In summary, the integration of blockchain with grain quality data provides an efficient, secure and trusted solution for grain supply chain management. It ensures data integrity and transparency, improves the trust of regulators and consumers in grain quality and safety, and is of great significance to the grain industry.

A blockchain smart contract is an automatically executed computer program that executes transactions and contracts based on predefined conditions and rules. In food quality and safety traceability, the application of smart contracts can provide an efficient, transparent, and trustworthy way to manage and execute contracts, transactions, and quality control. This section explores the specific applications and benefits of blockchain smart contracts in the food supply chain.

When specific conditions are met, the contract will be automatically executed without the intervention of an intermediary or third party. For example, when a batch of grain passes a quality test and meets standards, a smart contract can automatically release payment to the supplier, thereby accelerating the transaction process. This reduces contract execution time and the risk of manual errors.

Smart contracts can be combined with sensor technology to monitor parameters such as temperature, humidity and quality of grain. If an anomaly or non-conformity is detected, the smart contract can automatically trigger an alert or take predetermined action, such as stopping delivery or conducting further inspections. This helps to monitor grain quality in real time and reduce the circulation of substandard products.

Smart contracts can record information such as the source, production date, transportation history and test results of each batch of grain. This information is stored on the blockchain and can be viewed by various participants in the supply chain. Through smart contracts, consumers can scan the labels on the products or use mobile apps to trace the entire supply chain journey of the products, ensuring quality and traceability.

Smart contracts can automatically issue quality certificates. Once a grain batch has passed quality tests and met standards, smart contracts can generate a quality certificate attesting to the quality and compliance of the product. This eliminates the need to issue certificates manually and increases efficiency.

The data recorded by the smart contract is not tamperable, which means that supply chain participants cannot falsify or tamper with the quality data. This helps prevent fraud and the spread of false information, increasing the integrity of the supply chain.

The automated nature of smart contracts reduces the need for manual operations and intermediaries, thereby reducing administrative and transaction costs. This is attractive to all participants in the food supply chain.

Overall, the use of blockchain smart contracts in food quality and safety traceability provides an efficient, secure and trustworthy way to manage the supply chain. It accelerates contract enforcement, improves quality control, enhances supply chain transparency and traceability, and reduces the risk of fraud and disinformation, while lowering administrative costs. This makes it a powerful tool for food supply chain management, contributing to improved food quality and security.

2.3. Data fusion analysis methods

One of the key steps in data fusion analysis of food quality and safety traceability with blockchain technology is data collection and cleaning. In this process, it is necessary to collect food quality-related data from multiple sources and ensure the accuracy, completeness and consistency of the data. Data collection is the process of gathering data from different sources that are involved in multiple aspects of food production, transportation, storage and quality testing. The following are some of the key sources of data collection: Production chain: this includes information on how the food is grown, harvested, handled and packaged. Data can come from farms, farmer reports, or automated sensor technology. Transportation and logistics: Data needs to record the path and mode of transportation of food from the place of production to the consumer, including shipment by boat, truck, and rail. This data can come from records of transportation companies. Storage: Grain needs to be monitored for temperature, humidity, ventilation and other conditions during storage. The data can come from sensors in the storage equipment or from manual records. Quality testing: Testing the quality of grain is a critical step in ensuring its safety and compliance. Data includes various quality parameters such as moisture content, nutrient content, pesticide residues, etc. Consumer feedback: Consumer feedback is also an important source of data and can be collected through consumer surveys, complaint records, etc. After data collection, data often needs to be cleaned and pre-processed to ensure its quality and consistency. Data cleaning includes the following key steps: Missing value processing: detecting and processing missing data, either using interpolation methods to fill in the missing values or using other suitable strategies. Outlier Detection: Identifying and processing outliers, which may cause bias in the analysis results. Data normalization: Normalize data from different sources to ensure consistency in units, metrics, etc. Data Merging: Integrate data from different data sources to create complete data sets. Data validation: Validate the accuracy and completeness of data to ensure that it is free of errors. Data collection and cleaning is the basis of food quality and safety traceability, and its importance is reflected in the following aspects: Decision support: Accurate and complete data can provide strong support for decision making, for example, to help trace the source of contaminated grain and take timely measures. Quality control: In the food supply chain, data quality is directly related to the effectiveness of quality control. Only accurate data can ensure the quality and safety of food. Traceability: Data cleansing ensures consistency and traceability of data, which helps in the tracing and originating of grain. Trust building: Accurate and trustworthy data helps build trust among supply chain participants and improves the efficiency of cooperation. Data fusion is the integration of information from different data sources into a consistent framework for deeper analysis and decision making. In food quality and safety traceability, data fusion is crucial because it can integrate data from multiple processes, such as production, transportation, and quality inspection, to form a comprehensive view. This section explores the process and methodology of constructing a data fusion model.

The first task is to integrate information from different data sources into a single data warehouse. These data sources can include sensor data, production records, transportation logs, quality inspection results, and so on. The integrated data needs to be pre-processed to ensure data format consistency and data quality.

Data from different data sources may be recorded in different formats, units and time stamps. Therefore, data alignment and matching is a critical step in data fusion. This entails converting data into a uniform format and ensuring that the data match in time and space.

During the data fusion process, data cleansing and quality control are required to detect and deal with missing data, outliers and erroneous data. This ensures the accuracy and credibility of the fused data.

Feature engineering involves extracting valuable features from the fused data that can be used for subsequent analysis and modeling. Feature engineering can include statistical feature extraction, time series analysis, spatial analysis, etc.

Data fusion models are a key factor in determining how to integrate information from different data sources. Commonly used data fusion models include: Weighted average model: weighting and averaging information from different data sources based on the weights of the data to get an overall estimate. Decision tree models: use a decision tree algorithm to determine how to integrate information from different data sources, based on a set of rules that determine how the data will be fused. Neural network model: uses neural networks to learn how to integrate information from different data sources and can handle complex data fusion problems. Bayesian network model: uses Bayesian networks to model the relationships between different data sources to determine how to perform data fusion. Once the data fusion model is constructed, the fused data can be used for a variety of food quality and safety traceability applications, including quality analysis, anomaly detection, prediction and tracing. Data fusion allows for a comprehensive view of data to be shared by all parts of the grain supply chain, helping to identify problems, improve processes and enhance quality and safety in a timely manner.

Data privacy and security are issues that require special attention in data fusion. Ensuring the protection and compliance of sensitive information is critical to the construction of a data fusion model. Encryption techniques, access control and data anonymization can be used to protect data privacy and security.

Data fusion is a key step in food quality and safety traceability, which integrates information from different data sources and provides powerful support for food supply chain management and decision making. Through data fusion, better monitoring and management of grain quality and safety can be realized, and the traceability and quality control of the supply chain can be improved.

Information from data fusion often needs to be presented to decision makers and stakeholders in a way that is easy to understand and analyze. Data visualization is a key tool for achieving this goal by transforming complex data into graphs, charts and interactive interfaces that help users better understand the data, discover patterns and make decisions. To achieve effective data visualization, a variety of data visualization tools and techniques can be used, including but not limited to: Charts and graphs: Bar charts, line graphs, scatter plots, etc. can be used to present basic statistical information and trends in data. Map Visualization: Geographic Information Systems (GIS) and map visualization tools can present data on a geospatial scale for tracking the origin and flow path of food. Dashboards: Interactive dashboards can integrate multiple visualization elements, allowing users to customize the way they view data in order to explore information in greater depth. Heatmaps: Heatmaps can help users identify high and low points in the data, which can be used to spot anomalies or potential problems. Data visualization has several applications in food quality and safety traceability, including but not limited to the following: Quality monitoring: By visualizing the trend and distribution of quality parameters, anomalies can be detected in a timely manner to help decision makers take measures to ensure the quality and safety of grain. Tracing and traceability: Map visualization can help track the flow and source of grain to identify potential risks and problems. Decision support: Interactive dashboards and visualization tools can provide decision makers with a comprehensive view of data, helping them make data-based decisions to improve supply chain processes and quality management.

Communication and Sharing: Visualization is a powerful communication tool that can convey data to all parties in an easy-to-understand manner, facilitating collaboration and information sharing.

Data visualization not only provides a way of presenting data, but also an opportunity for deeper understanding and analysis of the data. This is critical for decision support for food quality and safety traceability. Below are a few key aspects of decision support: Real-time monitoring: Visualization tools can provide real-time data monitoring, allowing decision makers to quickly understand the current situation and take immediate action. Problem identification: Visualization can help identify potential problems and trends, e.g., quality anomalies, supply chain disruptions, etc. Simulation and Prediction: Visualization tools can be used to simulate the impact of different decision scenarios and perform predictive analysis to help choose the best decision path. Data sharing and collaboration: Visualization promotes data sharing and collaboration, and different stakeholders can jointly participate in decision making to improve the effectiveness of decision making.

In summary, the application of data visualization in food quality and safety traceability is crucial for decision support. By transforming complex data into intuitive visualization graphics and interfaces, decision makers can better understand the data, make timely decisions, and improve the quality and safety of the food supply chain. Therefore, data visualization is an indispensable tool in food quality and safety management.

3. Food quality and safety case studies

For the purpose of this case study, data related to food quality and safety were collected from different segments, including production, transportation, and quality control. The following are some of the main data sources:

This paper collected data on the food production process, including planting methods, pesticide use, harvest time, etc., as shown in Table 1. These data help to understand the food production process and quality control measures.

Table 1. Farm data

Farm Number	plantation	Type of pesticide used	Harvest date	Production (tons)
001	wheat	insecticide	2023-05-15	50
002	corn	Insecticides, herbicides	2023-06-02	70
003	soybeans	none	2023-05-25	45

This paper obtained data during the transportation of grain, including information on the transportation path, temperature, and humidity, as shown in Table 2. These data help to track the flow of grain and transportation conditions.

Table 2. Logistics data

Transportation number	Type of transportation	departure point	destination (location)	Date of shipment	Temperature (Celsius)	Moisture (%)
001	road transportation	Farm A	Processors A	2023-05-20	22	50
002	Railroad transportation	Farm B	Processors B	2023-06-05	18	55
003	road transportation	Farm C	Processors C	2023-05-28	23	48

This paper collected test data from grain quality control organizations, including test results for various quality parameters, as shown in Table 3. These data were used to assess the quality and safety of the grains.

Table 3. Quality control data

Sample number	Moisture (%)	Impurity content (%)
001	12.5	0.2
002	13.0	0.3
003	12.7	0.1

First, this paper analyzes the results of data alignment and matching. In blockchain, this paper ensures data consistency across different links through automatic matching and checking of smart contracts. In our case, the data alignment results show a high degree of consistency, which demonstrates the effectiveness of blockchain technology in data management.

Based on the quality control data and relevant standards, this paper assessed the quality of the grain. The results show that in this case, the quality of all samples meets the standards and is rated as "qualified". This reflects the effectiveness of quality control measures at the production stage and during transportation. However, it also emphasizes the value of blockchain technology, as it ensures transparency and verifiability of quality data.

This paper also identified and recorded issues and anomalies, such as mismatches between farm data and logistics data in some cases, or anomalies in the transportation of certain batches. The timely recording of these issues enables the relevant authorities to take steps to resolve the problem in order to ensure the quality and safety of the food.

Blockchain technology has obvious advantages in food quality and safety data fusion and analysis: Data immutability: Once data is uploaded to the blockchain, it cannot be easily tampered with or deleted, ensuring the credibility and integrity of the data. Transparency: The data on the blockchain network is public and can be viewed by any participant, increasing the transparency and verifiability of the data. Smart Contracts: Blockchain smart contracts can automatically perform operations such as data alignment, quality assessment, and problem logging, improving the efficiency of data processing. Decentralization: Blockchain is decentralized and does not depend on a single governing body, reducing the risk of a single point of failure.

Through blockchain data fusion and analysis, this paper is able to achieve full supervision and management of food quality and safety, improving the traceability and quality control of the food industry. This helps to safeguard food safety for consumers and also provides more effective tools and methods for food production and supply chain management.

Based on the results of our analysis, this paper proposes the following improvements to further enhance food quality and safety: Data monitoring and real-time feedback: Enhanced real-time monitoring of farm data and logistics data, as well as timely feedback on abnormal situations, can help prevent further expansion of the problem. Quality control standards update: Regularly review and update quality control standards to ensure that they are in line with the latest food safety regulations and standards. 3. education and training: Provide relevant information and training on food quality and safety. Education and training: Provide training and education for relevant practitioners to improve their understanding of food quality and safety and management capabilities. Blockchain extension application: consider extending blockchain technology to more food quality and safety areas, such as cold chain logistics supervision and raw material traceability. Data sharing and cooperation: Encourage partners in each link to share data in order to establish a more comprehensive food quality and safety supervision system.

In summary, the data fusion analysis of grain quality and safety traceability and blockchain technology provides effective tools and methods for grain quality management. Through real-time monitoring, quality control, problem identification and recording, this paper can better ensure food safety for consumers and improve the efficiency and credibility of food quality management. This approach can also be applied to the wider food industry, providing strong support for improvements in the food safety sector.

4. Conclusion

The focus of this study is to explore data fusion analysis of food quality and safety traceability with blockchain technology to address the increasing global food quality and safety challenges. By reviewing and integrating the key concepts of blockchain technology as well as data fusion analysis, this paper establishes a blockchain-based framework for food quality and safety traceability that improves the efficiency and accuracy of food quality and safety traceability through data collection, cleansing, fusion, and analysis. Through case studies, this paper demonstrates the potential and feasibility of the framework in practical applications and presents substantial results of fusion analysis.

However, this paper also recognizes the challenges faced in implementing the integration of food quality and safety traceability with blockchain technology. These challenges include issues such as data quality management, privacy protection, harmonization of technical standards, and regulatory compliance. Future research and practice should aim to address these challenges to ensure data reliability and security while promoting transparency and traceability in the global food supply chain.

In addition, this paper emphasizes the importance of financial markets and derivatives, which are critical to the success of food quality and safety traceability. With the continuous development of the financial sector, this paper encourages financial institutions to actively participate in and support the promotion and application of food quality and safety traceability and blockchain technology to better serve the food needs of the community.

In summary, the combination of food quality and safety traceability with blockchain technology offers new possibilities for global food security and quality management. This research provides strong support for the future development of the food industry and is expected to improve consumer confidence in food, thereby promoting the establishment and maintenance of a safer and higher quality food supply chain.

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