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NAME   BATSIRAI

SURNAME: CHIKOWE

REG NUMBER: B201229B

COURSE: PROJECT DOCUMENTATION

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Approval Form

The undersigned certify that they have supervised the student Batsirai Chikowe in the research dissertation entitled, "   ." submitted in partial fulfilment of the requirements for a Bachelor Of Science Honors Degree in   at Bindura University of Science Education.
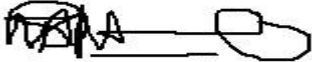
STUDENT: BATSIRAI CHIKOWE   **DATE: 07/10/2024**

SUPERVISOR: Mr P Chaka   **DATE: 07/10/2024**

CHAIRPERSON: MR T MHLANGANISO   **DATE: 07/10/2024**

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Dedication

I lovingly dedicate this research to myself and my friends since I have constantly work hard and get support from friends in all aspects of life. They have given me the drive and discipline to tackle any task with enthusiasm and determination, without them I wouldn't have reached this far. I will take this opportunity to mention a few, Innocent P Charamba was a motivator and almost my half parent, in anyway possible he tried his best to make sure I am happy financially and mental fitness as well. Myself as a hero, I managed to work hard to pay all the fees from part 1.1 until 4.2 though it was difficult to solely manage fees payment funded by a small glocery

tuckshop in Marondera located in Cherutombo. I would also dedicate this research to my Supervisor Mr P Chaka who was there to motivate and encourage me to work hard and improve punctuality in doing my research. He was in a position to enlighten me the value of the Degree compared to others on the current situation in Zimbabwe as well as the area of innovation I had raised. My effort and love with school has also boosted by the Provincial Magistrate Ms SB Chiwundura at Judicial Service Commission, who acted like a parent in motivating me financially and given me an inspiration which shows that the future is bright. This innovation stands as a testament to the boundless possibilities within the realm of computer science. With unwavering commitment and countless hours of exploration, I dedicate this work to visionaries who came before me, the mentors who guided my path, and limitless potential of technology itself. May this project serve as a stepping stone toward a brighter future, where technology transforms lives and empowers humanity. I also dedicate this project to the time spent deciphering complex algorithms and coding marvels. Dedicated to revolutionizing the way we interact with our food, this project celebrates the fusion of technology and sustenance. With profound gratitude to the farmers, suppliers, and culinary artisans who bring nourishment to our tables, this app is a tribute to their tireless efforts.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation and recognition to all those who contributed to the development and success of this food tracing app project. First and foremost, I extent my heartfelt gratitude to my mentor Mr P Chaka, whose guidance, expertise and unwavering support were instrumental in shaping this project. Your insightful feedback and valuable suggestion have truly elevated the app to new heights. I would like to thank the team members collaborators who dedicated their time, skills, and expertise to this endeavor. Your contribution in coding, designing, or data analysis have been invaluable in-bringing this vision to life. Special thanks to the farmers, producers and suppliers who shared their knowledge and insights with us. Your commitment to quality and sustainability has been a driving force behind the development of this app. We hope that this technology will help highlight your efforts and promote a more transparent and responsible food industry. I would also like to acknowledge the participants and users who provided the feedback during the testing and evaluation phases. Your

input and engagement were crucial in refining the app's features ensuring its usability and effectiveness. Furthermore I extent my appreciation to the academic community and researchers in the field of computer science and food technology. Your groundbreaking work and advancement save as a foundation for this project, inspiring us to explore new possibilities and push boundaries. Last but not least I am grateful to my friends to their unwavering support, encouragement, and understanding throughout this journey. Your belief in me and this project has been a constant source of motivation. Together we have created a food tracing app that not only enhances transparency and traceability in the food industry but also empowers consumers to make informed choices about the food they consume. May this project contribute to a healthier and more sustainable, and social responsible future.

ABSTRACT

The blockchain-powered food tracing app is a computer science project developed to address the growing demand for transparency and traceability in the food industry. This app utilizes cutting-edges technology to provide users with comprehensive information the origin, journey, and quality of their food products. The primary objective of the app is to empower consumers to make informed choices by gaining access to detailed information about the food they consume. Through the app's user-friendly interface, individuals can scan products bar code or enter product batch code or search for a specific items to retrieve a wealth of data, including the source of ingredients farming practices, processing methods and transportation details. The gestation period of this innovation was eight months and these were literally spent doing observations, experimental work and research with the help of my Supervisor Mr P Chaka. It is a prerequisite of Bachelor of Science Honor's Degree in Computer Science that the research be prepared to give insights of the practical experiences and its relevance to the academic curriculum.

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CHAPTER 1

1.0 Introduction

Food security and traceability have emerged as critical concerns in today's globalized food supply chains (World Food Programme, 2020). Ensuring the safety, authenticity, and transparency of food products from farm to fork is of paramount importance to safeguard public health, build consumer trust, and address the challenges posed by food fraud, contamination, and supply chain disruptions (Sundmaeker et al., 2016). Blockchain technology, with its unique attributes of transparency, immutability, and decentralized data management, has garnered considerable attention as a promising solution to address these issues (Meng et al., 2019).

Blockchain, initially designed to underpin cryptocurrencies like Bitcoin (Nakamoto, 2008), has since found applications in various industries, including the food sector (Mak, 2020). Its ability to create a tamper-proof and auditable ledger of transactions has paved the way for enhanced food security and traceability. Blockchain technology offers a decentralized and transparent ledger system that can track the journey of food products through the supply chain, enabling stakeholders and consumers to access real-time information about the origins, processing, and handling of these products (Iansiti & Lakhani, 2017). This transparency empowers consumers to make informed choices, assists regulators in enforcing food safety standards, and aids companies in identifying and addressing issues such as contamination, adulteration, and fraud (Yiannas, 2018).

Blockchain's role in the food industry extends beyond mere traceability; it also encompasses quality control, authentication, and recall management (Raj & Kumar, 2020). Smart contracts embedded within the blockchain can automate quality checks and trigger alerts or actions when deviations from established standards are detected. This feature not only ensures product quality but also reduces the risk of unsafe or compromised food products reaching consumers (Meng et al., 2019).Additionally, blockchain technology addresses the persistent challenges of food fraud and counterfeiting by enabling the recording of unique identifiers on the blockchain (Dorri et al., 2017). This prevents counterfeit or substandard products from infiltrating the supply chain, protecting both consumers and brand integrity (Mak, 2020).Moreover, in cases of food safety incidents or product recalls, blockchain expedites the identification of affected products, facilitating rapid and targeted responses (Iansiti & Lakhani, 2017). It provides a clear and immutable record of the product's journey, enabling companies to pinpoint the source of the issue and take corrective actions swiftly (Raj & Kumar, 2020).

Blockchain's utility in the food sector extends to regulatory compliance, sustainability, ethical sourcing, and reducing food waste (Meng et al., 2019). By providing a comprehensive and

tamper-proof record of all supply chain transactions, it eases compliance with food safety regulations and empowers companies to showcase sustainable and ethical sourcing practices (Sundmaeker et al., 2016).As consumers become more conscious of the environmental and social implications of their food choices, blockchain can provide the necessary transparency to verify claims related to sustainability and ethical sourcing, thus meeting the evolving demands of today's food market (Yiannas, 2018).

1.1 Background of Study

The study of applying blockchain technology for food security traceability arises from the growing concerns and challenges associated with the modern food supply chain (Smith, 2017). As global trade in food products has expanded, so too have the complexities and risks in ensuring the safety, quality, and authenticity of these products (Hartmann et al., 2019). Foodborne illnesses, contamination, adulteration, and fraud have become recurring issues, jeopardizing public health and consumer trust (Manning, 2018).

Traditional methods of traceability and supply chain management have limitations in addressing these challenges. Paper-based records, manual audits, and disconnected data systems are susceptible to errors, fraud, and inefficiencies (Yiannas, 2018). As a result, stakeholders in the food industry, including consumers, regulators, and businesses, have sought innovative solutions to enhance transparency and accountability throughout the food supply chain (Mak, 2020).

Blockchain technology, introduced by the pseudonymous entity Satoshi Nakamoto in the context of Bitcoin (Nakamoto, 2008), gained prominence as a potential game-changer for various industries due to its unique characteristics (Iansiti & Lakhani, 2017). A blockchain is a distributed ledger that records transactions in a secure, transparent, and immutable manner (Swan, 2015). These attributes make it well-suited to address the intricate challenges of the food supply chain.

The application of blockchain technology in the food sector has gained traction over the past decade, with numerous pilot projects and initiatives exploring its potential benefits (Meng et al., 2019). The concept revolves around creating a decentralized and tamper-proof ledger of transactions and data related to food products. Each step of a food product's journey, from cultivation and processing to distribution and retail, can be recorded on the blockchain. This

ledger can be accessed by all authorized participants, including consumers, allowing for realtime tracking and verification of the product's origin, quality, and safety (Dorri et al., 2017).

This research topic has gained prominence in academia, industry, and government circles due to its potential to address critical issues such as food safety, fraud prevention, supply chain efficiency, and consumer confidence (Sundmaeker et al., 2016). Several scholarly studies, industry reports, and government initiatives have delved into the practical applications, challenges, and implications of using blockchain technology to enhance food security and traceability (Raj & Kumar, 2020). These studies have explored various facets of the technology, including its role in quality control, authentication, recall management, regulatory compliance, sustainability, and reducing food waste (Mak, 2020).

As the world becomes more interconnected, consumers increasingly demand transparency and accountability from food producers and suppliers (Yiannas, 2018). This shift in consumer behavior, coupled with regulatory pressures to ensure food safety and traceability, has driven the exploration and implementation of blockchain solutions in the food industry.

In summary, the background of the study on applying blockchain technology for food security traceability stems from the need to address the pressing challenges facing the modern food supply chain (Hartmann et al., 2019). The adoption of blockchain technology offers a promising avenue for improving food security, transparency, and traceability, with potential benefits for all stakeholders involved in the production and consumption of food products (Smith, 2017).

1.2 Problem Statement

The global food supply chain faces significant challenges, including fragmented and opaque supply chains that hinder accurate tracking, increasing incidents of food fraud and contamination, complex regulatory compliance requirements, consumer demands for transparency, inefficiencies contributing to food waste, counterfeit and substandard products entering the supply chain, and the need for interoperability and standardization in implementing blockchain-based solutions. These challenges call for a comprehensive approach to leverage blockchain technology effectively and address the pressing issues of food security and traceability in the food industry.

1.3 Research Aim

The aim of this research is to investigate the potential of blockchain technology as a solution to enhance food security and traceability in the global food supply chain. This study seeks to comprehensively explore the applications, benefits, challenges, and implications of implementing blockchain technology in the food industry. Additionally, it aims to provide insights and recommendations for stakeholders, including businesses, regulators, and consumers, to maximize the advantages of blockchain in ensuring the safety, transparency, and authenticity of food products.

1.4 Research Objectives

1. To evaluate the efficiency gains achieved through blockchain technology.
2. To design and implement a blockchain-based food traceability system.
3. To analyze the blockchain technology using the required metrics.

1.5 Research Questions

1. What has been achieved by other researchers in the domain of blockchain technology?
2. What are the methods and tools to be used by the author to implement and design the technology?
3. What are the metrics to be applied by the author to analyze and evaluate the technology?

1.6 Research Justification

This research is essential due to the pressing challenges in the global food supply chain. Ensuring food safety, building consumer trust, and addressing issues like contamination and fraud are paramount for public health and confidence. Blockchain technology offers a promising solution by enhancing transparency, accuracy, and efficiency throughout the supply chain.

Consumer concerns about food quality and origin, coupled with the complexity of global supply chains, make a compelling case for blockchain. It simplifies these complex systems, providing consumers with transparent information about their food's journey, thereby fostering trust.

The persistent problems of food fraud and counterfeiting are also mitigated through blockchain's tamper-proof records, ensuring product authenticity. Moreover, compliance with evolving food safety regulations is simplified, reducing compliance risks.

Efficiency gains, cost-effectiveness, and reduced food waste have significant economic and environmental implications, making the exploration of blockchain's potential in the food industry timely and relevant.

1.7 Tools used for application development.

- ✓ Java
- ✓ Android
- ✓ Laravel
- ✓ MySQL
- ✓ Agile Software Development
- ✓ Blockchain Technology

1.8 Research Limitations

This research, while endeavoring to explore the applications and advantages of blockchain technology in enhancing food security and traceability, must acknowledge several inherent limitations:

Technological Maturity: Blockchain technology is in a continuous state of evolution, and its application within the food industry is still in its early stages. Consequently, the research may encounter limitations concerning the maturity and scalability of available blockchain solutions.

Resource Constraints: Carrying out comprehensive blockchain implementations in realworld food supply chains can be resource-intensive. Budgetary constraints and access to the necessary technology and expertise may constrain the research's scope and scale.

Data Privacy and Security: While blockchain's transparency ensures data integrity, it simultaneously raises concerns about data privacy and security. The research needs to carefully consider how to strike a balance between transparency and safeguarding sensitive information.

Interoperability Challenges: Integrating blockchain with existing systems and achieving interoperability with diverse blockchain platforms can be daunting. Compatibility issues may emerge when linking with the systems of various stakeholders.

Regulatory Hurdles: Blockchain implementations in the food industry must adhere to local and international regulations, which can be intricate and subject to **change**. Ensuring legal compliance and navigating these regulations may pose challenges.

Limited Industry Adoption: It is crucial to acknowledge that not all participants in the food supply chain may have adopted blockchain technology. This could **lead** to potential gaps in data coverage and interoperability. The research must consider the implications of **incomplete** adoption.

Generalization: Findings derived from a specific implementation or case study may not be readily applicable to all food supply chain scenarios. Different supply chains possess unique characteristics that may yield varied outcomes.

Consumer Behavior: Although blockchain can augment transparency, it cannot guarantee changes in consumer behavior or a widespread increase in consumer trust. The adoption and response of consumers to blockchain-enabled traceability systems may exhibit variations.

Environmental Impact: Certain blockchain technologies, especially those reliant on energyintensive consensus mechanisms, may have environmental ramifications. Evaluating the environmental footprint of blockchain implementations becomes essential.

Temporal Factors: Given the rapid pace of technological advancement, the blockchain landscape within the food industry may undergo significant changes during the course of the research, potentially influencing the relevance of the findings.

These limitations underscore the need for a thoughtful and context-sensitive approach when investigating and implementing blockchain solutions for food security and traceability. Researchers and practitioners should remain cognizant of these constraints while exploring the potential benefits of blockchain technology in the food sector.

1.9 Research Hypothesis

H0: The integration of blockchain technology does not significantly improve food traceability in terms of accuracy, transparency, and efficiency within the food supply chain.

H1: The implementation of blockchain technology significantly enhances food traceability, ensuring accurate and transparent tracking of food products across the supply chain, thereby addressing critical challenges related to safety, fraud, and inefficiencies.

1.10 Definition of terms

Understanding Blockchain Technology and Food Traceability

Blockchain technology represents a paradigm shift in record-keeping, offering a decentralized and distributed ledger that ensures secure, transparent, and tamper-resistant transactions (Blockchain Council, n.d.). This technology operates through a series of blocks, each containing a timestamped list of transactions linked together using cryptographic hashes (Nakamoto, 2008). The immutable nature of blockchain ensures that once data is recorded, it cannot be altered or deleted, thereby preserving the integrity and transparency of records across the network.

Food traceability, on the other hand, is the process of tracking and tracing food products throughout the entire supply chain, encompassing production, processing, distribution, and retail (European Commission, 2017). This involves meticulously documenting critical details such as the food's origin, manufacturing methods, handling practices, and distribution routes. Effective traceability systems are essential for ensuring food safety by enabling rapid identification of issues such as contamination and facilitating the swift removal of affected products from circulation to protect public health.

An immutable ledger, such as blockchain, plays a fundamental role in supporting traceability efforts by guaranteeing the historical integrity of records (Swan, 2015). This feature ensures that once data is added to the ledger, it remains unchanged and resistant to tampering, thereby enhancing trust and transparency in the information stored within the system.

Decentralization is a core principle of blockchain technology, distributing authority, control, and decision-making across multiple nodes or participants in the network (Antonopoulos, 2014). By eliminating the need for a central authority, decentralization reduces the risk of manipulation or failure at a single point, thereby enhancing the security and resilience of the network.

Tamper-resistance is another critical attribute of blockchain, achieved through cryptographic techniques that protect the ledger from unauthorized changes or fraudulent activities (Tapscott & Tapscott, 2016). This ensures the security and reliability of the data stored in the blockchain, making it suitable for applications requiring high levels of trust, such as food traceability.

The supply chain, which encompasses all stages from production to consumption, plays a pivotal role in ensuring the integrity and safety of products (Christopher, 2016). In the context of food traceability, thorough monitoring of the supply chain helps prevent and manage contamination incidents by swiftly identifying and isolating affected products (Food Standards Agency, 2020). This proactive approach not only protects public health but also maintains consumer confidence in the safety and reliability of food products

1.11 Conclusion

In conclusion, this introductory chapter lays the groundwork for a comprehensive investigation into the application of blockchain technology for food traceability. The identified problem statement highlights the existing challenges in the food supply chain, and the research hypothesis establishes the framework for assessing the impact of blockchain solutions. The research objectives provide a roadmap for exploring key aspects of blockchain implementation, and the justification emphasizes the significance of addressing current issues in the food industry. As the study progresses, subsequent chapters will delve into the methodology, empirical findings, and implications for the broader field of food traceability and supply chain management.

CHAPTER 2

2.0 Introduction

A literature review functions as an academic manuscript presenting a thorough comprehension of scholarly works pertinent to a specific subject within a broader academic framework. This evaluative survey not only entails summarizing extant literature but also involves a critical analysis of the materials. The term "literature review" is apt, given that it necessitates both the scrutiny of existing literature and the creation of a written discourse on the subject (Newton, R.R., 2021). In essence, it encapsulates the dual processes of reviewing and composing scholarly discourse.

2.1 Food Safety and Traceability

Foodborne disease incidents arising from various contamination sources pose significant global public health threats in the 21st century (Moe, 2018). Challenges related to food safety, agroprocessing, and the environmental impact of agriculture are exacerbated by incidents such as

BSE, genetically engineered foods, and contamination of fresh and processed agriculture (Opara & Mazaud, 2018). The globalization of trade, consumer demands, and terrorism threats have underscored the necessity of traceability systems in food and agriculture supply chains (Varga & Csukas, 2017). The costs associated with food safety include human, economic, and political issues and can be exacerbated by the proliferation of human pathogens, antibioticresistant bacteria, and zoonotic pathogens in meat and dairy products. Additionally, unsafe agricultural practices, including the use of manure, chemical fertilizers, pesticides, and contaminated water on fresh fruits and vegetables, contribute to food safety concerns.

Modern food production, processing, and distribution systems integrate and commingle food from multiple sources, farms, regions, and countries. Food products covered by traceability standards encompass fresh produce, bulk foods, fish and seafood, and livestock for meat and dairy (Opara, 2003). The smallest traceable unit depends on the food product and industry practices. Good practices in traceability involve making lot numbers and the name of the

production facility visible on each product case, along with recording quantity and shipping location. Typical traceability data include the physical location that last handled the product, supply chain partner, production amount, shipping location, lot number, and date/time of product receipt, shipment, or harvesting. Traceability requires recording data when a product is moved between premises, transformed, and further processed or when data capture is necessary to trace the product. Instances like these are known as critical tracking events and are vital for linking products across the supply chain.

Growing consumer awareness of food-related safety issues drives the demand for more information about the vertical food supply chain, emphasizing the origin and handling of basic commodities and food products worldwide. According to the International Organization for

Standardization (ISO), traceability is defined as the ability to trace the history, application, or location of an entity through recorded identifications. Traceability is an essential subsystem of quality management, managed by setting up a traceability system that keeps tracking data of product routes and selected attributes.

A traceability system comprises two elements: the routes of the product, including manufacturing, distribution, and retail procedures, and the desired extent of traceability (Wang, Li, & Li, 2009). Food traceability system is aimed to provide information visibility throughout the supply chain process and has attracted enthusiastic research interests due to the globalization of the food supply chain. Accuracy and transparency of products and activities throughout the supply chain are crucial quality indices in food and agribusiness (Pouliot & Sumner, 2008). Food traceability requires all stakeholders in the food supply chain, including agriculture and feed producers, food manufacturers, retailers, to identify the source of all raw materials and ingredients, as well as the recipients of the products. Food companies need to apply identification systems and data-handling procedures integrated into their quality management system. The sector encompassing IT centers ought to find a reasonable compromise between passing traceable unit IDs step-by-step for neighboring actors and accumulating databases. The traceability system aims to provide cooperative services for supply chain actors and support supply chain and value chain management, along with the work of health authorities (Golan et al., 2023).

Opara (2023) reviews concepts of supply chain management and traceability in agriculture, emphasizing technological challenges and the integration of traceable supply chains. Wang et al. (2013) address the integration of traceability values with supply chain management processes to enhance business performance. By modeling the stylized marketing chain composed of farms, marketers, and consumers, Pouliot and Sumner (2014) demonstrate that increased food traceability creates incentives for farms and marketing firms to supply safer food by increasing liability costs. Golan et al. (2014) summarize motives for food suppliers to establish product tracing systems, including supply management improvement, marketing differentiation, and facilitation of trace-back for food safety and quality.

The aim of a traceability system is to collect product-related information along the supply chain, crucial during food safety crises and product recall actions. Although a recall action could be critical, most companies currently lack reliable methods to estimate the amount of product to be discarded. Dabbene and Gay (2017) introduce criteria and methodologies for measuring the quantity of products to be recalled in the case of mixed batches. Considering the food traceability system as part of logistics management, Bosona and Gebresenbet (2018) summarize the literature on food traceability issues, covering definitions, driving forces, barriers, benefits, technologies, improvements, and performances of food traceability systems. The development of a full-chain food traceability system is complex, requiring a deeper understanding of real processes from various perspectives such as economic, legal, technological, and social issues. Studies on the integration of traceability activities with food logistics, the linkage between traceability systems and food manufacturers, standardization of data capturing, communication protocols, and performance evaluation frameworks for food traceability systems need focus (Dabbene & Gay, 2011; Bosona & Gebresenbet, 2018) chains.

2.2 Current Developments for Food Traceability

It's clear that concerns surrounding the safety and transparency of our food supply are paramount across the globe. Whether in the US, Europe, Japan, or elsewhere, consumers are increasingly vigilant about understanding where their food comes from and how it's produced.

This heightened awareness isn't just a passing trend; it's becoming a fundamental expectation.

Businesses operating within the global food supply chain are feeling the pressure to implement traceability measures. Without them, staying competitive and maintaining consumer trust becomes a significant challenge. This pressure isn't just coming from consumers; it's also being exerted by media scrutiny, merchants demanding accountability, and government regulatory bodies enforcing standards.

In 2017, the UN General Assembly recognized the critical importance of food safety for consumer health, elevating it to one of the top three areas of concern in a resolution focused on consumer protection. This recognition underscores the gravity of the issue and emphasizes the need for comprehensive guidelines to address it.

From these UN guidelines emerged the FAO Codex Alimentarius, a set of standards and guidelines developed to ensure the safety, quality, and fairness of international food trade. This framework serves as a vital tool for governments, producers, and consumers alike, offering a roadmap for establishing and maintaining food safety standards across borders.

Ultimately, embracing traceability and adhering to internationally recognized standards isn't just a matter of compliance; it's a strategic imperative for businesses looking to thrive in the modern food landscape. By prioritizing transparency and safety, companies can not only meet regulatory requirements but also build trust with consumers and secure their place in the evolving global market.

The General Food Law, Regulation (EC) 178, of the European Parliament and the Council referring to traceability is effective since January 1, 2005, and consists of five major concerns:

Establishing and maintaining traceability throughout the entirety of the food supply chain is a fundamental aspect of ensuring consumer safety and regulatory compliance. These guidelines, which encompass various facets of traceability, underscore the necessity for meticulous tracking at each stage of production, processing, and distribution (Food and Agriculture Organization of the United Nations [FAO], 2019). Firstly, the ability to trace food, feed, and related substances from their origins through to their incorporation into final products is emphasized (FAO, 2019).

This entails implementing robust systems and procedures to monitor the journey of these items, providing a comprehensive overview of their production history.

Secondly, businesses operating within the food and feed industry are required to have mechanisms in place to identify their suppliers accurately (FAO, 2019). This involves maintaining detailed records that allow for the swift retrieval of information regarding the source of supplied goods. Similarly, the ability to track the recipients of products is deemed essential, ensuring transparency and accountability throughout the supply chain (FAO, 2019). By having systems and procedures in place to identify where their products have been supplied, businesses can contribute to enhanced traceability efforts and facilitate effective regulatory oversight.

Furthermore, clear labeling and documentation play a pivotal role in facilitating traceability within the food supply chain (FAO, 2019). Adequate labeling or identification of food and feed products enables authorities to readily trace their origin and distribution, thus streamlining recall procedures and response efforts in the event of safety concerns. Additionally, adherence to sector-specific provisions ensures that unique requirements for traceability within particular industries are addressed comprehensively.

The European Union (EU) red-meat system places a significant emphasis on ensuring hygiene through Hazard Analysis Critical Control Point (HACCP) systems, beginning at the farm level (Bosona & Gebresenbet, 2018). Compliance with traceability directives is crucial for food and feed business operators across the EU, driven by the rigorous criteria set by large retailers like Aldi, Lidl, Real, Metro, and Marks & Spencer (Bosona & Gebresenbet, 2018). In Italy, the Italian Standards Institute (UNI) has enacted specific legislative measures to regulate traceability, issuing standards such as UNI 10939 and UNI 11020 (Bosona & Gebresenbet, 2018). Similarly, Canada introduced mandatory cattle identification in 2002 through the Canadian Cattle Identification Agency (CCIA) (Bosona & Gebresenbet, 2018).

Despite various legislative acts introduced in European countries like France, Spain, and Greece, focusing primarily on quality issues, the importance of traceability for food safety remains paramount (Bosona & Gebresenbet, 2018). Consumer perceptions of traceability are influenced by factors such as confidence in provided information, convenience, product quality and safety, impact on health and the environment, and ethical and privacy considerations (Chrysochou et al., n.d.). Regulatory issues surrounding genetically modified organisms are also addressed by EU legislation, mandating labeling for foods containing detectable transgenic material (Bosona & Gebresenbet, 2018).

Following mad cow disease outbreaks, Japan mandated the adoption of radio frequency identification (RFID)-enabled traceability systems in 2004 and developed web-based traceability systems for other food products (Bosona & Gebresenbet, 2018). Similarly,

Australia and Korea have adopted web-based food traceability systems (Bosona & Gebresenbet, 2018). However, despite the importance of traceability, its establishment in food chains remains voluntary in many regions, including the United States, where traceability systems are primarily developed by pioneering companies (Bosona & Gebresenbet, 2018).

A comparative study highlighted that the U.S. red-meat system lags behind its major competitors in terms of traceability and transparency (Bosona & Gebresenbet, 2018). While the U.S. food inspection system focuses on controlling pathogens, competitors' systems prioritize tracing meat back to its origin and providing information on other characteristics (Bosona & Gebresenbet, 2018). Despite this, private sector food firms in the U.S. have developed substantial traceability capacities (Golan et al., n.d.).

Effective government policies can incentivize firms to invest in traceability while ensuring the swift removal of unsafe or falsely advertised foods from the system (Bosona & Gebresenbet, 2018). Balancing the costs and benefits of traceability, U.S. food producers have developed considerable capacity to track food along the supply chain, with traceability systems varying in depth (Bosona & Gebresenbet, 2018).

2.3 Blockchain Technology

Blockchain technology is a decentralized and distributed ledger system designed to facilitate secure, transparent, and tamper-resistant record-keeping of transactions across a network of computers. At its core, blockchain operates without the need for a central authority, such as a bank or government, and relies on a network of nodes, where each node possesses a copy of the entire blockchain (Gebresenbet ,2018). This decentralized structure eliminates the need for intermediaries and promotes a trustless and efficient system.

Transactions within a blockchain are recorded in blocks, and these blocks are linked together in a chronological chain, forming a distributed ledger. The distributed nature of the ledger ensures that all nodes in the network have access to the same information, fostering transparency. The consensus mechanisms employed by blockchain, such as Proof of Work (used in Bitcoin) or Proof of Stake, are crucial for validating and agreeing on the state of the ledger (Debbane and Gay ,2017). These mechanisms ensure that participants in the network collectively validate transactions.

One key feature of blockchain is immutability. Once a block is added to the blockchain, it becomes extremely challenging to alter its contents. This is achieved through cryptographic hash functions and the decentralized consensus mechanism, making the system resistant to tampering and fraud. Smart contracts represent another significant aspect of blockchain technology (Gebresenbet ,2018). These are self-executing contracts with terms written into code. Smart contracts automatically execute and enforce predefined terms when specific conditions are met, streamlining and automating contractual agreements.

Blockchain's applications extend beyond cryptocurrencies. It is widely used in supply chain management, healthcare for secure patient data sharing, voting systems, identity verification, and more. Despite its potential, blockchain faces challenges such as scalability, energy

consumption (in the case of Proof of Work), regulatory uncertainties, and the need for standardization. Blockchain technology comes in various types. Public blockchains, such as Bitcoin and Ethereum, are accessible to anyone and maintained by a decentralized network. Private blockchains restrict access and are typically used within organizations for specific purposes. Consortium blockchains strike a balance, being semi-decentralized and managed by a group of organizations.

2.4 Reviews of previous researchers

The recent occurrences of foodborne illnesses linked to pathogens like E. coli and Salmonella, particularly in fresh produce such as spinach, green onions, and tomatoes, have significantly impacted consumers' trust in the safety of specialty crops (Buzby and Frenzen, 1999). These outbreaks have raised concerns about the vulnerability of the specialty crops supply system and its potential repercussions on public health.

The globalization of the world economy and the increased free trade in agricultural products have further compounded the challenges associated with food safety. The unrestricted movement of food products across national and regional borders heightens the risk of widespread foodborne diseases. This evolving landscape has intensified the demand from consumers and stakeholders in the food supply chain for enhanced assurance and transparency regarding the quality, safety, and environmental impact of fruits and vegetables (Opara and Mazaud, 2001).

In response to these challenges, food traceability has emerged as a critical concept. Food traceability is termed as the capability to uncover the complete trends of each food item, encompassing its origin, cultivation practices, and the sources of inputs (Langan, 2000). This traceability is essential not only for addressing safety concerns but also for providing comprehensive information to consumers and stakeholders about the journey of food products from farm to table.

In the realm of food traceability, a prevalent method involves the application of a twodimensional label, with the QR code being a commonly adopted format, affixed to the packaging of food or agricultural products. One notable instance is the Traceability Agricultural Product (TAP) system, introduced in 2007 to facilitate the traceability of agricultural products.

Noteworthy is the voluntary nature of the TAP system's usage, where farmers and agrobusinesses choose to employ it rather than it being a mandatory requirement.

Illustrative instances of traceability labels in Taiwan are depicted, showcasing diverse products, including rice, eggs, vegetables, and seafood such as shrimps and fishes. The labels incorporate QR codes, and consumers have the convenience of utilizing a mobile phone to scan these codes affixed to the product packaging. This scanning process provides consumers with immediate access to comprehensive traceability information about the respective product, contributing to an informed and empowered consumer base.

A technological solution that has gained prominence in recent years for enhancing traceability is Radio-Frequency Identification (RFID). RFID technology allows for the unique identification of items and has proven to be particularly promising in the management of global supply chains. When applied to the production and supply chain of fruits and vegetables, RFID offers a means to efficiently and accurately trace the movement of products through various stages, from cultivation to distribution.

The utilization of RFID in the traceability of fruits and vegetables represents a significant advancement in supply chain management. It not only enables real-time tracking of products but also enhances the overall visibility and control of the supply chain. By leveraging RFID technology, stakeholders can swiftly and accurately access information about the origin and journey of each food product, contributing to a more secure and transparent food supply chain.

Food traceability plays a crucial role in the food safety supply chain, offering a means to effectively track produce and mitigate risks associated with contamination and foodborne diseases. In the context of the post-Covid-19 health and nutrition landscape, establishing a resilient and diversified food supply chain is imperative, with traceability emerging as a key component in this endeavor. Given the burgeoning interest in traceability and its technological dimensions, a comprehensive examination of the scientific trends and research activities in this domain becomes essential.

This study undertakes a scientometric analysis to shed light on the evolving landscape of food safety management systems, particularly focusing on traceability. The Scopus database served as the primary source for documents spanning the years 1992 to 2021, with a specific emphasis on research papers and conference papers. The scientometric analysis, facilitated by Vosviewer

software, encompasses various facets, including the distribution and growth trends of documents, the geographical distribution of publications at the country level, and the collaborative relationships among authors.

Examining the intensity of publications across different countries and exploring collaborative endeavors through the bibliometrix R-package, the findings unveil a noteworthy surge in research activities related to traceability systems for enhancing food safety. This surge becomes particularly pronounced from the year 2014 onward, with substantial contributions originating from the USA and China. However, despite this upward trajectory, the research landscape appears to be in a developmental phase relative to advancements in other technological domains and automation. This observation underscores the continued potential and room for growth in comprehending and implementing traceability systems for bolstering food safety.

2.5 Conclusion

This chapter serves to outline the previous researches that have been done by various authors. The author serves to explain the much-needed information to prove the feasibility of the system with respect to other researches that has paved a way. Henceforth in addition the author explains in detail how the author is going to tackle the problem at hand with technological practical solutions. This helps the researcher in the deep research.

CHAPTER 3: RESEARCH METHODOLOGY

3.0 INTRODUCTION

The objective of this chapter is to elucidate the strategies and tools essential for realizing the research and system objectives. Building upon the information gathered in the preceding chapter, the author will devise methods necessary to develop a solution and navigate through various strategies to achieve the anticipated research outcomes.

Blockchain technology has significant potential in enhancing food traceability by providing transparent, immutable, and decentralized records of food products throughout the supply chain.

3.1 RESEARCH DESIGN

This study aims to investigate the application of blockchain technology for food traceability, focusing on its potential impact on supply chain transparency and consumer trust. A mixedmethods research design will be employed, incorporating both quantitative and qualitative approaches. Firstly, a quantitative survey will be conducted among key stakeholders in the food industry, including farmers, distributors, retailers, and consumers, to assess their awareness of blockchain technology and its perceived benefits and challenges in enhancing food traceability. This survey will utilize a structured questionnaire to gather data on variables such as knowledge of blockchain, willingness to adopt blockchain-based systems, and perceived barriers to implementation. Additionally, qualitative interviews will be conducted with a select group of industry experts and policymakers to gain in-depth insights into the specific mechanisms through which blockchain can improve traceability, such as real-time data sharing,

immutable records, and enhanced visibility. Through the triangulation of survey results and interview findings, this research seeks to provide a comprehensive understanding of the potential applications of blockchain technology in food traceability, as well as the factors influencing its adoption and effectiveness within the food supply chain.

3.2 REQUIREMENTS ANALYSIS

The success or failure of any project hinges on the critical process of requirements analysis. Formulated requirements must possess key attributes to contribute to success, including being realistic, documented, testable, actionable, traceable, measurable, and aligned with identified business needs (Abram Moore, Bourque, & Dupuis, 2004). At this pivotal stage, it is imperative to meticulously document all functional and non-functional specifications of the required system. Organizing incoming data, assessing it, and considering potential limitations on the consumer's end are advisable steps.

The requirements analysis for applying blockchain technology for food traceability, integrating Android, Java, Laravel, and JavaScript, involves defining crucial functionalities and features. Firstly, within the Android application, provisions must be made for seamless data collection and recording, ensuring that traceability data such as product origin, processing details, and transportation specifics can be efficiently inputted. Java programming will be pivotal in developing the blockchain's immutability and security features, determining the consensus mechanism, encryption methods, and access controls to safeguard sensitive information. Laravel, with its robust backend capabilities, will facilitate interoperability and standardization efforts, enabling the integration of industry-wide data standards and blockchain interoperability protocols. JavaScript will play a key role in designing the user interface for the Android app, ensuring an intuitive experience for stakeholders to interact with the blockchain platform, access real-time tracking information, and verify product authenticity. Furthermore, the application will leverage JavaScript for implementing smart contracts and automation, allowing for the seamless execution of predefined actions based on trigger events such as temperature fluctuations or delivery deviations. Scalability and performance considerations will also be addressed, utilizing Java and JavaScript for optimizing transaction speeds and exploring scalability solutions like sharding. Compliance with regulatory frameworks, including GDPR, will be ensured through Java and Laravel's capabilities for regulatory reporting and data privacy measures. Lastly, training resources and technical support will be provided through the Android app's interface, empowering stakeholders to navigate the platform effectively. Through the integration of Android, Java, Laravel, and JavaScript, this blockchain solution aims to

revolutionize food traceability, offering a secure, transparent, and user-friendly system for all participants in the supply chain.

3.2.1 Functional Requirement

Functional requirements delineate the functions of a system or its individual modules, typically specifying the interactions between inputs and outputs (Fulton & Vandermolen, 2017). In essence, these requirements outline the services the system delivers upon the completion of specific tasks. They describe how the system responds to a set of inputs, detailing its behavior and the resulting output.

The proposed system must be able to meet the following requirements.

- ✓ Companies are required to register and their trade
- ✓ Companies are required to add food in a food supply
- ✓ Companies can view their products
- ✓ Companies can track their products by entering batch number
- ✓ Consumers can track products by entering batch number

3.2.1 Non-Functional Requirement

These requirements are commonly known as quality requirements, and their purpose is to evaluate the performance of a system rather than its intended behavior. The proposed system is expected to meet the following criteria:

- ✓ System should have very relatively small response time and decision time
- ✓ The system should be easy to assemble

3.3 Tools Used (Hardware and Software)

- ✓ Android studio 10
- ✓ Java
- ✓ PHP
- ✓ Laravel
- ✓ Blockchain logic
- ✓ Core i3 and above

3.4 SYSTEM DEVELOPMENT

This provides an overview of the system and details the development process undertaken to yield the results. It outlines the specific software tools and models employed in the system's development.

3.4.1 System Development Tools

By leveraging these software development tools, the author was able to develop a comprehensive application that combines mobile app functionality (using Android Studio and Java) with web-based features (using PHP and Laravel) while incorporating blockchain technology for enhanced security and transparency. This approach enables the creation of a versatile and robust solution that meets the needs of both mobile and web users, leveraging the benefits of blockchain technology in the process.

3.4.2 Experimental Research Methodology

Experimental research involves manipulating one or more variables to observe their effects on an outcome of interest. It typically utilizes controlled settings and random assignment to treatment conditions to establish causal relationships.

Figure 1

3.4.3 Characteristics

Emphasis on control, manipulation, and randomization to isolate the effects of specific variables. Allows researchers to draw causal inferences and test hypotheses rigorously.

3.6 ALGORITHMS USED

✓ Blockchain Logic

3.7 TECHNOLOGIES APPLIED

The author employed a range of software development tools to construct their application, each serving specific purposes throughout the development process. First and foremost, Android Studio 10 served as the primary integrated development environment (IDE) for crafting

Android applications. With its comprehensive set of tools for building, testing, and debugging Android apps, Android Studio 10 offers enhancements and features geared towards improving developers' efficiency and productivity.

Java, a widely used programming language, was another crucial component utilized by the author. As the primary language for Android app development, Java provides a robust and platform-independent environment for building scalable and secure applications. Its simplicity, readability, and extensive ecosystem of libraries and frameworks make it a preferred choice for mobile application development.

In addition to Android development tools, the author employed PHP, a server-side scripting language, for web development tasks. PHP is well-suited for building dynamic and interactive web applications, handling form data, and interacting with databases. Its wide support and seamless integration with HTML and other web technologies make it a popular choice for server-side scripting.

To further streamline web development tasks, the author utilized Laravel, a PHP web application framework. Laravel provides a rich set of tools and features for building modern

and scalable web applications. Following the Model-View-Controller (MVC) architectural pattern, Laravel includes built-in support for routing, authentication, database management, and templating, among other functionalities.

Lastly, the author incorporated blockchain logic into their application. This refers to the algorithms, protocols, and smart contracts used to implement blockchain technology. By leveraging blockchain technology, the author aimed to enhance the security and transparency of their application, enabling features such as secure data storage, decentralized transaction processing, and immutable audit trails.

3.8 GENERAL OVERVIEW OF ECOSYSTEM EVALUATION APPLICATION USING SUPERVISED MACHINE LEARNING
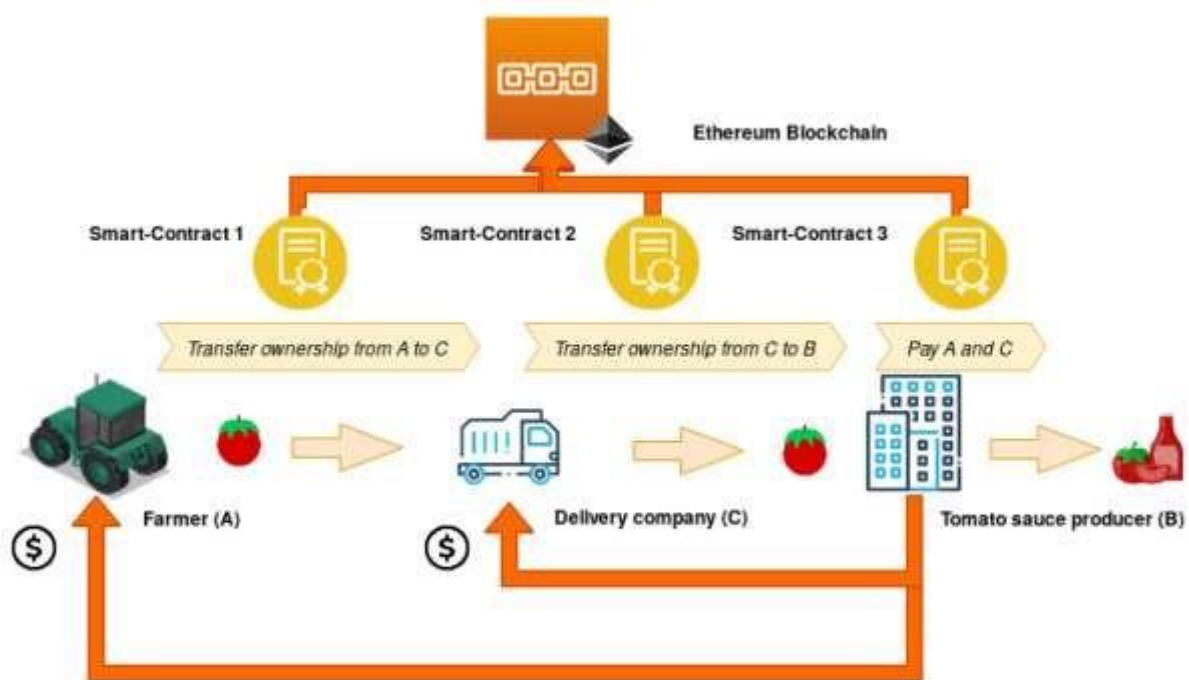
Figure 2

3.7 PROPOSED SYSTEM FLOWCHART
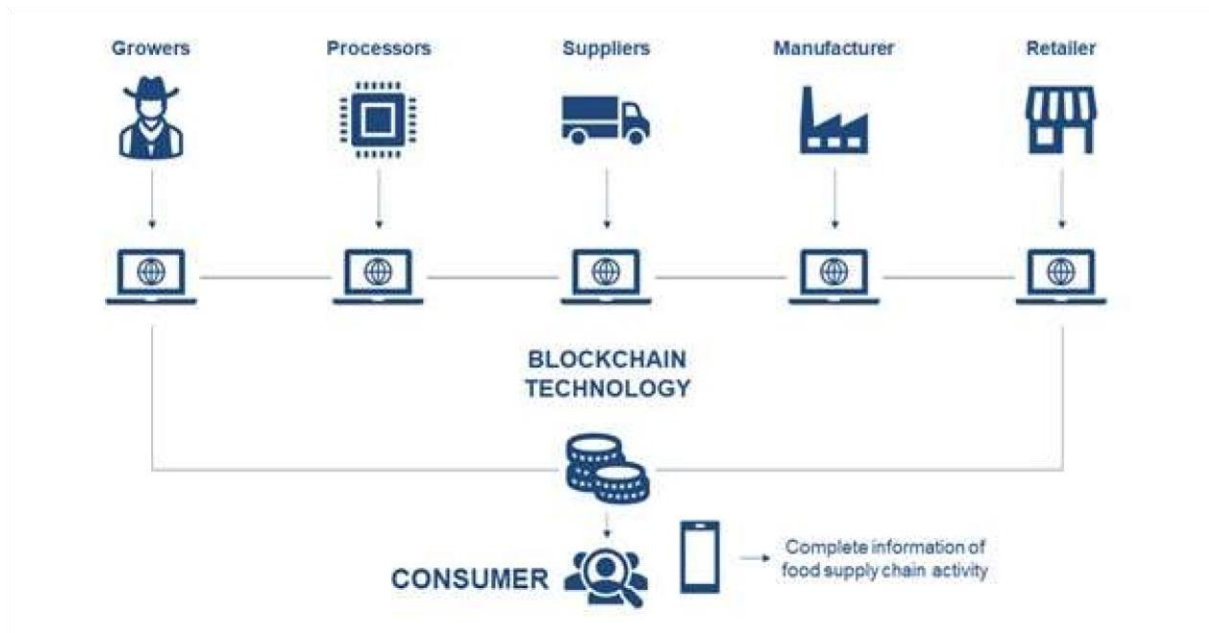
Figure 3

3.8 IMPLEMENTATION

The implementation of blockchain technology for food traceability, integrating Android, Java, Laravel, and JavaScript, entails a systematic development approach to create a seamless and user-friendly system. The Android application will be crafted using JavaScript for its intuitive user interface, allowing stakeholders to input vital traceability data such as product origin and processing details. Java will play a pivotal role in the blockchain's core functionalities, including the development of smart contracts for automating transactions and implementing the chosen consensus mechanism to ensure data integrity. Additionally, Java will handle encryption for security measures, safeguarding sensitive information within the blockchain network. Leveraging Laravel's backend capabilities, industry-wide data standards will be integrated, ensuring data consistency and facilitating interoperability with other blockchain networks. API development with Laravel will enable the Android app to communicate with the blockchain, enabling real-time data retrieval and transaction submission. On the frontend, JavaScript will drive user interactions, allowing stakeholders to track products, scan QR codes for verification, and receive real-time updates on product status. Extensive integration, testing, and security audits will precede deployment, with user training sessions provided for effective utilization. Continuous monitoring, updates, and data backup mechanisms will ensure the system's

reliability, scalability, and adherence to evolving industry standards, ultimately enhancing food traceability and consumer confidence in the supply chain.
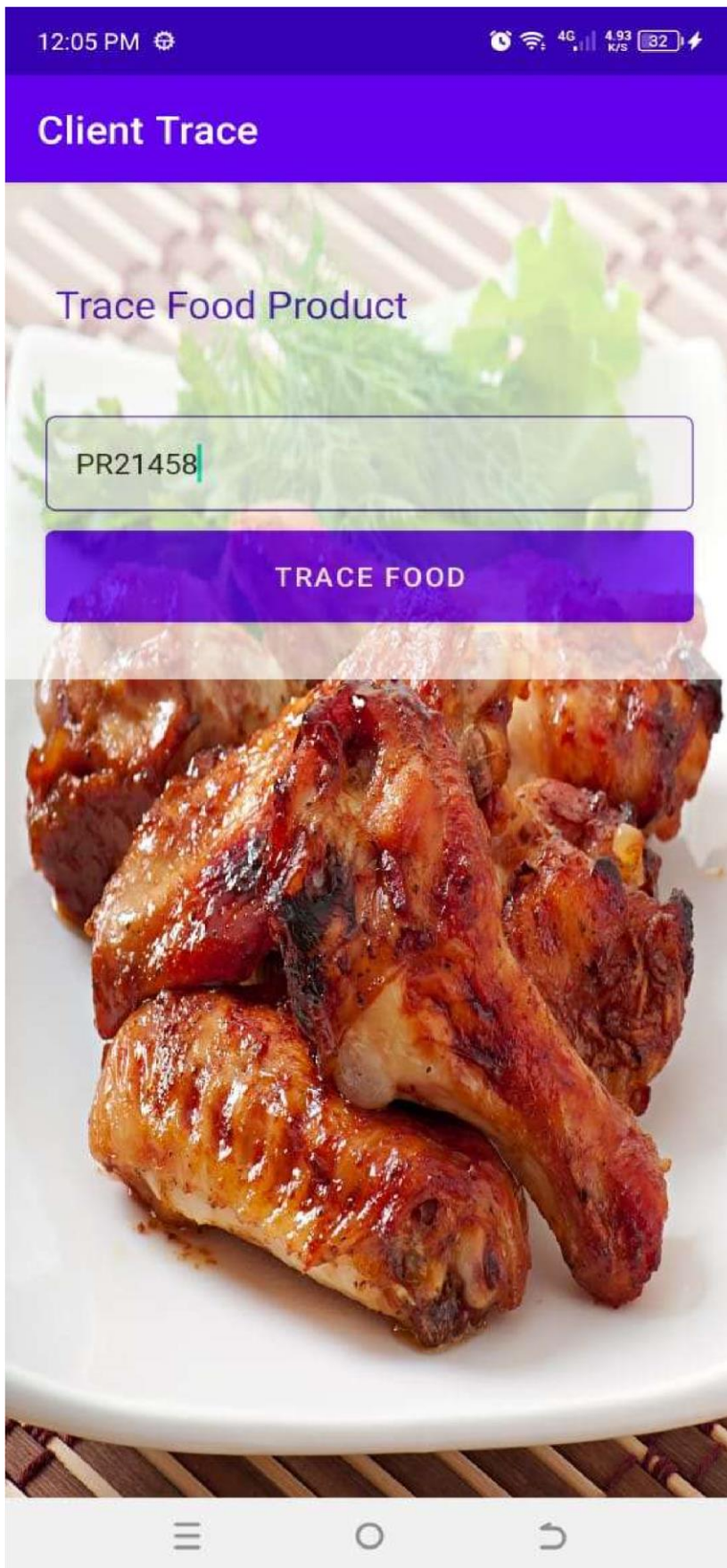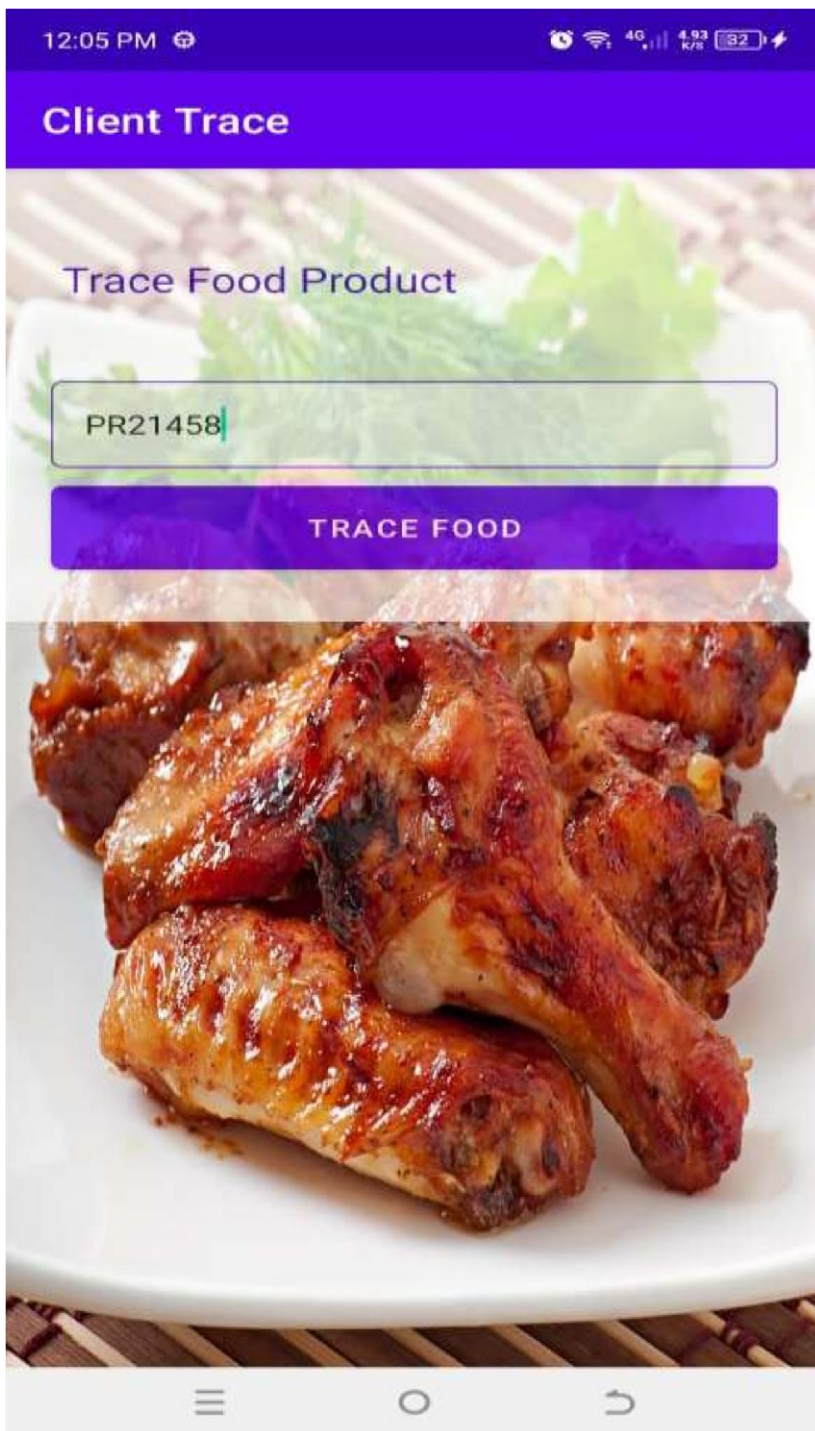
3.9 FOOD TRACING SYSTEM

Figure 4

Figure 5
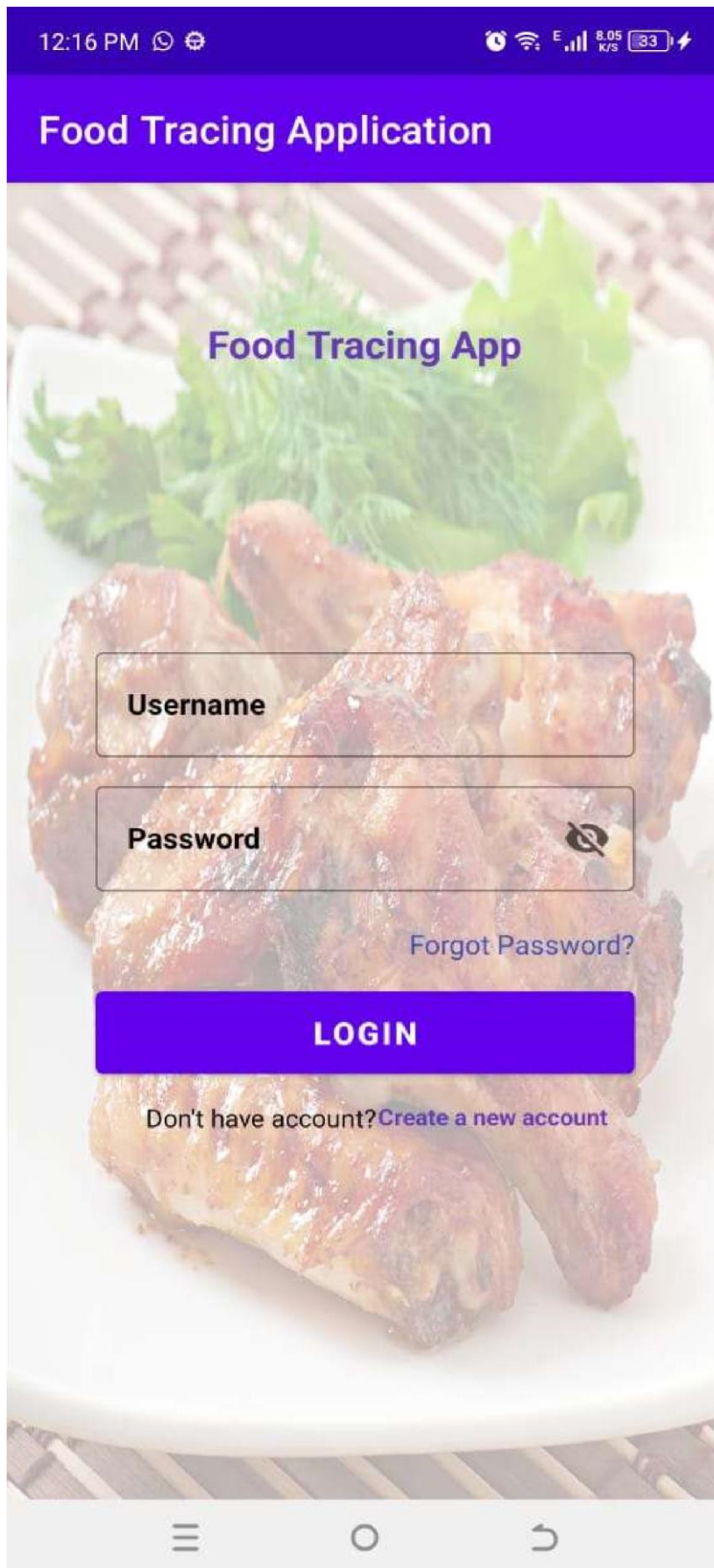
Figure 6

Figure 7

Figure 8
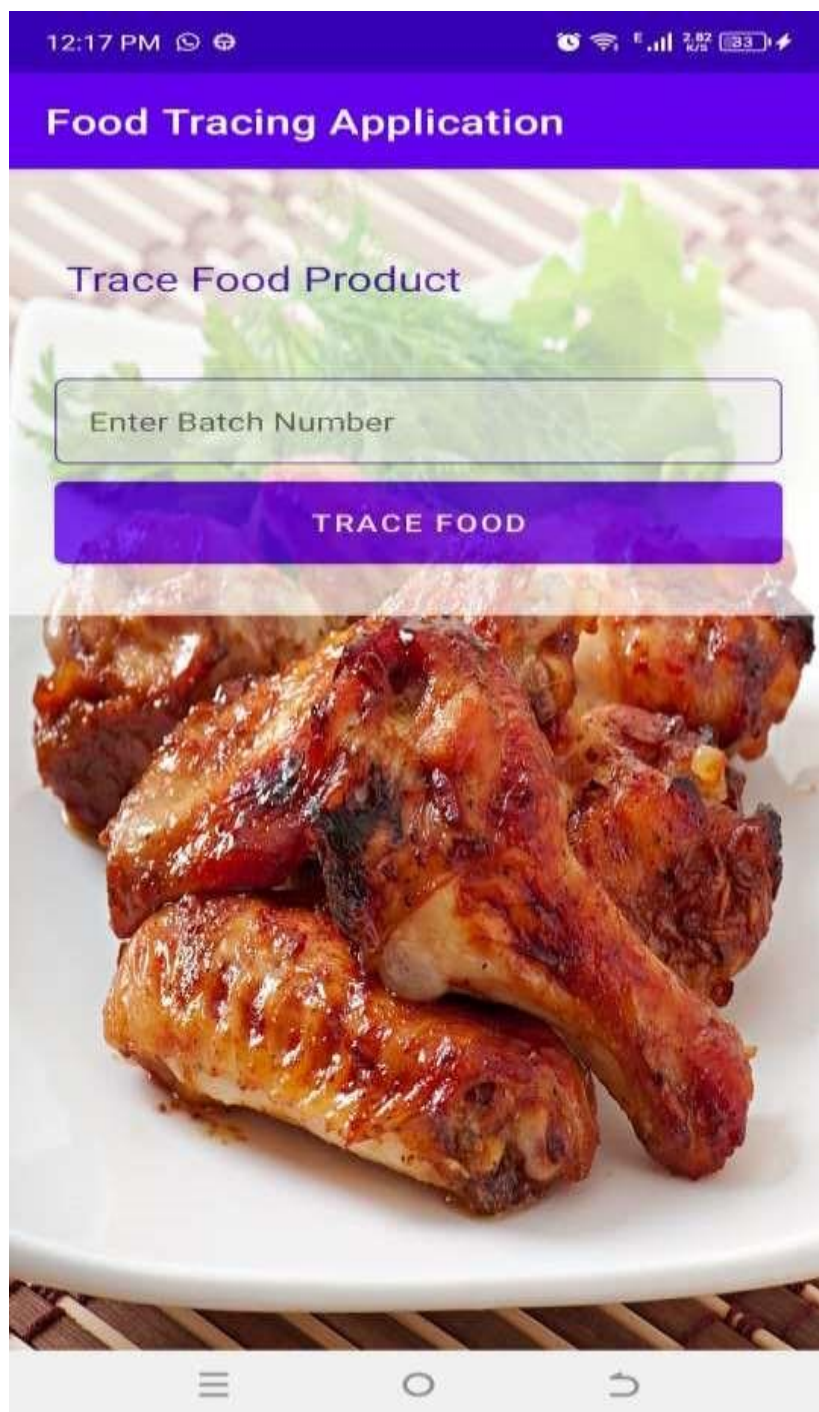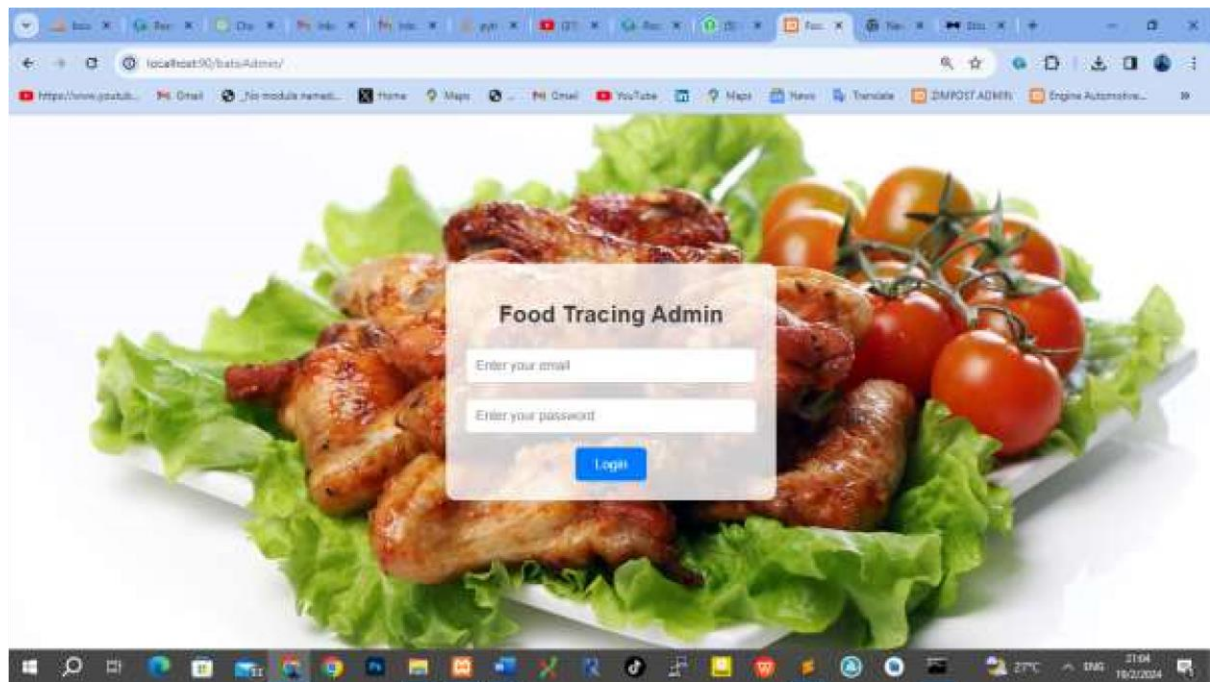
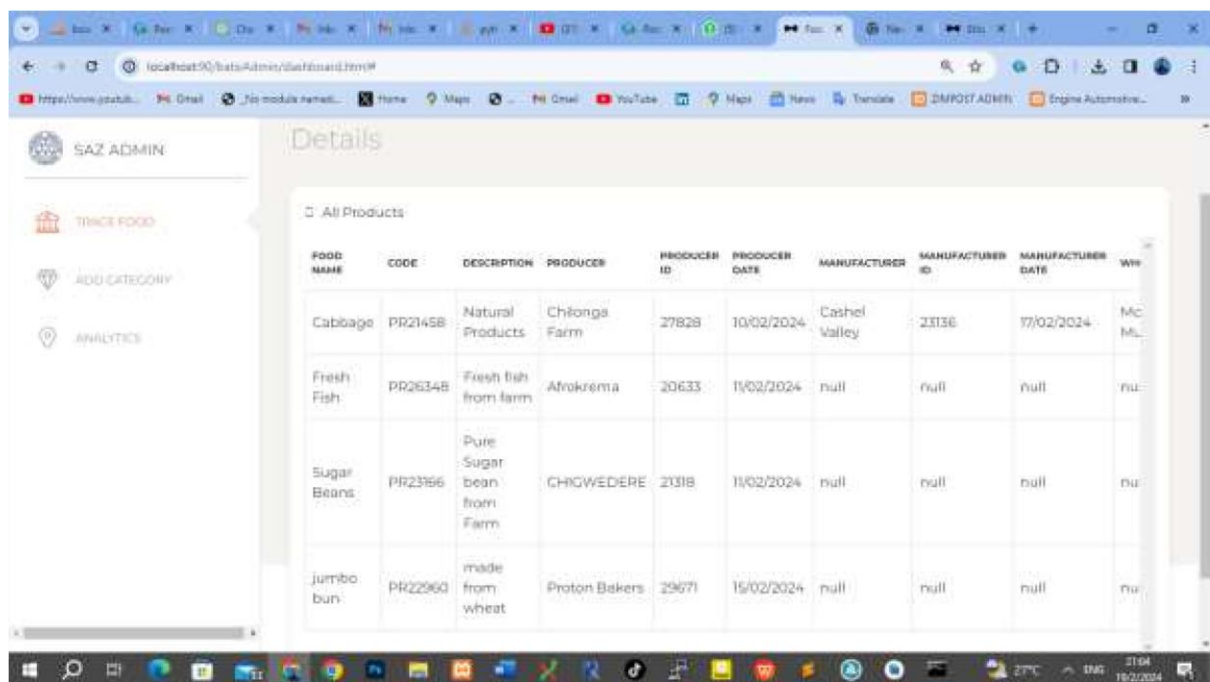Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

3.12 SUMMARY OF HOW THE SYSTEM WORKS

Blockchain technology is utilized in food traceability to create transparent, immutable, and decentralized records of food products throughout the supply chain. By leveraging blockchain, every step in the journey of a food product from farm to table can be tracked, verified, and recorded in real-time. Each transaction or event related to a food item is stored in a secure and tamper-proof digital ledger, ensuring the integrity and authenticity of the data.

One of the key aspects of blockchain in food traceability is its ability to provide provenance tracking. Each food product is assigned a unique identifier or digital "token" that contains information about its origin, production methods, transportation, and storage conditions. This enables consumers and stakeholders to trace the journey of a food item back to its source, ensuring transparency and trust in the supply chain.

CHAPTER 4: DATA ANALYSIS AND INTERPRETATIONS

4.0 Introduction

It is vital to evaluate the effectiveness of the supplied solution after the system has been completed. Accuracy, performance, and response time were the matrices used to determine the efficiency and efficacy of the final solution. To arrive at helpful conclusions, the information obtained in the preceding chapter was analyzed. Under various settings, the behavior of the developed system was also investigated. This chapter focuses on presenting study findings, analyses, interpretations, and conversations, which is an important element of the research process.

4.1 System Testing

System testing is a crucial phase in evaluating a fully integrated software solution. Unlike other testing phases, it falls under black-box testing, meaning the testers don't need to know the internal workings of the code. The main goal is to ensure the software's completeness and its ability to work well with other components (Sommerville, 2011).

Software often needs to interact seamlessly with various other software and hardware systems. System testing includes a series of evaluations aimed at putting the entire system through its paces to ensure everything works together as intended (Myers, Sandler, and Badgett, 2011).

4.1.2 Black box Testing

Black box testing is a software testing method that focuses on evaluating the software's functionality without examining its internal structure or code. This approach is typically based on the customer's requirements (Beizer, 1995). In black box testing, the tester selects a function, inputs specific values, and checks whether the function produces the expected output. If the

output is as expected, the function passes the test; otherwise, it fails. The results are then communicated to the development team before proceeding to test the next function. If any

major issues are identified after testing all functions, the software is returned to the development team for corrections (Myers, Sandler and Badgett, 2011).

When applying black box testing to a blockchain-based food traceability system that uses Android, Java, Laravel, and JavaScript technologies, the focus is on verifying the system's functionality without needing to understand its internal code structure. This involves providing input data to the system and examining the output to ensure it meets the specified requirements (Pressman, 2014).

For the Android application, black box testing will assess user interface elements such as data entry forms, buttons, and navigation flows. Test scenarios might include entering traceability data like product origin, inputting verification codes, and tracking product movements. In the Java-based blockchain, testing will focus on the functionalities of smart contracts, ensuring they execute transactions automatically based on predefined triggers such as temperature changes or delivery confirmations. Additionally, it will validate the accuracy of the consensus mechanism in maintaining data integrity and the effectiveness of encryption protocols in securing sensitive information (Sommerville, 2011).

The Laravel backend will be tested to ensure it integrates industry standards and achieves blockchain interoperability, verifying data consistency and API functionalities for communication with the Android app. JavaScript-driven frontend testing will evaluate user interactions, including real-time updates on product status, notifications for supply chain events, and the accurate execution of smart contract actions.

Through comprehensive black box testing, the overall functionality, usability, security, and compliance of the system with the specified requirements will be thoroughly evaluated, ensuring a robust and reliable blockchain solution for enhanced food traceability and supply chain transparency (Kaner, Falk and Nguyen, 1999).

Running the system
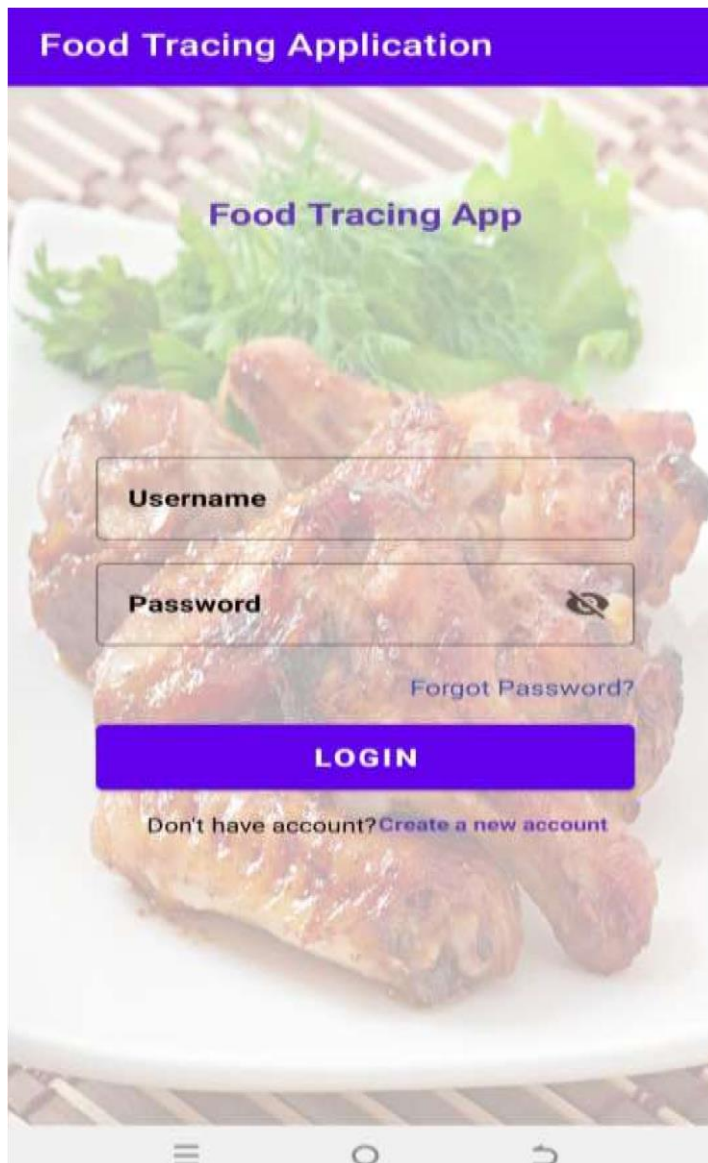
Food Tracing Mobile App for Clients Login
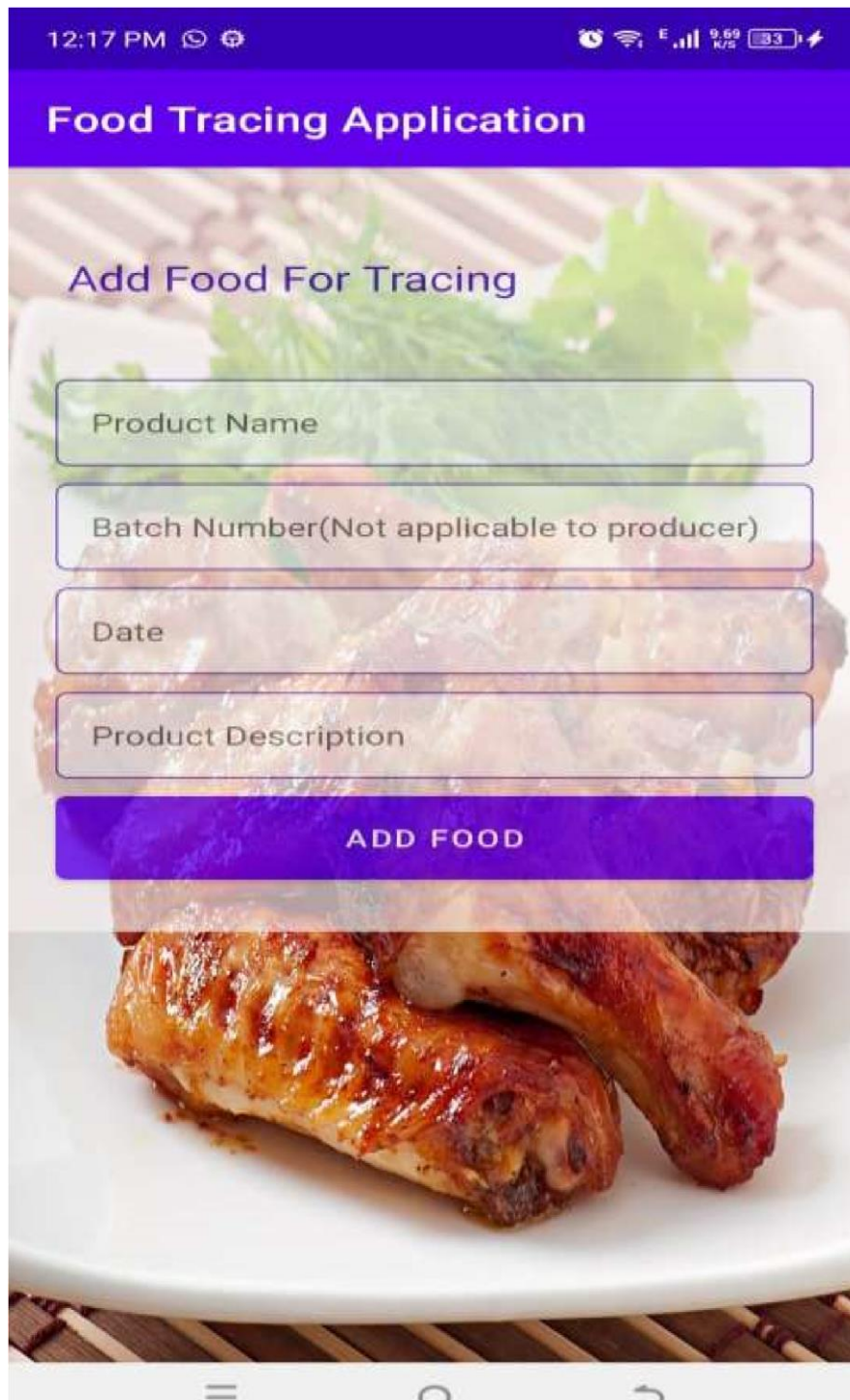
Figure 15

Food Tracing Mobile App Registration for Clients

Figure 16
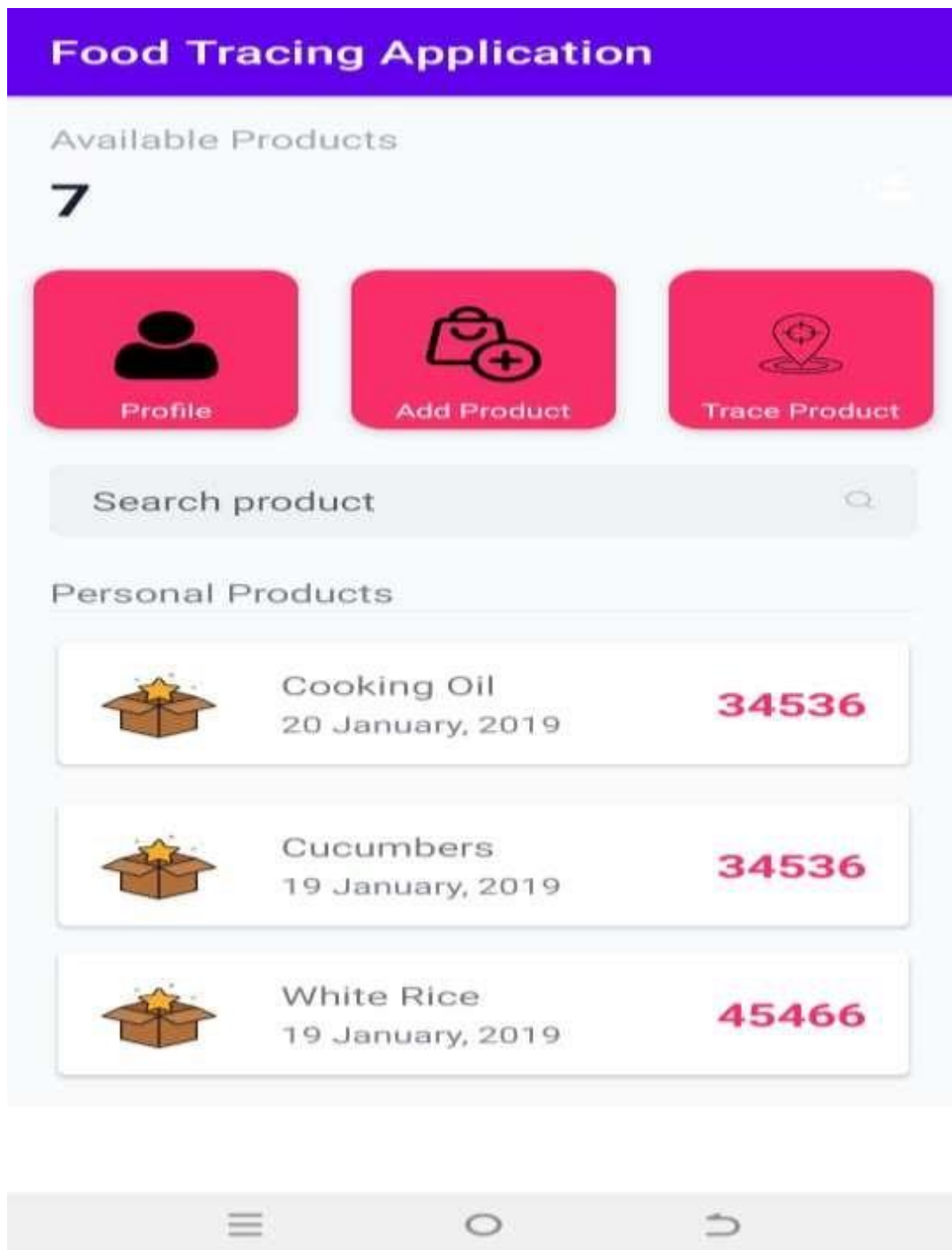
Food Tracing Mobile App Dashboard for Clients

Figure 17

Food Tracing Mobile App for Clients

Figure 18
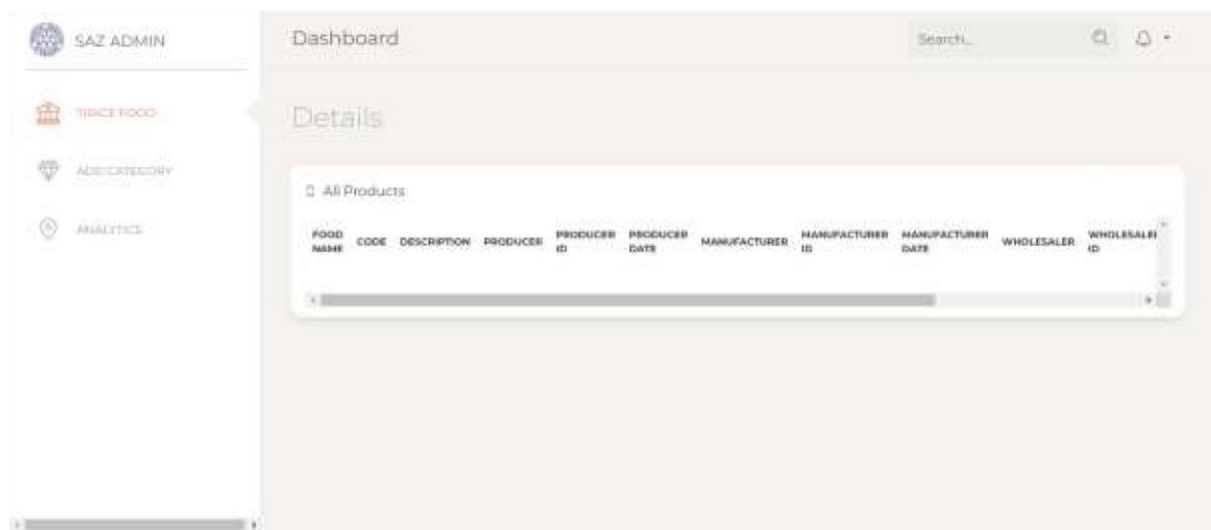
Food Tracing Portal

Figure 19

Food Tracing Portal For Clients

Figure 20

Food Tracing Web App Admin Login Portal

Figure 21

Food Tracing Web App Admin Dashboard

Figure 22

The system was well tested within a complete food chain supply to be able to trace the food within the supply chain.

4.1.2 White box testing

White box testing is a software testing technique that involves examining the product's internal structure, design, and code to verify input-output flow and improve design, usability, and security. Also known as clear box testing, open box testing, transparent box testing, code-based testing, and glass box testing, this method requires testers to have visibility into the code.

For a blockchain-based food traceability system incorporating Android, Java, Laravel, and JavaScript technologies, white box testing delves into the system's internal logic, code structure, and execution paths. This approach ensures the correctness of the underlying code and provides thorough coverage of all possible scenarios.

Android Application Testing: White box testing for the Android app involves examining the source code to verify each function's proper operation. This includes checking data input validation, error handling, and the accuracy of data processing algorithms. Test cases will be designed to validate the functionalities of user interface elements, such as buttons triggering specific actions, forms handling various inputs, and navigation paths within the app.

Java-Based Blockchain Testing: In the blockchain component, white box testing scrutinizes the smart contract code to ensure the correct implementation of transaction logic. This includes testing for accurate execution of contract conditions, proper handling of exceptions, and the integrity of data storage and retrieval operations. The consensus mechanism will be thoroughly assessed to ensure its reliability in reaching agreements on valid transactions. Additionally, the encryption algorithms will be tested to verify data protection measures and access control mechanisms within the blockchain network.

Laravel Backend Testing: The backend, built on Laravel, will undergo testing to assess the correctness of data standardization processes, API endpoint functionality, and integration with the blockchain. This includes checking routing logic, middleware implementation, and database interactions for accuracy and efficiency.

JavaScript-Driven Frontend Testing: For the frontend, white box testing will focus on verifying the correctness of user interface behaviors, such as dynamic content updates, event handling, and responsive design across different devices.

By meticulously examining the system's internal components and code paths, white box testing ensures comprehensive test coverage, identifies potential vulnerabilities, and validates adherence to design specifications. This rigorous approach aims to deliver a robust, secure, and reliable blockchain solution for enhancing food traceability and supply chain transparency.
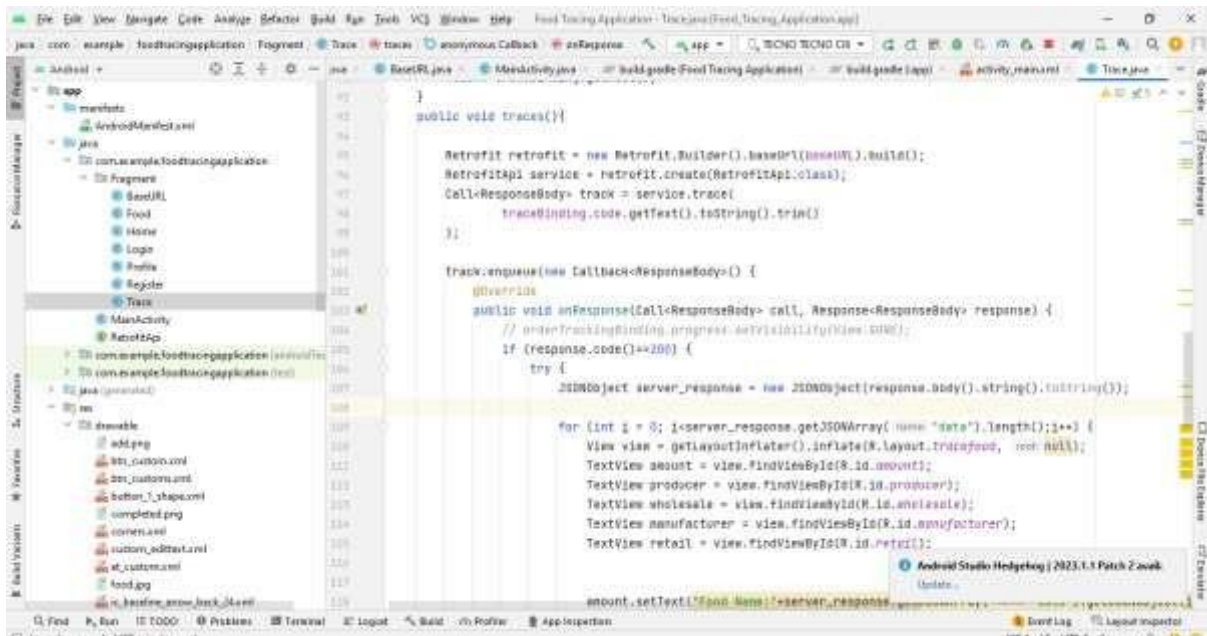
Initialization of the tracing algorithm using blockchain

Figure 23
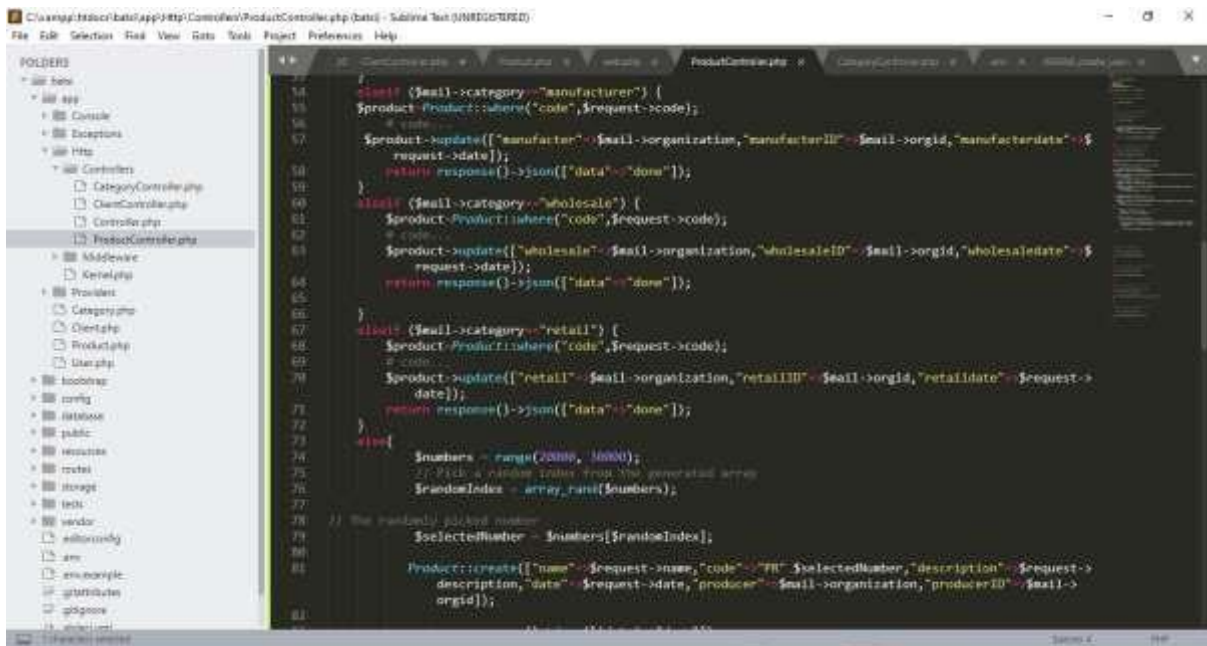
Preforming tracing operation

4.2 Evaluation Measures and Results

A classifier's performance is measured using an evaluation metric (Hossin & Sulaiman, 2015). Furthermore, model evaluation metrics can be classified into three types, according to Hossin & Sulaiman (2015): threshold, probability, and ranking. The system's performance is determined by its capacity to reliably to trace food in a supply food chain. There are several metric evaluations to be used to test the blockchain algorithms. Some of the commonly used are Throughput, Latency, Consensus, Energy Efficiency and Scalability.

4.2.1 Throughput

An evaluation metric is used to assess the performance of a classifier (Hossin & Sulaiman, 2015). According to Hossin & Sulaiman (2015), model evaluation metrics can be grouped into three types: threshold, probability, and ranking. This metric measures the number of transactions that can be processed per second by the blockchain. In this scenario the author will determine the number of transaction or traces to be performed per second.

TEST	BLOCK TIME(SECONDS)	BLOCK SIZE(MBS)	TRANSACTION SIZE(BYTES)	FORMULA FOR THROUGHPUT	THROUGHP FOR THROUGHPUT
1	10	1	400	(Block Size/Block Time) *Transaction Size	40
2	8	1.3	543	(Block Size/Block Time) *Transaction Size	88.24
3	11	2.1	423	(Block Size/Block Time) *Transaction Size	80.75
4	7	1.3	500	(Block Size/Block Time) *Transaction Size	92.86
5	12	1.4	600	(Block Size/Block Time) *Transaction Size	70
6	9	0.8	345	(Block Size/Block Time) *Transaction Size	30.67

7	15	2.3	457	(Block Size/Block Time) *Transaction Size	70.07
8	8	0.7	674	(Block Size/Block Time)	58.98
				*Transaction Size	
9	13	1.9	765	(Block Size/Block Time) *Transaction Size	111.81
10	11	2.2	890	(Block Size/Block Time) *Transaction Size	178
Average Throughput			**73.314**		

Table 1

4.3 Precision and Recall

By going beyond recognition accuracy, precision and recall measurements enable us to gain a more detailed knowledge of model evaluation. The precision of our model indicates its effectiveness when the forecast is positive.

$$Precision = \frac{TP}{TP + FP}$$

$$= \frac{32}{32+3} * 100$$

=91.4%

Positive forecasts are the main focus of precision. It shows the proportion of accurate positive forecasts. The recall of our model indicates how well it predicts positive classifications. Recall is centered on real positive classes. It shows the number of positive classifications that the model can accurately predict.

$$Recall = \frac{TP}{TP + FN}$$

$$= \frac{32}{32+5} * 100$$

$$= 86.4\%$$

Recall and precision have a trade-off that prevents both from being optimized. Recall falls when precision rises and vice versa. Since the prediction required to be correct, we needed a higher level of precision in this instance.

4.4 Latency Time

Latency time refers to the time it takes for a transaction to be performed i.e. trace the food in a supply food chain .It is used as a measure of system performance. To test for the system response time the author used the average and the peak response times to determine the overall performance of the system.

Table 2 System response time

Test	Reading Time in Seconds
1	2.0
2	0.6
3	3.0
4	0.4
5	0.7
6	0.9
7	1.0
8	0.5
9	0.4
10	1.0
11	0.8
12	0.9
13	0.7
14	1.9
15	1.0
16	1.3
17	1.0
18	0.6
19	0.5
20	0.5

Table 3

All the readings where rounded to the nearest one decimal place.

Average system response time = sum of all response time/ number of readings

= (0.5+0.6+0.5+1.0+2.3+ 0.9+1+0.5+0.4+0.6+0.8+0.9+0.7+1.9+2+1.3+1+1)/20

$= 16.9/20 = 0.845 = 0.8$ second (1dp)

4.5 Summary of Research Findings.

The author discovered that the system performed satisfactorily after doing all of the essential black, white box tests and performance testing utilizing the throughput metric evaluation. The system performed well on throughput evaluation as well as the latency time. The system has a latency time of 0.8 seconds on average and **73.314** average throughput. C0mme

4.6 Conclusion.

The test findings showed that the blockchain algorithm solution/system had a high level of accuracy, with an average rate of throughput of **73.314** and an average response time of 0.8 seconds as a consequence of the throughput evaluation analysis

Chapter 5: Recommendations and Future Work

5.1 Introduction

This chapter presents recommendations and outlines potential future avenues of research and development in the context of the application of blockchain technology for food traceability. Building upon the aims and objectives of the study, this section provides guidance for stakeholders and researchers interested in further advancing the field.

5.2 Aims and Objectives Realization.

The study's aims and objectives were focused on demonstrating the feasibility and benefits of utilizing blockchain technology for enhancing food traceability. Through the implementation of blockchain-based solutions, the study successfully realized its objectives, showcasing the potential of this technology to revolutionize the food supply chain.

5.3 Conclusion

In conclusion, the study highlights the transformative impact of blockchain technology on food traceability, offering increased transparency, efficiency, and trust throughout the supply chain. By leveraging blockchain-based solutions, stakeholders can enhance food safety, reduce fraud, and improve consumer confidence in the products they consume.

5.4 Recommendations

Based on the findings of the study, the following recommendations are proposed:

Collaborative Adoption

Encourage collaboration among stakeholders across the food supply chain, including producers, processors, distributors, retailers, regulators, and consumers, to facilitate the widespread adoption of blockchain technology for food traceability.

Data Standardization

Establish standardized protocols and data formats for recording and sharing information on the blockchain to ensure interoperability and consistency across different supply chain participants.

Regulatory Frameworks

Develop regulatory frameworks and guidelines to govern the use of blockchain technology in food traceability, addressing issues related to data privacy, security, and compliance with food safety regulations.

Education and Training

Provide education and training programs to stakeholders to enhance their understanding of blockchain technology and its potential applications in food traceability, fostering a culture of innovation and adoption.

Continuous Improvement: Continuously evaluate and improve blockchain-based solutions for food traceability through feedback mechanisms, performance monitoring, and technological advancements, ensuring their effectiveness and scalability over time.

5.5 Future Work

In future work, advancing blockchain-enabled food traceability entails exploring various avenues. Scalability solutions, such as sharding and sidechains, should be investigated to address performance limitations in handling the increasing volume of transactions in largescale food supply chains. Integration with Internet of Things (IoT) devices and artificial intelligence (AI) algorithms offers potential to enhance data collection, validation, and analysis capabilities, thereby improving traceability and quality control. Extending blockchain applications beyond traceability to address broader sustainability challenges, including ethical sourcing and environmental impact assessment, is crucial for promoting a more sustainable food system. Developing consumer-facing applications and platforms leveraging blockchain can empower consumers with transparent information about food provenance and safety, facilitating informed choices. Additionally, fostering international collaboration and knowledge sharing initiatives is

essential to standardize and promote the adoption of blockchain solutions globally, thereby enhancing transparency, trust, and integrity in the global food supply chain.