Enhancing Food Safety Using Blockchain-Based Traceability

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Abstract

Ensuring food safety is a growing challenge as food supply chains become longer and more complex. Contamination, spoiling, and food fraud can happen at any point, and current traceability systems frequently don't have the speed, openness, and dependability required to identify and address these problems. This study investigates the application of blockchain technology as a means of improving food safety and traceability. Every transaction or event pertaining to a food product, including its origin, processing techniques, storage conditions, and transportation details, is documented in a descriptive manner, tamper-resistant ledger that blockchain technology offers. It is simple to track a product's history in real time because each entry is time-stamped and saved forever. Participants in the food supply chain, including farmers, manufacturers, distributors, and retailers, can exchange precise, current information in a safe and reliable setting by utilize blockchain technology. This enhances responsibility and facilitates quicker reaction in the event of a food safety incident, including locating and isolating the contamination source. Additionally, buyers have greater insight into the goods they purchase, which boosts trust and helps them make wise choices. The implementation obstacles of blockchain are also covered in the report, including problems with data accuracy, integration with current systems, and adoption costs. Blockchain has the potential to completely change food safety procedures by improving the transparency, efficiency, and dependability of the complete supply chain, nevertheless these obstacles .

Keywords

Food Safety, Blockchain Technology, Traceability, Supply Chain Transparency, Decentralized Ledger, Food Contamination, Secure Data Sharing, Consumer Trust, Food Supply Chain, Real-Time Tracking.

I. Introduction

As food supply chains become more complicated, food safety has become a key factor on a global scale. Because agricultural products go through so many steps, such as cultivation, processing, packaging, storing, shipping, and distribution, it is now harder than ever to guarantee the authenticity, safety, and quality of food. In addition to compromising the public's health, incidents such as contamination, mislabeling, and food fraud also weaken customer confidence and result in large financial losses.

Manual record keeping and central databases, which are sometimes disjoint, slow, and at risk of human error, are the foundation of traditional food traceability systems. Since these technologies are unable to provide real-time tracking and transparency, it can be challenging to promptly identify the source of a safety issue. This has made the demand for a more transparent and dependable solution more pressing.

One possible tool to deal with these issues is blockchain technology. A distributed, unbreakable electronic register that securely and transparently records data and transactions is what it provides. Blockchain technology can be used to record a product's whole path, from the farm to the customer, in the context of food supply chains, guaranteeing that all information is precise, traceable, and unchangeable. This promotes more trust throughout the chain, enables stakeholders to identify problems more quickly, and improves their ability to respond to food safety incidents.

This study investigates the potential integration of blockchain technology with food tracking systems to improve food safety. It examines the shortcomings of conventional systems as they stand today, describes the salient characteristics of blockchain that make it appropriate for this use case, and examines practical instances and possible implementation issue. The intention is to show how traceability based on blockchain technology may enhance food safety, boost customer trust in agricultural products, and promote transparency.

II. Literature Review

Strong regulatory frameworks and efficient enforcement mechanisms are emphasised in this paper's thorough review of food safety and quality control systems. The difficulties that many nations, especially developing ones, have putting into place and keeping up effective food control systems because of things like disjointed laws, scarce resources, and poor infrastructure are covered. According to the report, in order to safeguard consumers and promote international trade, national food safety regulations must be harmonised with international norms. It also highlights how current technology usage and scientific risk assessment can improve food safety protocols. The study ends by suggesting strategic policy changes, stakeholder cooperation, and capacity building to fortify national food control systems. [1] The potential of edible insects as a wholesome and sustainable food source to improve global food security is examined in this review. It positions insects as suitable substitutes for traditional livestock by highlighting their high protein content, vital amino acids, and micronutrients. The advantages of insect farming for the environment are covered in the report, including less greenhouse gas emissions and less water and land consumption. It also discusses the necessity for standardised processing techniques, regulatory frameworks, and issues with customer acceptance. To incorporate edible insects into regular meals, the authors advocate more study and policy assistance. [2] Pomegranate juice's antioxidant qualities are examined in this study, with particular attention paid to how processing techniques and the fruit's phenolic makeup affect its effectiveness. The study reveals the strong correlation between the juice's phenolic content—specifically, substances like anthocyanins and punicalagins—and its antioxidant potential. It was discovered that the stability and accessibility of these bioactive substances were considerably impacted by several processing methods, including pasteurisation and concentration. The results highlight how crucial it is to optimise processing conditions in order to maintain pomegranate juice's health-promoting properties. The general knowledge of functional foods and how processing preserves nutritional advantages is expanded by this work. [3] The current research looks at how consumers' food preferences and their understanding of food quality and additives relate to one another. The results show that more discriminating eating choices are associated with a greater level of knowledge about food additives, which frequently results in avoiding goods thought to contain dangerous ingredients. The study emphasises the role that consumer education plays in promoting healthier eating practices and driving the demand for better food items. Enhancing public awareness of food composition can have a big impact on consumer choices and behaviour, it says. [4] The dual function of edible insects as a sustainable food supply and a possible food safety risk is examined in this thorough research. As a feasible substitute for conventional cattle, it emphasises the nutritional advantages of insects, such as their high protein content and vital micronutrients. As a result of growing and processing circumstances, the report also discusses safety issues such allergenicity, microbiological contamination, and heavy metal accumulation. The authors stress that in order to guarantee the safe incorporation of edible insects into international food systems, uniform rules and additional study are required. All things considered, the study emphasises how crucial it is to strike a balance between the nutritional benefits of edible insects and thorough safety evaluations in order to safeguard public health. [5] The chemical makeup and characteristics of food ingredients, such as water, proteins, enzymes, lipids, carbohydrates, vitamins, and minerals, are thoroughly examined in this extensive textbook. It also explores issues like pollutants, food additives, and scent compounds. The book offers thorough insights into a variety of food products, including dairy, meat, grains, fruits, and vegetables, and is rationally arranged according to food ingredients and commodities. The fourth edition has been completely updated to cover modern topics such food allergies, acrylamide production, BSE detection, and phytosterols. With more than 600 tables, almost 500 figures, and roughly 1,100 structural equations, it is an invaluable resource for professionals and students studying nutrition, food science, and technology. [6]The current article explores the mechanisms underlying the creation of food texture, specifically the processes of protein aggregation and gelation. It highlights the differences between particulate and fine-stranded gels and how pH affects their structural properties and development. The study highlights the need for more research on the breakdown of these gels, which is essential for comprehending food texture during eating, even though their creation has been thoroughly studied. The author argues that in order to close the gap between food's macroscopic textural qualities and nanoscale structures, mechanical and sensory investigations should be combined. [7] The mechanisms of protein aggregation and gelation, which are essential processes in the creation of food texture, are examined in this paper. It makes a distinction between particulate and fine-stranded gels, emphasising the ways in which pH affects the formation and structural properties of each. Although the production of these gels has been thoroughly studied, the breakdown of these gels, which is essential for comprehending food texture during ingestion, needs more research, the study notes. The author promotes the use of combined mechanical and sensory analysis to close the gap between food's macroscopic textural qualities and nanoscale structures. [8]The effect of high-pressure processing (HPP) on the quality characteristics of red pepper paste is assessed in this study. The study shows that HPP efficiently deactivates bacteria populations without compromising the nutritional value or texture of the paste. Notably, compared to conventional heat procedures, the treatment preserves the product's colour, flavour, and bioactive ingredients better. According to the results, HPP is a viable non-thermal preservation method that can extend the shelf life and safety of red pepper paste without sacrificing its quality. [9]The impact that high-pressure processing (HPP) has on the quality attributes of red pepper paste is examined in the article ”Effect of high-pressure processing on the quality of red pepper paste”. According to the study, HPP efficiently deactivates bacteria populations without compromising the nutritional value or sensory appeal of the paste. Notably, compared to conventional heat procedures, the treatment preserves the product's colour, flavour, and bioactive ingredients better. According to the results, HPP is a viable non-thermal preservation method that can extend the shelf life and safety of red pepper paste without sacrificing its quality. [10]In order to solve the issues of global food security, this thorough research investigates the potential of edible insects as wholesome and sustainable food sources. It positions insects as suitable substitutes for traditional livestock by highlighting their high protein content, vital amino acids, and micronutrients. The advantages of insect farming for the environment are covered in the report, including less greenhouse gas emissions and less water and land consumption. It does, however, also address safety issues such allergenicity, microbiological contamination, and heavy metal deposition, highlighting the necessity of more research and standardised rules. To make it easier to incorporate edible insects into regular diets, the authors propose more consumer education and legislative initiatives. [11]Food security, biodiversity, and human health are all intertwined, as examined in the essay ”The food security–biodiversity–health nexus: Towards a conceptual framework” that was published in Global Food Security. In order to establish sustainable food systems, it highlights the necessity of integrated approaches that take ecological and health factors into account. In order to address the intricate problems at the nexus of these crucial fields, the authors suggest a conceptual framework that will direct future studies and policy decisions. [12]The fundamentals and uses of food engineering are thoroughly covered in this classic textbook. In the context of food processing activities, it encompasses fundamental subjects including fluid flow, heat and mass transfer, mass and energy balances, and thermodynamics. By fusing theoretical ideas with real-world examples, the book gives readers a comprehensive grasp of how engineering principles are used to develop and improve food processing systems. [13]A fundamental examination of agricultural systems is provided in C. Spedding's book An Introduction to Agricultural Systems, which highlights the intricacy of these systems and the need for a systems-based approach to comprehending agricultural output. It explores the relationships between biological, physical, and socioeconomic factors, offering insights on how these factors affect farming methods and choices. For anyone who want to understand the complex nature of agriculture and its place in larger environmental and economic contexts, this study is an invaluable resource. [14] The limitations of traditional agriculture in tackling global issues including food insecurity, environmental degradation, and biodiversity loss are highlighted in the chapter "Agronomy for Sustainable Agriculture: A Review" by Lichtfouse et al. In order to create resilient and ecologically friendly farming systems, it promotes sustainable agriculture as an integrative strategy that blends ecological, social, and economic principles. The authors stress how agronomy is becoming more and more crucial in coming up with creative ideas for sustainable food production. [15]Simon Maxwell and Rachel Slater's paper "Food Policy Old and New" explores how food policy has changed in response to urbanisation, technological development, and the industrialisation of food systems in developing nations. It presents an assessment framework to investigate new policy options, highlighting the fact that although these problems are more prevalent in more industrialised and urbanised countries, the emerging food policy agenda is essential in all countries, especially in the poorest areas where problems are getting worse quickly. [16] For food chemistry research, Molyneux and Schieberle's article "Compound Identification: A Journal of Agricultural and Food Chemistry Perspective" describes the exacting criteria for recognising novel or unidentified compounds. It highlights the importance of using combustion analysis or high-resolution mass spectrometry to determine chemical formulae and requires thorough reporting of spectroscopic, spectroscopic, and physical data. For flavour and fragrance compounds, the authors recommend thorough investigations that include comparisons with reference standards and gas chromatography retention indices on different stationary phases in order to guarantee accurate compound identification and uphold the journal's strict publication requirements. [17] Development in Practice released an article by Ian Scoones titled "Sustainability" that critically analyses the term's development and complexity. From the forestry practices of the 18th century to the concept's current significance in the discourse on global policy and development, it traces its origins. As a result of its broad appeal and conceptual ambiguity, the author emphasises how "sustainability" has become a catchphrase with several meanings in various situations. By highlighting the significance of comprehending the political and social factors that influence sustainability narratives, Scoones promotes more complex and situation-specific methods in practice and policymaking. [18]Food microbiology and allied disciplines like mycology, bacteriology, virology, parasitology, and immunology are the subjects of research papers, short communications, review articles, and book reviews published by the peer-reviewed International Journal of Food Microbiology. In collaboration with the Committee on Food Microbiology and Hygiene and the International Union of Microbiological Societies, it is currently published by Elsevier. L. Cocolin (Università di Torino) serves as its editor. [5]The possibility of edible insects as wholesome and sustainable food sources is investigated in the essay "Edible Insects: A Food Security Solution or a Food Safety Concern?" that was published in Comprehensive Reviews in Food Science and Food Safety. While addressing safety issues including allergenicity and microbial contamination, it also emphasises their high protein content and environmental advantages, highlighting the need for more research and standardised legislation. [19] To improve data integrity and traceability in agricultural food supply chains, the paper

”Smart Contract-Based Agricultural Food Supply Chain Traceability” offers a blockchain-based framework that makes use of the InterPlanetary File System (IPFS) and Hyperledger smart contracts. Transparency, security, and efficiency are enhanced for all stakeholders by the system’s decentralised data storage and transaction automation. At Shanwei Lvfengyuan Modern Agricultural Development Co., Ltd., a real-world application showed how successful the framework is in practical situations. [20]The article ”Applying blockchain technology to improve agri-food traceability: A review of development methods, benefits and challenges” offers a thorough examination of the ways in which blockchain technology might improve supply chain traceability for agri-food. It talks about several approaches to development, emphasises advantages like better openness and data integrity, and tackles drawbacks like scalability and legal issues. [21]For improving food safety and traceability, the article ”Biosensor in Smart Food Traceability System for Food Safety and Security” offers a thorough analysis of current developments in biosensor technologies. From pre-harvest plant disease identification to post-harvest contamination monitoring, it explores the use of biosensors throughout the food supply chain, highlighting their contribution to the creation of more intelligent and responsive food traceability systems. [22]To improve food traceability in smart cities, the paper ”A Novel Blockchain and Internet of Things-Based Food Traceability System for Smart Cities” offers a layered framework based on BIOT that makes use of the Ethereum and EOSIO blockchain platforms. The suggested solution surpasses conventional Ethereum-based systems in terms of efficiency and transparency, with a block creation rate of 0.5 seconds and a confirmation time of 1 second. [23]A thesis from Pennsylvania State University titled ”Food Supply Chain Traceability Using Blockchain and Radio Frequency Identification Technology” examines how blockchain and RFID technology can be combined to improve food supply chain traceability. In order to guarantee data integrity and transparency across the supply chain, it suggests a system in which RFID tags gather real-time data at different points in time and securely store it on a blockchain. [24] ”Blockchain Technology in the Food Industry: A Review of Potentials, Challenges, and Future Research Directions” offers a thorough examination of the ways in which blockchain technology can improve traceability in agri-food supply chains. It talks about different development approaches, emphasises advantages like better data integrity and openness, and tackles drawbacks like scalability and legal issues. [25] In order to improve transparency and accountability in food supply chains, the paper ”Design and Implementation of a Blockchain-Based Food Traceability System” offers a thorough framework including blockchain technology. The technology addresses issues like fraud, contamination, and inefficiencies in conventional traceability techniques by utilising smart contracts and decentralised ledgers to provide safe and unchangeable food product tracking from point of origin to consumer. [26]The paper ”ePedigree Traceability System for the Agricultural Food Supply Chain to Ensure Consumer Health” discusses the emerging issues in food safety, including adulteration, contamination, and counterfeiting, all of which present serious health hazards to consumers. In order to ensure the safety and integrity of food products, it suggests an electronic pedigree (ePedigree) system that makes use of cutting-edge technologies to improve traceability and transparency throughout the agricultural food supply chain. [27]At Pennsylvania State University, the thesis ”Food Supply Chain Traceability Using Blockchain and Radio Frequency Identification Technology” explores the ways in which RFID and blockchain technology can improve asset traceability in the food supply chain. To ensure data integrity and transparency across the supply chain, it suggests a system in which RFID tags gather real-time data at different points in time, which is subsequently safely stored on a blockchain. [23]Incorporating blockchain technology into food safety traceability systems (FSTS) is thoroughly examined in the essay ”Redefining Food Safety Traceability System Through Blockchain: Findings, Challenges, and Open Issues”. Aiming to create a strong foundation for improving security and transparency in food supply chains, it evaluates different consensus algorithms, identifies security concerns, and addresses unresolved issues. It does this by methodically reviewing previous studies. [28].

III. Problem Statement

A. Existing System (Rich Picture As Is)

At almost every point in the current food supply chain, from the farmer to the distributor, manufacturer, and retailer, there is a lack of real-time visibility. Farmers continue to use manual record keeping systems, raising the risk of human error and transmission delays. There are significant gaps in tracking product movements and confirming food safety because distributors and manufacturers have few tracking systems in place. Because of this, problems such as contamination are frequently reported much later, usually after they have affected the customer. This reactive strategy increases the risk to public health and results in sluggish responses and delayed recalls.Additionally, the contamination investigation process is very manual and disjoint. Without access to real-time traceability data, distributors and regulatory agencies are forced to perform laborious investigations. In addition, retailers are ill prepared to act quickly to address a food safety emergency because they do not have upstream visibility into the origin and handling of the products they sell. Inefficiencies in this supply chain are exacerbated by the continued disconnect of stakeholders, inadequate communication, and lack of system integration.

In general, the system is reactive rather than proactive, slow and opaque, making consumers and regulatory bodies vulnerable to food-related incidents.

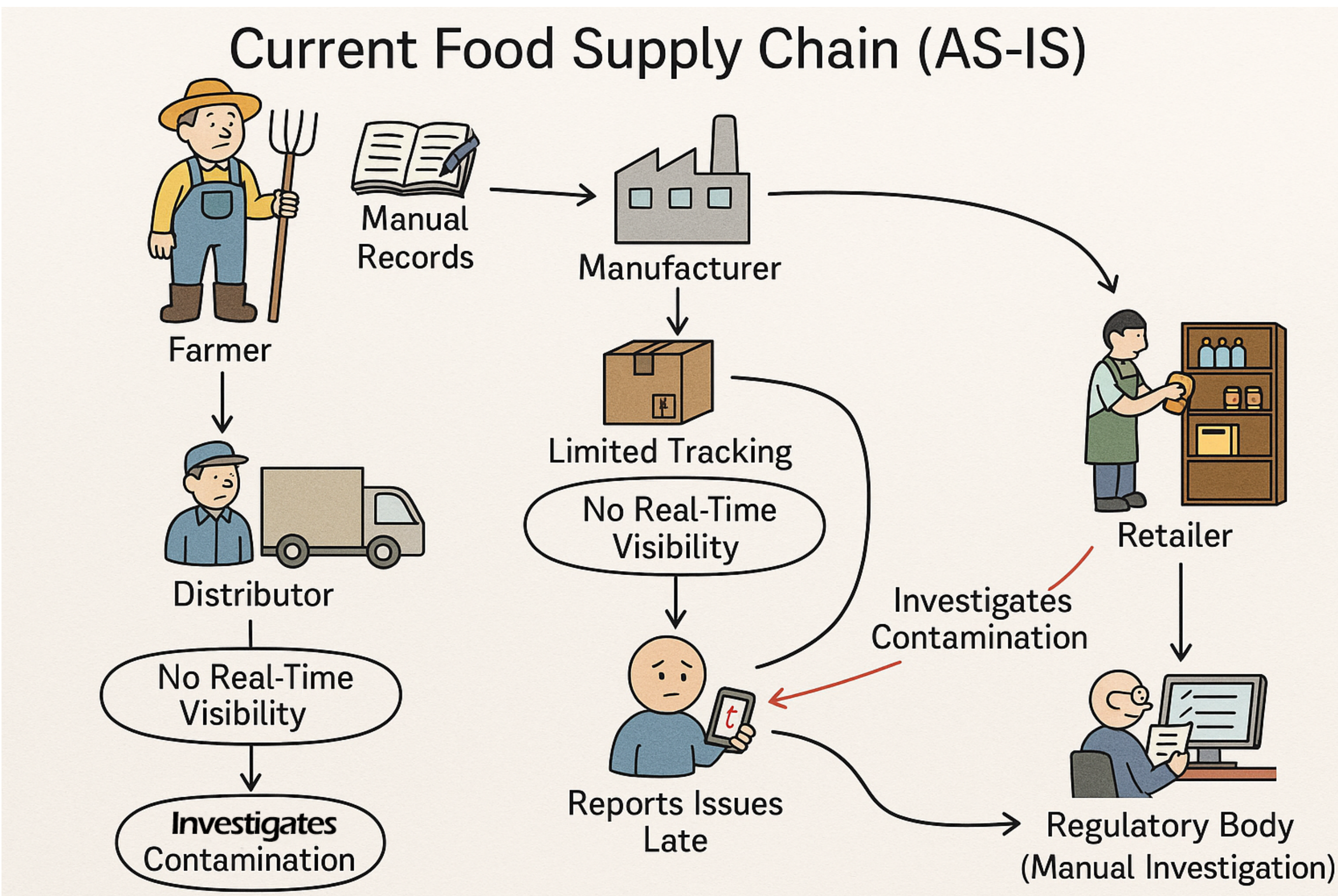

Fig. 1. RICH PICTURE AS-IS

B. *Gap Analysis*

The efficiency, transparency and responsiveness of the current food supply chain (AS-IS) are hampered by a number of serious flaws. A fragmented view of the product journey between stakeholders, including farmers, distributors, manufacturers, and retailers, is the first consequence of the system's lack of real-time visibility.

Delays and missed opportunities for proactive problem solving result from the inability to track shipments in real time. Farmers also use manual record keeping, leading to mistakes and inefficient data sharing. Additionally, this manual process slows down the flow of vital information throughout the supply chain, making it more difficult to promptly address problems.

Manufacturers' capacity to maintain quality control and traceability is hampered by their use of simple tracking systems that do not offer comprehensive insights into production processes, batch details, and shipments. Furthermore, it is common for contamination and other problems to go unreported, which exacerbates the issue and puts customers at risk for health problems. The manual and slow nature of the current contamination investigation process makes it impossible to identify and address issues quickly.

In addition, the supply chain as a whole is disjointed, with stakeholders functioning independently and without an integrated system that could speed up decision-making and enable real-time communication.

This fragmentation results in inefficiencies in the overall flow of goods and slower reactions to disturbances.Lastly, food safety and compliance are monitored by regulatory agencies using antiquated manual procedures, which further postpones inspections and remedial measures. Problems are frequently discovered too late in the absence of an integrated, real-time regulatory system, which delays recalls and increases public health risk.

All things considered, the existing system is reactive, ineffective, and devoid of the real-time connectivity required to guarantee openness, security, and prompt problem solving.

IV. Methodology

A. *Proposed System (Rich Picture To be)*

The TO-BE rich picture is a perfect example of a future food supply chain that incorporates blockchain technology to increase data security, traceability, and transparency. Under this system, farmers record and update product details like quality, production methods, and place of origin using digital platforms. Since these documents are time-stamped and tamper-proof due to their storage on the blockchain, the information is reliable and verifiable.

Smart contracts and tamper-proof records help manufacturers by ensuring that the data they receive from farmers is authentic. This blockchain-backed data reduces the possibility of mistakes or contamination and guarantees precise tracking of the production process. Distributors have complete visibility into the movement of goods through the supply chain thanks to the blockchain's real-time shipment data. This makes it possible to manage deliveries and inventory more quickly and effectively.

Retailers have QR codes that connect straight to the blockchain records, making it simple for customers to scan and obtain comprehensive details about the product's path from farm to shelf.

In addition to guaranteeing product authenticity, this raises consumer confidence in the caliber and security of the food they buy. By using a QR code, consumers can quickly confirm the product's origin and quality, giving them peace of mind that the food they purchase is genuine and safe.

Real-time access to blockchain data benefits regulatory agencies by enabling them to keep an eye on the supply chain, promptly identify the sources of contamination, and guarantee adherence to food safety laws. These organizations can carry out investigations more quickly and effectively thanks to blockchain technology, which also guarantees timely remedial action. At the core of this system is the blockchain, which serves as a decentralized, transparent, and secure platform for storing all supply chain data.

This technology ensures that all records are immutable and traceable, offering a reliable and tamper-proof system for managing the movement of goods. In summary, the TO-BE food supply chain enhances every stage from farm to consumer, providing real-time tracking, instant issue reporting, and a secure, transparent way to manage food safety, compliance, and product quality.

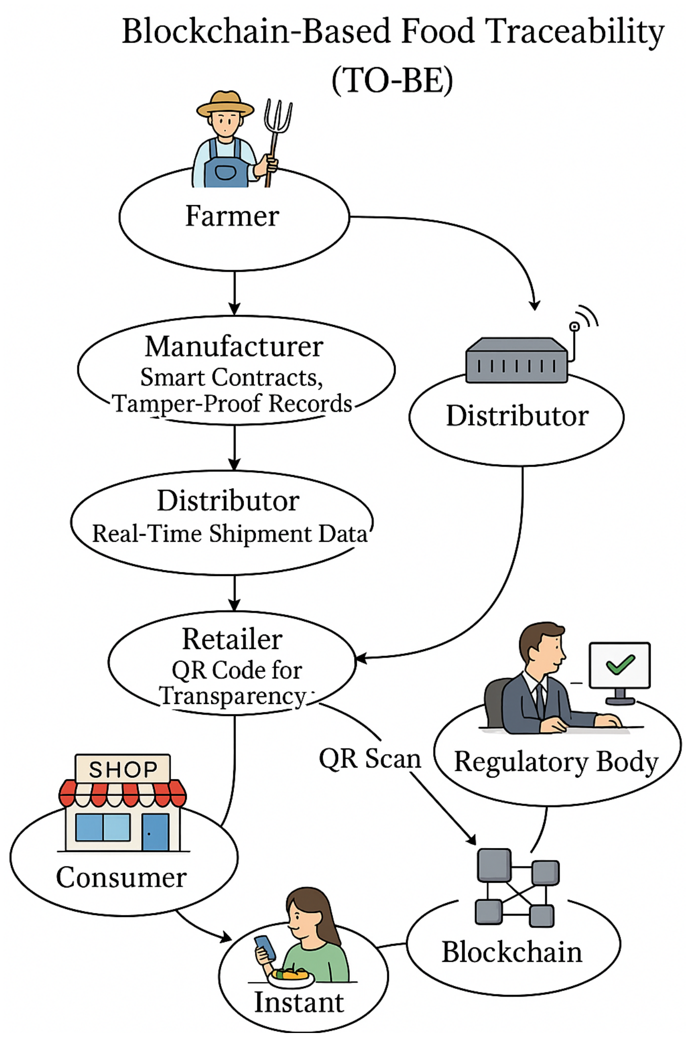

Fig. 2. RICH PICTURE TO-BE

B. ERD

In this food traceability system, each Farmer is responsible for producing one or more Products, which contain details such as name, origin, variety, and harvest date.
These products are managed by an Admin, who also assigns Product Batches that include lot numbers and barcodes. Each product can be associated with a Certification that verifies quality and safety standards.
The Product Batches are produced at designated Production Sites, which may be farms or storage facilities, and are subject to Quality Control Inspections to ensure compliance with food safety regulations.
If issues arise, affected batches are recorded in the Affected Batches entity with descriptions and distribution points.
Customers place Orders that include multiple products, leading to one or more Deliveries handled through Shipments.
These shipments are arranged by Vendors who use Transport vehicles, each with its own specifications such as vehicle number and capacity.
During the production and storage process, Sensors monitor environmental conditions such as temperature and humidity, with readings stored in Sensor Data for traceability.
These sensors are deployed at production sites and help in maintaining product quality by recording real-time environmental data.
The entire system ensures that products can be tracked from the farm to the customer, allowing for timely responses to quality issues and complete transparency throughout the supply chain.

In this comprehensive food traceability system, each Farmer plays a fundamental role by producing one or more Products, which include key attributes such as the product name, origin, variety, harvest date, and timestamps indicating when the product data was created and last updated. These products are linked to specific Certifications, which validate the product's compliance with quality or safety standards—such as organic status or food safety approval—described by certification type, name, and status. All products are overseen and managed by an Admin, who is responsible for tracking updates and assigning Product Batches. Each Product Batch represents a segment of a product identified by a lot number and barcode, and is created at a particular Production Site. These sites—whether farms, greenhouses, or warehouses—have their own attributes, including location, type, and site name. As batches are prepared, they are subject to Quality Control Inspections at various stages of the production process. These inspections capture the stage of inspection, the result, and the date it was conducted, helping maintain strict product quality.

If any batch is found to be defective, contaminated, or compromised in any way, it is tracked in the Affected Batches table, which stores issue descriptions, the affected distribution points, and the timestamp of when the issue was recorded. The Admin also plays a vital role here, ensuring proper tracking and resolution of affected goods. Once ready for sale, Customers can place Orders, each of which includes a variety of Products and records the order date and total amount. These orders trigger Deliveries, which are the logistical execution of moving goods to customers, with each delivery linked to a Shipment.

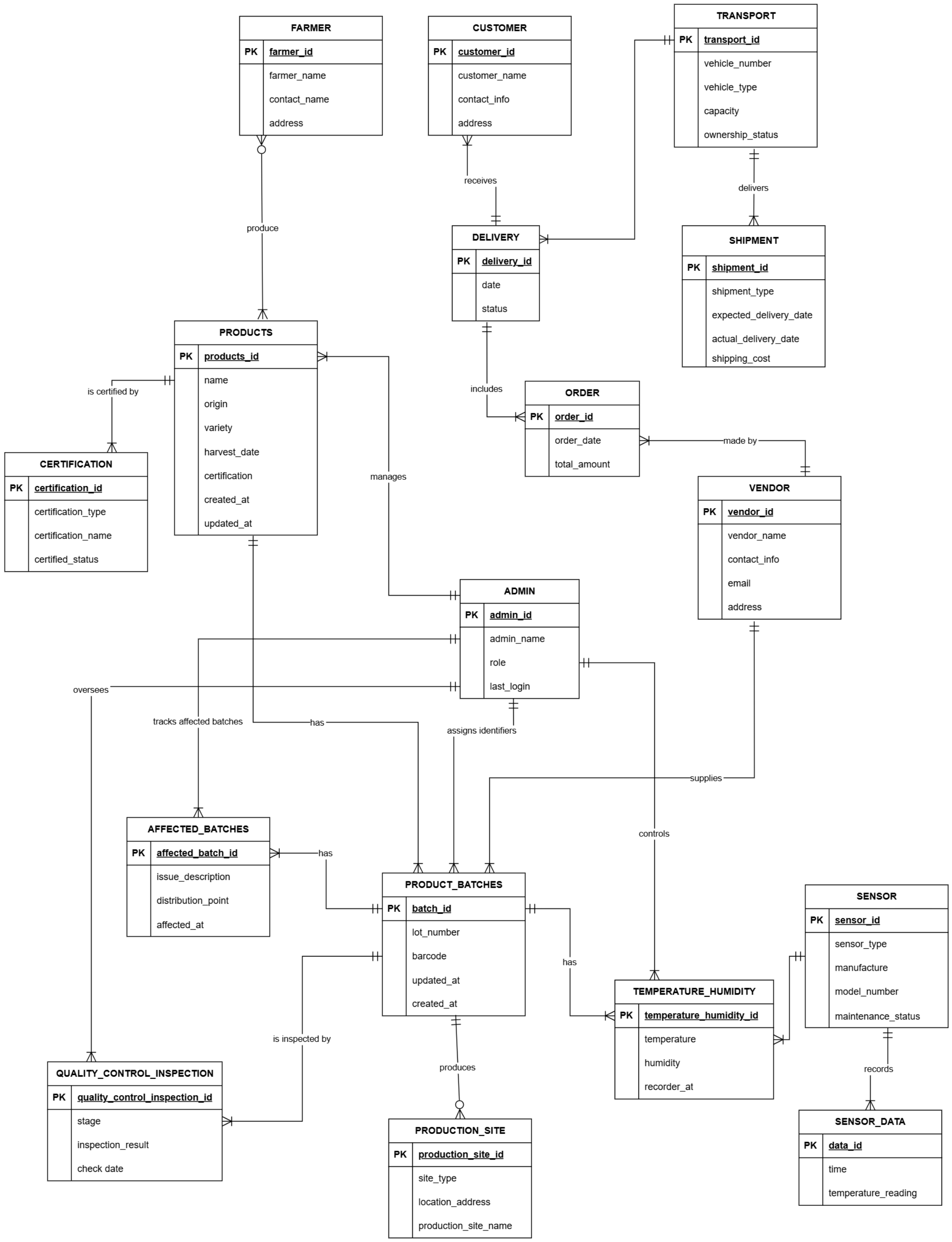

Fig. 3. Caption for the image

C. Front End UI

The login page has a simple and clean design with fields for entering a username and password. A ”Login” button is provided for submission. The UI is minimalistic, with a focus on user authentication. Once logged in, the user is greeted with a sidebar on the left containing various management options. This sidebar includes options such as Dashboard, Manage Products, Assign Identifiers, View Identifiers, Record QC, Record Temp/Humidity, and Record Affected under different sections like Batch Tracking, Quality Control, Environment, and Issue Tracking. The dashboard view displays key statistics, such as Total Products, Recent Issues, and Recent QC Checks, providing a quick overview of system activities. The Manage Products UI allows users to add and manage product details. It includes input fields like Product Name, Origin, Variety, Harvest Date, and Certifications. Below the form, a table displays the list of products with options to Edit or Delete each entry. The Assign Identifiers page lets users enter identifiers for products. It includes input fields for Product ID, Lot Number, and Barcode, along with a button labeled Assign Identifiers to save the information. The View Identifiers UI shows a table displaying Product ID, Batch ID, Lot Number, and Barcode. Users can view and track the product identifiers that have been assigned. The Record QC UI page is designed to log quality control inspections. Users are prompted to input Batch ID, Stage (e.g., Post-Production, Cold Storage, Distribution), and Inspection Results. A button labeled Record Inspection is provided to submit the data. The View QC page shows a table with entries for Batch ID, Stage, Inspection Results, and Check Date, allowing users to review recorded inspections. The Record Temp/Humidity page lets users input environmental data for batches, specifically the Temperature in °C and Humidity in The Record Affected Batch page allows users to log issues with batches. It includes input fields for Batch ID, Distribution Point, and Issue Description, with a button to Record Affected Batch. The View Affected page presents a table with Batch ID, Distribution Point, Issue Description, and Affected Date. This enables users to track and manage affected product batches.

D. Schema Design

The Farmer table stores information about individuals or organizations involved in growing agricultural products. Each farmer is associated with a specific product, including details such as farmer name, contact person, and address.The Products table holds information about the agricultural goods being tracked, including their name, origin, variety, harvest date, and certification status. Each product is linked to a farmer and an admin who oversees the product record.The Product Batches table captures specific groups of products produced or harvested at the same time. It includes batch identifiers such as lot number and barcode, and tracks the creation and update times. Batches are linked to products, vendors, and admins.The Production Site table contains data about where batches are processed or stored. This includes the site type, address, and site name, and links directly to batches.The Certification table manages records of quality or safety certifications linked to products. Tracks certification type, name, and status.The Affected Batches table logs any issues with particular product batches, such as contamination or recalls. The Quality Control Inspection table records inspection results for each batch, noting the inspection stage, result, and check date.The Temperature Humidity table monitors environmental conditions like temperature and humidity for each batch, recorded using sensors.The Sensor table holds information about the monitoring devices used for tracking environmental conditions, including type, manufacturer, model, and maintenance status.The Sensor Data table contains the actual temperature readings over time from the sensors, providing historical data for analysis.The Administration table manages user accounts of system administrators, including login info and their role. Admins are responsible for recording and monitoring other tables such as products, batches, and issues.The Customer table stores data about customers who receive deliveries, including name, contact details, and address.The Delivery table records deliveries made to customers, with date and status, and links to transport and orders.The Order table tracks orders placed, with total amount and related delivery and vendor details.The Vendor table holds supplier information like name, contact, and address, which links to product batches and orders.The Transport table tracks vehicles used for product shipment, including vehicle number, type, capacity, and ownership status.Finally, the Shipment table records details of the physical transportation process, including delivery dates, costs, and the transport method used.

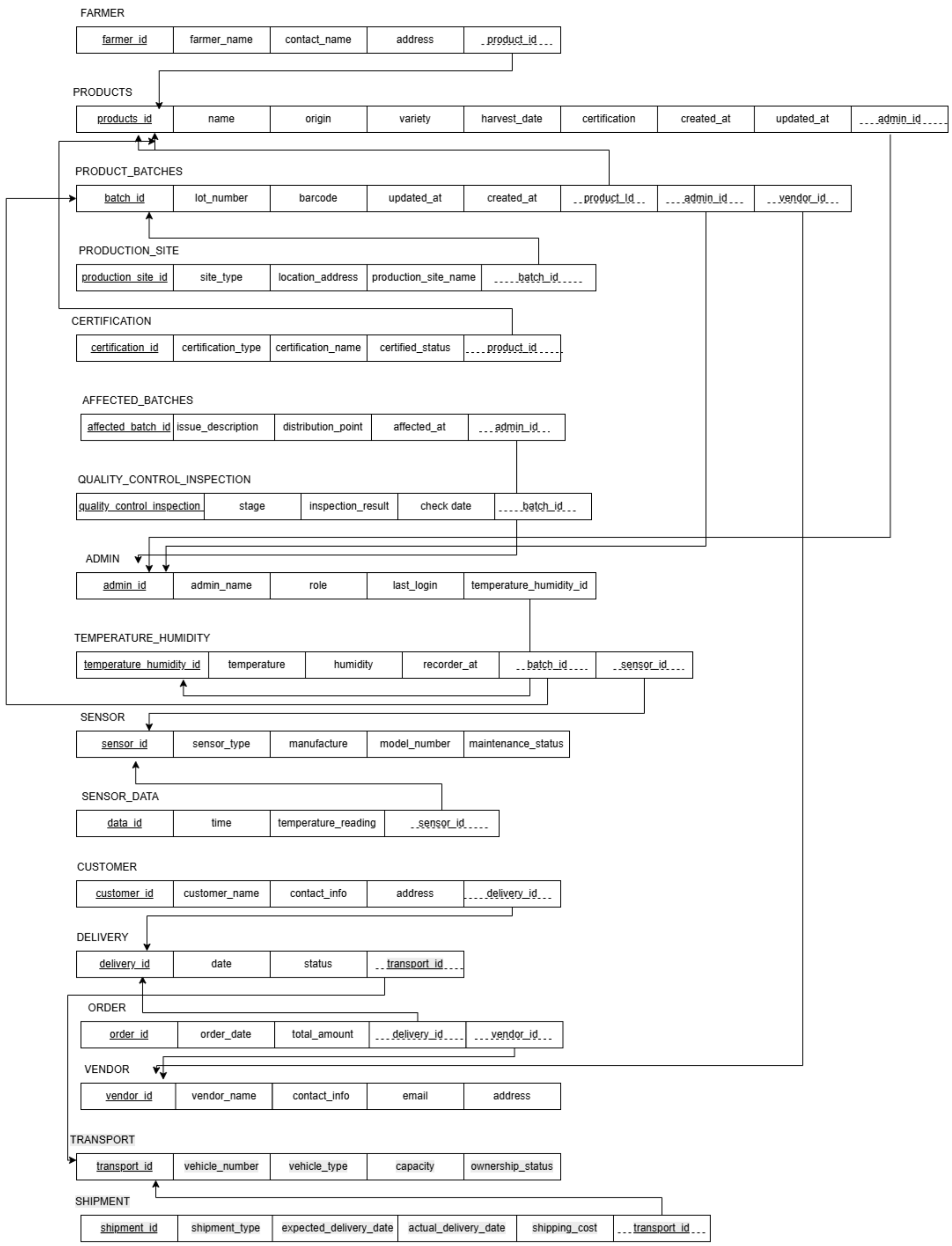

Fig. 4. Schema

E. Normalization

This represents a well-normalization where the relationships between entities such as Customers, Orders, Products, Vendors, Payments, etc. are clearly defined to eliminate redundancy and improve efficiency and many more.
1NF (First Normal Form):Ensures atomicity by eliminating repeating groups and multi-valued attributes.

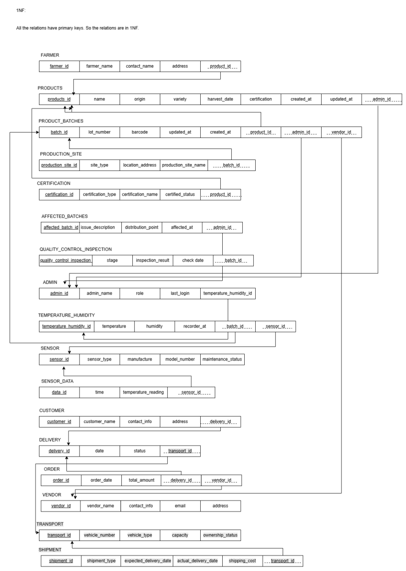

Fig. 5. 1NF

2NF (Second Normal Form): Removes partial dependencies all non key attributes must depend on the entire primary key.

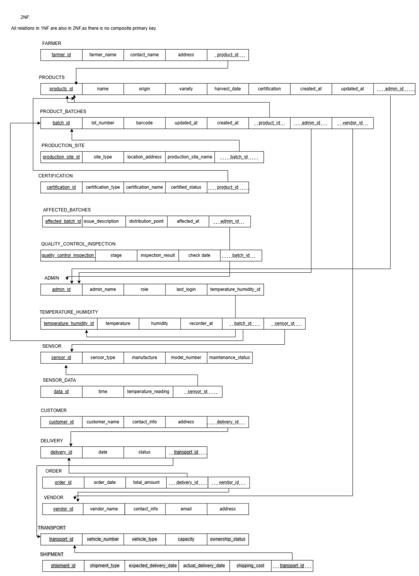

Fig. 6. 2NF

3NF (Third Normal Form): Eliminating transitive dependencies ; non key attributes must depend on the primary key.

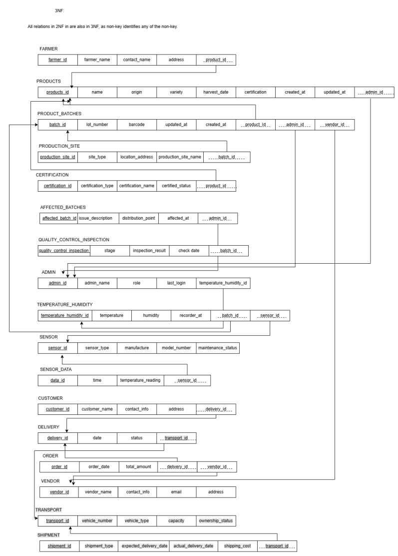

Fig. 7. 3NF

BCNF (Boyce - Codd Normal Form): A stricter version of 3NF where every determinant is a candidate key value.

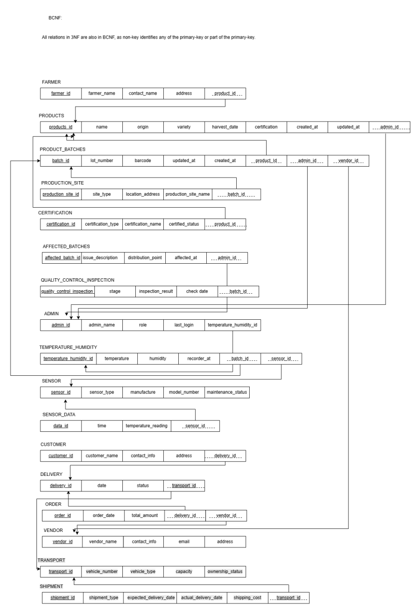

Fig. 8. BCNF

Basically in our project normalization we can see it goes for 2NF, since these were already in 3NF and BCNF. That’s why we need not to show 3NF and BCNF in our normalization file.

V. Discussion

A. Food Traceability System Dashboard

A software program called the Food Traceability System was created to monitor and control food items as they move through the supply chain. In order to guarantee safety, quality, and compliance, it allows stakeholders to keep an eye on different production, distribution, and transportation phases. The Food Traceability System's dashboard is a centralized interface that provides real-time insights and a summary of important metrics. Critical information like product identifiers, batch tracking, temperature and humidity readings, quality control inspections, and problems pertaining to particular batches are all easily accessible.

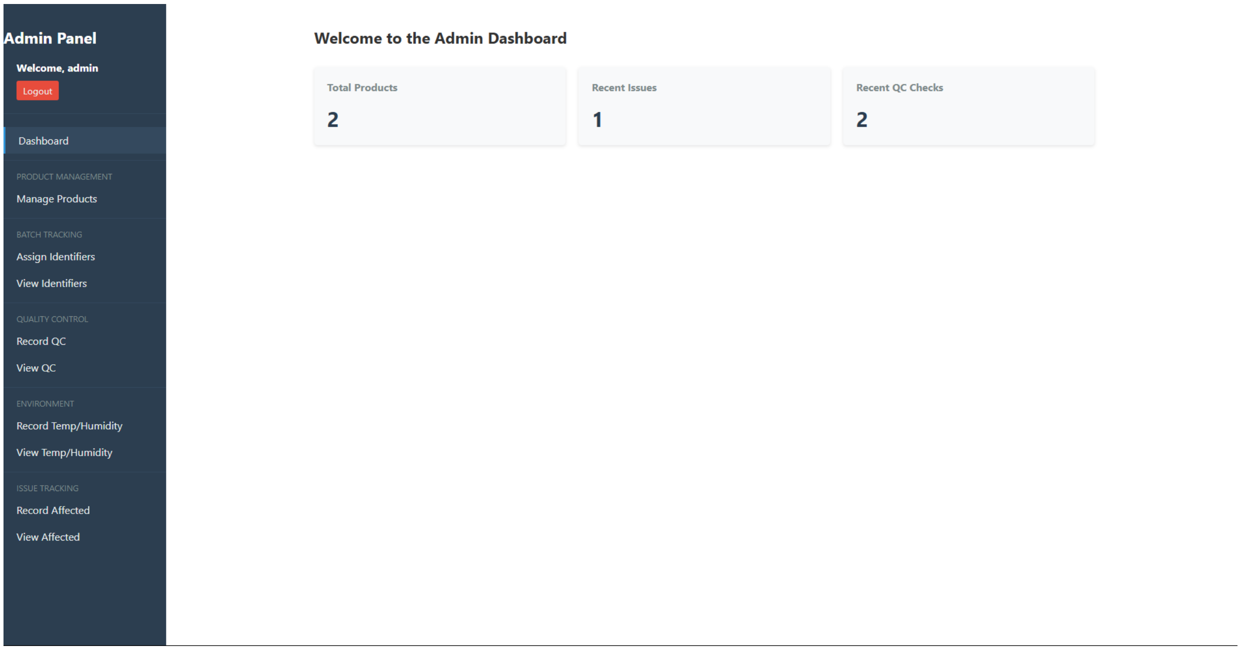

Fig. 9. Food Traceability System Dashboard

B. Analytics Highlighting the Benefits of Using Food Traceability System

By streamlining food product management and utilizing solid analytics, the Food Traceability System increases supply chain efficiency, safety, and compliance. Users can effortlessly track performance metrics thanks to the dashboard's integration of all pertinent information about product batches, quality control inspections, and environmental conditions. These analytics offer insights into the overall performance of the supply chain and assist in identifying possible problems, such as temperature variations or discrepancies in quality control. This proactive strategy increases consumer safety, decreases waste, and improves decision-making.

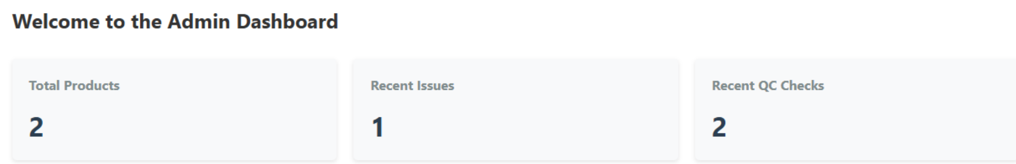

Fig. 10. Analytics Highlighting

C. Implementation of Food Traceability System Mitigating Real-Life Problems

Real-world issues that the food industry faces, like product recalls, contamination risks, and supply chain management inefficiencies, are successfully addressed by the Food Traceability System. The system lowers the likelihood of fraud, guarantees adherence to safety regulations, and facilitates the prompt identification of possible problems by offering real-time tracking and monitoring. This system reduces consumer risk by allowing businesses to respond quickly to issues and guarantee that any impacted products are promptly identified and taken out of distribution.

D. Implementation of Food Traceability System in Organizations, Stakeholders Using It

The Food Traceability System is designed for implementation across various levels of the food supply chain, including farms, manufacturers, distributors, retailers, and regulatory bodies. Key stakeholders using the system include food producers who use it to track product origins and conditions during transit, quality control teams that monitor compliance with safety standards, and regulators who use the system to ensure adherence to food safety laws. Retailers benefit from transparent product information, which helps them assure consumers of the safety and quality of food items sold.

VI. Conclusion

The use of blockchain technology to improve food safety and traceability in food supply chains is investigated in this study. The results show that blockchain can greatly enhance data accuracy, transparency, and real-time tracking while tackling problems like fraud and contamination. The study demonstrated blockchain's potential to offer a safe and impenetrable way to track food products from farm to consumer, demonstrating that the research objectives were successfully met. Adoption costs, accuracy, and data integration are still issues, though. For food traceability solutions to be even more effective and scalable, future research should concentrate on removing these obstacles, refining the blockchain's implementation, and investigating how it can be integrated with current systems.

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