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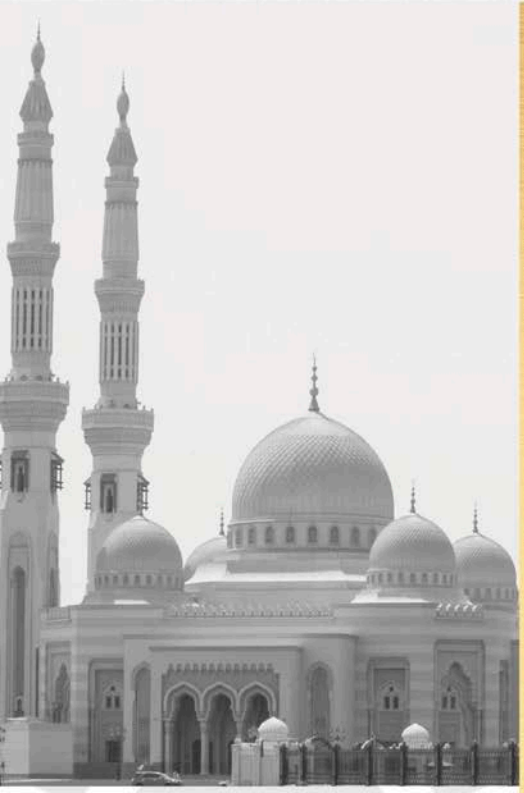

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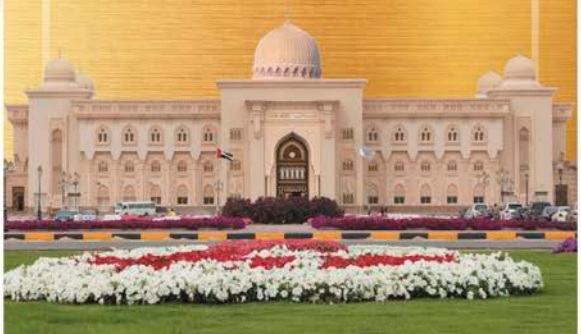

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نموذج تعاوني لسلاسل توريد المنتجات الحلال للتأكد من السلامة والشفافية باستخدام تقنية سلسلة الكتل موذج تعاوني لسلاسل توريد المنتجات الحلال للتأكد من السلامة والشفافية باستخدام تقنية سلسلة الكتل

A COLLABORATIVE *HALAL* SUPPLY CHAIN MODEL TO ADDRESS SAFETY AND TRANSPARENCY BASED ON BLOCKCHAIN TECHNOLOGY[1]

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الملخص

ينمو إنفاق المسلمين على المنتجات الحلال بنسبة 6.3% سنويا، حيث وصل إلى 2 تريليون دولار هذا العام 2024. ويأتي توريد المنتجات الحلال من أجزاء مختلفة من العالم من مورّدين مسلمين وغير مسلمين. وقد أدى ذلك إلى زيادة قلق المستهلكين المسلمين بشأن مصداقية الادعاءات الحلال بسبب عدم القدرة على تتبع المنتجات عبر سلسلة التوريد. ومع ذلك، لا يمكن لنماذج سلسلة التوريد الحالية تتبع هذه المنتجات الغذائية طوال سلسلة التوريد من المزرعة وطوال عملية النقل. يهدف هذا البحث إلى تحقيق هدفين رئيسيين: الأول هو تقييم وعي المستهلكين بتطبيقات تقنية سلاسل الكتل (blockchain) في صناعة المنتجات الحلال، والثاني هو تطوير نموذج لامركزي لتتبع المنتجات الحلال باستخدام تقنية سلاسل الكتل لتمكين التسجيل الشفاف وغير القابل للتلاعب بالبيانات المتعلقة بالمنتجات الحلال، بما في ذلك معلومات المنشأ والجودة والتعامل والمعالجة. سيؤدي ذلك إلى تحسين شفافية سلسلة التوريد، وتعزيز كفاءة حفظ السجلات، وتعزيز سلامة الأغذية وضمان الجودة، وتمكين التتبع الشامل، وبناء ثقة المستهلك. يتضمن تطوير نموذج سلسلة التوريد الحلال استخدام العقود الذكية وتقنيات التشفير وتحليلات البيانات. تم استخدام منصة تطوير Ethereum 2.0 blockchain وWeb3.js بشكل تفاعلي لتنفيذ نموذج أولي للنظام. تظهر نتائج اختبار النظام المطبق قابلية توسع ملحوظة، وإدارة الأحمال المرتفعة دون التضحية بالكفاءة. بالإضافة إلى ذلك، أظهرت إجراءات الاختبار مدى التزام النظام بالمبادئ التوجيهية والمعايير المحددة مسبقًا، مما يعزز الثقة في الجودة العامة للنظام.

Abstract

Muslim spending on *halal* food is growing at 6.3%, projected to reach $2 trillion by 2024, raising concerns about the authenticity of *halal* claims due to the inability to trace products throughout the supply

chain. This research has two primary objectives: first, to develop a decentralized model for *halal* tracking using blockchain technology, and second, to assess Customers' awareness of blockchain applications in the *halal* industry. The proposed system uses blockchain's decentralized and immutable nature to record data transparently and securely, covering *halal* product origin, quality, handling, and processing. This will enhance supply chain transparency, improve record-keeping efficiency, strengthen food safety and quality assurance, and build consumer trust through end-to-end traceability. The development process involves smart contracts, cryptographic techniques, and data analytics, implemented using Ethereum 2.0 and Web3.js. Testing of the prototype system demonstrated strong scalability, handling high loads without compromising efficiency, and adhered closely to predefined guidelines, enhancing trust in the system's reliability.

الكلمات الدالة: سلاسل توريد المنتجات الحلال، تكنولوجيا سلاسل الكتل، العقود الذكية، تقنيات التشفير.

Keywords: *Halal* Food Supply Chain, Blockchain Technology, Supply Chain Integrity, Consumer Trust.

1.0 Introduction

In his book, Kettani (2019) predicts that the global Muslim population will increase to 2.8 billion by the year 2050. As for today, Muslim spending on *halal* food is growing at 6.3%, reaching $2 trillion by 2024 (Statista, 2024). The supply for *halal* products comes from various parts of the world including Muslim and non-Muslim suppliers (Hee Yul Lee et al., 2019). This has led to increasing concerns from Muslim consumers with regards to whether the *halal* status of these food products can really be guaranteed throughout the supply chain in these countries and whether the *halal* claim is authentic (Rejeb et al., 2021). Especially, since the food supply chain between the producer and the consumer has become long and complex. Also, there is a

chance of data manipulation as the records concerning the movement of food are usually paper-based or digitally centralized.

Hence, a few documented incidents of counterfeit *halal* certification can raise consumers' concerns about the authenticity of the Halal products and lose confidence in the *halal* industry in general. The failure of the supplier to deliver products that comply with *halal* standards reduces the industrial economic advantage and outbreaks scandals like "Meat Cartel" case in Malaysia end of year 2020 revealing that fake *halal* meat was sold to Muslims for 40 years (Abdullah S. M., 2020),the detection of porcine DNA and subsequently pork meat in some processed "*halal*" products in the UK (Fuseini et al., 2017), and other scandals in Cambodia in early 2023, and Bangkok in the summer of 2020. *Halal* status can be lost through contamination during storage, transport, or handling, before reaching the customer. The integrity of *halal* food supply chains is affected by the risks involved in Halal food supply chains. Faults in handling, monitoring, processing, and other factors along the supply chain might lead to the change of food products from *halal* to *haram* (Busyra & Ardi, 2020).

Adopting new technologies can manage, monitor, and optimize supply chain processes. The *halal* industry can develop robust and relatively infallible methods of guaranteeing a product's *halal* status (Mohd Aman et al., 2020). Hence blockchain technology enables quick and easy verification of location, history, and status of a particular food product. Farm origination details storage temperatures, batch numbers, expiry dates, shipping details and factory and processing data, which can be recorded on the blockchain, such that stakeholders can readily access the data. This end-to-end traceability can improve the efficiency of the food supply chain. This technology was developed to synchronize the data and transactions over the supply chain network (Adetunmbi et al., 2021). Blockchain technology offers a solution by providing a shared, decentralized ledger for data consistency, real-time visibility, traceability, seamless collaboration, authenticity verification, and regulatory compliance.

This research aims to develop and implement a blockchain-based system, a FoodGuardian platform, that ensures safety and transparency in the *halal* supply chain. This includes the creation of a

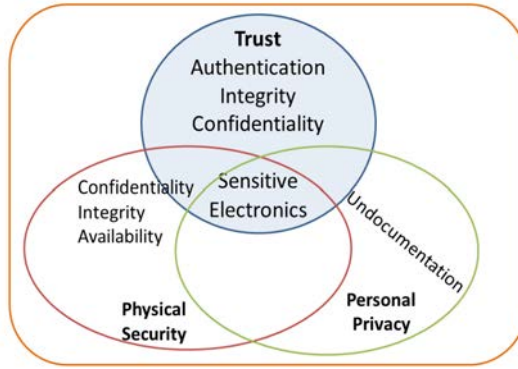
secure and decentralized platform, integration with existing systems, standardization and validation of data, secure data sharing and collaboration, authentication of *halal* product authenticity, consumer-facing transparency, and provision of training and support for stakeholders. By encompassing these aspects, the FoodGuardian platform was developed to improve the *halal* supply chain, enhancing safety, transparency, and trust among all participants.

2.0 Literature Review

Emerging technologies such as blockchain, artificial intelligence, big data, the internet of things, and geographic information systems form the foundational elements of robust and sustainable food supply chains (Hee-Yul Lee et al., 2019). Ongoing research in food supply chain management mainly revolves around ensuring food safety, traceability, and integrity. Currently, supply chains comprise many stages scattered across different geographic locations, involving a multitude of invoices and payments. This complexity creates challenges in tracking events or investigating incidents. Customers and purchasers face difficulties in verifying the authentic origin of the products they acquire. Furthermore, the lack of transparency within supply chains significantly hampers the ability to investigate and hold individuals accountable for illegal activities, contributing to cases of fraud, forced labor, and several scandals. These issues not only affect reputations but also result in substantial financial losses for the implicated companies (Y. Chang et al., 2020). Key criteria for an optimal supply chain include end-to-end visibility (transparency), flexibility, trust (truthfulness), and the capacity to monitor all relevant activities (J. Chang et al., 2018). the correlation between some of these parameters are shown in Figure 1.

Transparency in the supply chain is commonly defined as the extent to which information is accessible and visible to relevant stakeholders (Hussain et al., 2021).Several dimensions of transparency have been identified, including information sharing, communication, visibility, and traceability. Effective transparency involves disclosing information about suppliers, processes, and product origins throughout the supply chain (Sunmola & Burgess, 2023).

Figure 1: Correlation among visibility, privacy, access control and trust



(Zubair Ahmad et al., 2010)

One of the technologies which has solutions for current supply chain drawbacks is the blockchain since it uses the distributed public general ledger. It can reduce errors, eliminate fraudulent activities, avoid product delays, improve management, and increase consumer/supplier trust. Blockchain can make supply chain activities transparent. It provides recorded information about a variety of transactions in goods and services, which are recorded and tracked in real-time opening a way of automating processes among partners without using centralized IT infrastructure. All participants will have access to the same data at any time (Sumayyah Bukola Adetunmbi et al., 2021). Blockchain technology can increase the innovation potential of all major industries by providing low cost, transparency, auditing, and reliability (Ahmad & Bailey, 2021; Hellani et al., 2021). Knowing that the chain members cannot use low-quality or fake products ensures the originality and quality of products which will save in expenses. This needs transparency, visibility, and traceability of products by eliminating the intermediaries, which requires the use of unchangeable data, controlled access, and distributed reservoirs, for which strategies such as the use of blockchain platforms may be useful. One other problem faced in a traditional supply chain is the lack of trust between suppliers and their identity verification problems (Ellahi et al., 2023). This may be solved by using smart contracts and recording the data in a reliable and unchangeable database with controlled accessibility.

Blockchain technology can be integrated with IoT-based data feed to guarantee the reliability and security of information. Such a combination also would enable suppliers to capture compliance conditions in a smart contract. In this case, the actual temperature feeds during the journey could be compared against the defined conditions in the contract to demonstrate compliance as well as any exceptions. However, the traditional blockchain protocol still cannot be used for the IoT ecosystem that has a different architecture and requirements. Hence, more suitable blockchain architecture and encryption schemes for IoT are needed (Azizi et al., 2021; Gohil & Thakker, 2021).

Duan et al. (2023) focuses on the implementation challenges of blockchain in food supply chains, identifying critical barriers such as regulatory constraints, scalability issues, and the need for stakeholder collaboration. It also highlights the benefits, such as improved transparency, trust, and food safety, positioning blockchain as a key enabler of modern supply chains. The research outlines case studies that demonstrate how blockchain can prevent food fraud and contamination incidents. Ali et al. (2021)focuses specifically on blockchain adoption within *halal* food supply chains. It explores how blockchain can strengthen the verification process for *halal* certifications, reduce fraud, and improve consumer confidence in *halal* products. It also identifies key obstacles to adoption, such as the lack of standardization and high implementation costs, while advocating for industry-wide collaboration to overcome these barriers.

Currently, there are some existing websites and platforms are using blockchain to provide comprehensive solutions for monitoring and authenticating the flow of goods across the supply chain. These platforms focus on different aspects, including ensuring the traceability of products, verifying authenticity, and safeguarding supplier data. By decentralizing records and making them immutable, blockchain ensures that information about the origin, handling, and safety of products remains unmodified, thereby reducing the risk of fraud and enhancing overall supply chain security. The following table provides a comparison of several key websites utilizing blockchain technology for supply chain management based on critical features such as traceability, authenticity checks, supplier authentication, and more. Table 1 summarizes the features of the blockchain-based websites and platforms for supply change management.

Table 1: Summarizing System functionalities blockchain-based platforms

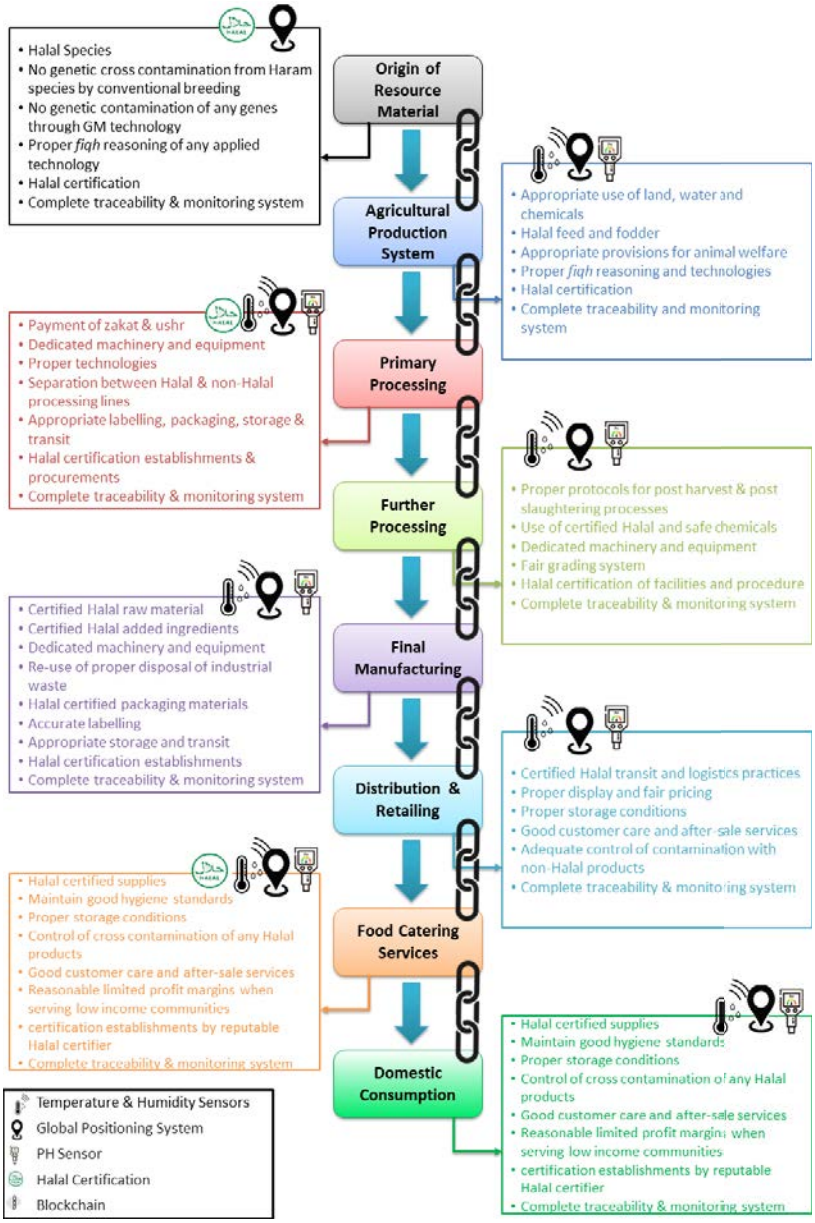
Website	Traceability	Authenticity Check	Supplier Authentication	Quality & Safety Info	Supply-chain Authentication	User Friendly
IBM	√	√		√	√	
Walmart	√		√	√		√
Provenance	√	√	√		√	
Tyson Foods	√	√	√	√		√
Bumble Bee	√	√		√	√	

* Source: Authors' own work

According to (Adroit Market Research Report, 2021), the global *halal* market size is expected to reach close to USD 3.0 trillion by 2029 with an annualized growth rate of 5.6%. In food industry business networks, it is important to collect and share certain data such as location, temperature, vibration, and humidity. However, when it comes to *halal*-certified products, more requirements (i.e additional data) are often included. *Halal* is not only about how the slaughter process of the animal or the use of alcohol in any food products, but it also involves all of the standards and processes that adhere to the *halal* classification (Hendayani, 2024).

The term *halal* means justifiable, lawful, and permissible to consume under what has been stipulated under Islamic Law. *Halal* encompasses the safety of consumption, cleanliness, reliability, and food quality assurance (Rejeb et al., 2021). Another issue related to *halal* products is the mixing of *halal* and non-*halal* food which can be divided into two aspects. The first aspect is the mixing of non-*halal* ingredients in *halal* food production. This includes the substitution of non-*halal* meat such as pork, undeclared blood plasma, and the usage of prohibited ingredients with *halal* ingredients. Additionally, mixing also refers to putting *halal* and non-*halal* meat in the same physical location, either in the same transport storage containers, or retail shelf (Zulfakar et al., 2019). Figure 2 encapsulates the critical points *halal* products go through in the supply chain consisting of different parties (e.g. Certification bodies, farms, storages, transportation vehicles, devices, supermarkets, and so on) who need collaboration and transparency in order to manage trust and food safety (Saifudin et al., 2017).

Figure 2: Critical control point of *halal* products



(Saifudin et al., 2017)

3.0 Methodology

This section outlines the methodology used to conduct the study, focusing on both the research approach to gather insights into consumer perceptions and the technical approach to develop the FoodGuardian platform for a decentralized *halal* supply chain. The research methodology encompasses data collection through surveys, while the platform development methodology involves the technical design and implementation of the blockchain-based system.

3.1 Research Methodology

The research methodology used in this study was designed to assess consumer perceptions regarding blockchain technology and its application in the *halal* food supply chain. The primary objective was to understand the level of awareness, interest, and potential adoption of blockchain among consumers, with a specific focus on Malaysian university students. The methodology included the following components:

3.1.1 Research Design

A quantitative research design was adopted for this study, employing a structured survey as the primary data collection instrument. This design was chosen to enable the collection of measurable data related to consumer awareness and opinions about blockchain technology in the food industry.

3.1.2 Survey Implement

The survey consisted of a combination of open-ended and closed-ended questions, divided into sections to explore various aspects of blockchain technology. The questions were designed to evaluate participants' knowledge, perceptions, and willingness to adopt blockchain as part of the *halal* food supply chain. The questionnaire included:

- Demographic information (age, gender, academic background)
- Awareness of blockchain technology
- Perceptions of blockchain's economic and financial benefits in the food industry
- Concerns regarding food safety and trustworthiness

- Willingness to pay a premium for blockchain-verified *halal* food products

3.1.3 Sample and Population

A total of 69 Malaysian university students were selected as the survey respondents, based on convenience sampling. Participants were drawn from diverse academic backgrounds, including business, information technology, and engineering. The decision to focus on university students was motivated by their exposure to emerging technologies and their role as future decision-makers and adopters of innovations in various industries.

3.1.4 Data Collection

The data was collected using online survey tools, distributed through university networks and social media platforms. Participants were informed about the study's objectives and given clear instructions on how to complete the survey. The responses were anonymized to maintain confidentiality and ensure unbiased participation.

3.1.5 Data Analysis

After data collection, the responses were analyzed using descriptive statistical techniques. The analysis focused on summarizing key trends in blockchain awareness, interest in blockchain for food supply chains, and the perceived benefits of blockchain in ensuring *halal* compliance and food safety. The results provided insights into the overall level of understanding and interest among university students, highlighting areas where further education and promotion of blockchain technology may be needed.

3.2 Platform Development Methodology

The methodology for developing the FoodGuardian platform follows a systematic approach to ensure that the platform meets the specific requirements of the *halal* beef supply chain. The platform utilizes blockchain technology to provide transparency, traceability, and verification throughout the supply chain, from producers to consumers.

3.2.1 Requirements & Specifications

A requirement refers to something that is necessary or essential, while a specification provides a detailed description of the specific criteria for the components, construction, appearance, performance, and other aspects. In Table 2, detailed descriptions of the system's requirements and specifications are stated.

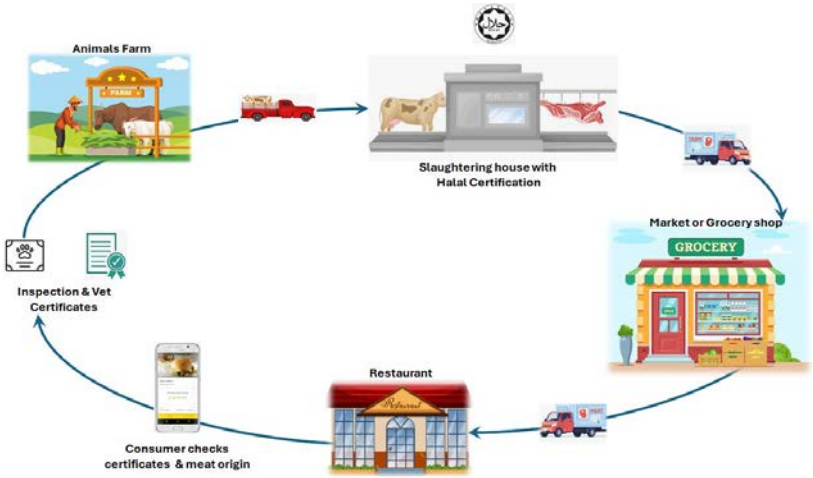
Table 2: Requirements and specifications for user interface & processes

	Requirements	**Specifications**
User Interface	Simple user interface	➢ Not a lot of unnecessary visual elements are incorporated
	Easy to navigate	➢ Icons are placed strategically for easy navigation
	Easy to understand	➢ Icons used are familiar to the process intended
Processes	Personalize user account	➢ Users can create their own account. ➢ Users can save a list of food items for purchase in the shopping cart
	Food ingredients authenticity	➢ Users can see the food ingredients. ➢ Users can see the food nutrition details
	Supply Chain traceability	➢ QR code to trace food supply chain. ➢ Users can see the supply chain details and certifications
	Upload product details & certification	➢ Users can easily upload and store beef details & images in blockchain. ➢ Upload certification file and stored to show.
	Safe payment system	➢ Payment can be made securely through a safe payment gateway

* Source: Authors' own work

To design the platform, an interview with related stakeholders is necessary to collect data for existing *halal* supply chain. Figure 3 explain who the basic actors for local *halal* beef supply chain could be.

Figure 3: Main actors of a local beef *halal* supply chain in restaurants business.



* Source: Authors' own work

Considering Figure 3 Muslim customers can be concerned about the actual state of the beef in the storage, transportation, and distribution of *halal* food to end users. This is due to the uncertainty surrounding the beef's potential contamination with supply chain data before it is transmitted to customers. Not every party involved in the supply chain of beef possesses a *halal* certificate and not necessary that all parties involved are Muslims or following Islamic teachings in this matter. But blockchain technology that prohibits data temperament can be the solution to this problem.

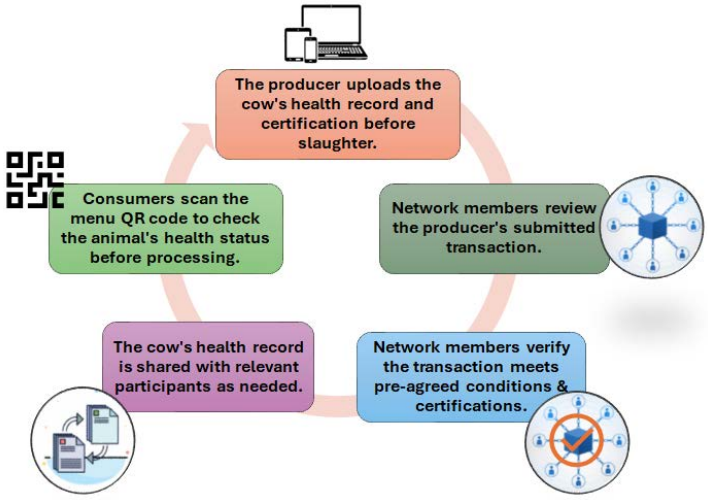
3.2.2 Functional Design using Blockchain Technology

Currently, the challenges facing the *halal* industry are managed through traditional methods of communication and verification, which can face inefficiencies, fraud, and lack of transparency. However, as the industry becomes more globally distributed and consumers demand higher standards of authenticity and traceability, these methods are proving limited and insufficient. The rise of advanced technologies is reshaping industries very fast, and blockchain has the potential to be a key element in this change. It can offer an unchallengeable ledger for tracking *halal* certifications, ensuring

product authenticity from farm to shelf, and verifying compliance with strict *halal* standards across the supply chain. By using blockchain, the *halal* industry can gain a competitive edge, enhance consumer trust, and streamline the authentication process, setting itself apart in an increasingly demanding and competitive global market. This technology not only enhances traceability but also transforms how businesses interact with consumers and each other, providing the way for transparency-driven differentiation and long-term market leadership.

In Figure 4, the mechanism by which users authenticate data through smart contracts is illustrated, operating on a need-to-know basis. By scanning a QR code integrated into the food menu, users can retrieve detailed information regarding the health status of the animals from which their food is sourced. Blockchain technology facilitates the verification and validation of these data transactions by all parties involved in the supply chain. Once the data is recorded on the blockchain, it becomes immutable, thus ensuring that the information is protected against tampering. This immutability enhances the credibility and transparency of the supply chain, safeguarding the integrity of the data and further reinforcing trust in the system.

Figure 4: Functional design of beef supply chain in Blockchain

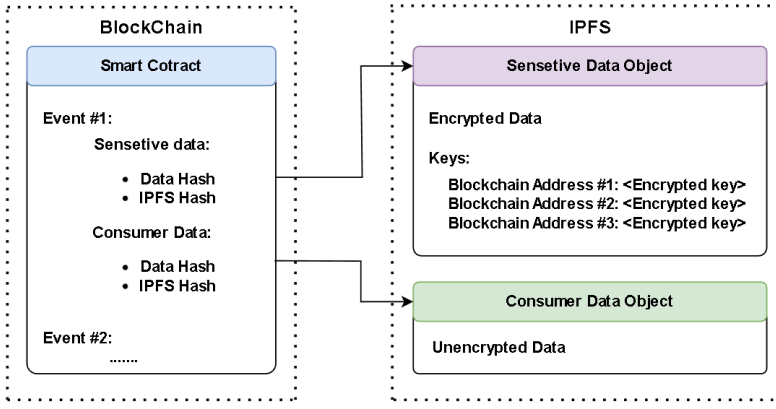


Source: Authors' own work

3.2.3 Interplanetary File System (IPFS)

The Interplanetary File System (IPFS) is a decentralized file storage and sharing solution that operates independently of blockchain networks, relying on an IPFS server for functionality (Fachrian et al., 2024). A key characteristic of IPFS is its ability to automatically replicate data based on user interactions, such as when data is accessed. Although off-chain data storage in IPFS does not share some of the fundamental attributes of blockchain technology, it offers distinct benefits, including greater cost efficiency, improved performance, and increased flexibility compared to storing data within smart contracts. However, one limitation of off-chain storage is the difficulty in automating blockchain-based processes, as smart contracts cannot directly access off-chain data. Figure 5 shows the interaction between smart contracts and IPFS.

Figure 5: Relationship between smart contracts & IPFS



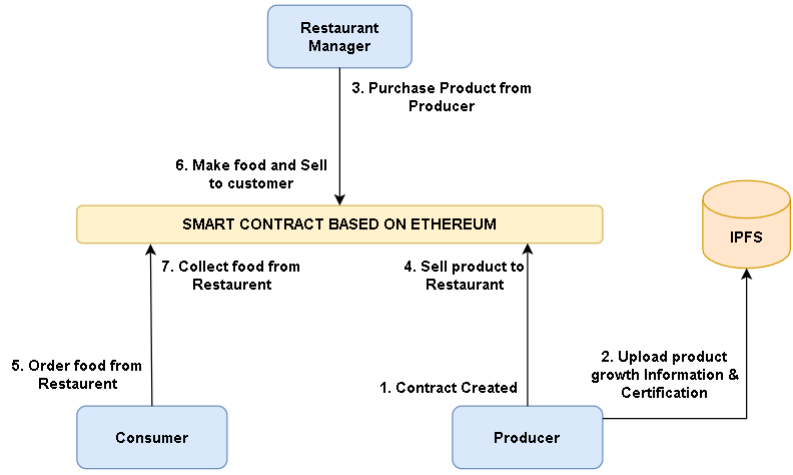
(Prashar et al., 2020)

3.2.4 System Architecture Design using Blockchain Technology

The next phase focuses on identifying the most appropriate consensus algorithm and blockchain framework for the project (Jain et al., 2025). For a blockchain that is stable, dependable, and cost-efficient, it is recommended to implement a consensus algorithm capable of managing Byzantine Faults. The Istanbul Byzantine Fault-Tolerant (IBFT) algorithm is particularly suitable in this context, as it

effectively enables validators to uphold the decentralization of the blockchain (Ye et al., 2024).Figure 6 shows IBFT algorithm's architecture with the interaction between decentralized nodes, a blockchain layer, smart contract execution, and the consensus mechanism, highlighting secure and transparent data flow for smart contract-based transactions.

Figure 6: System architecture using smart contracts with IBFT algorithm



Source: Authors' own work

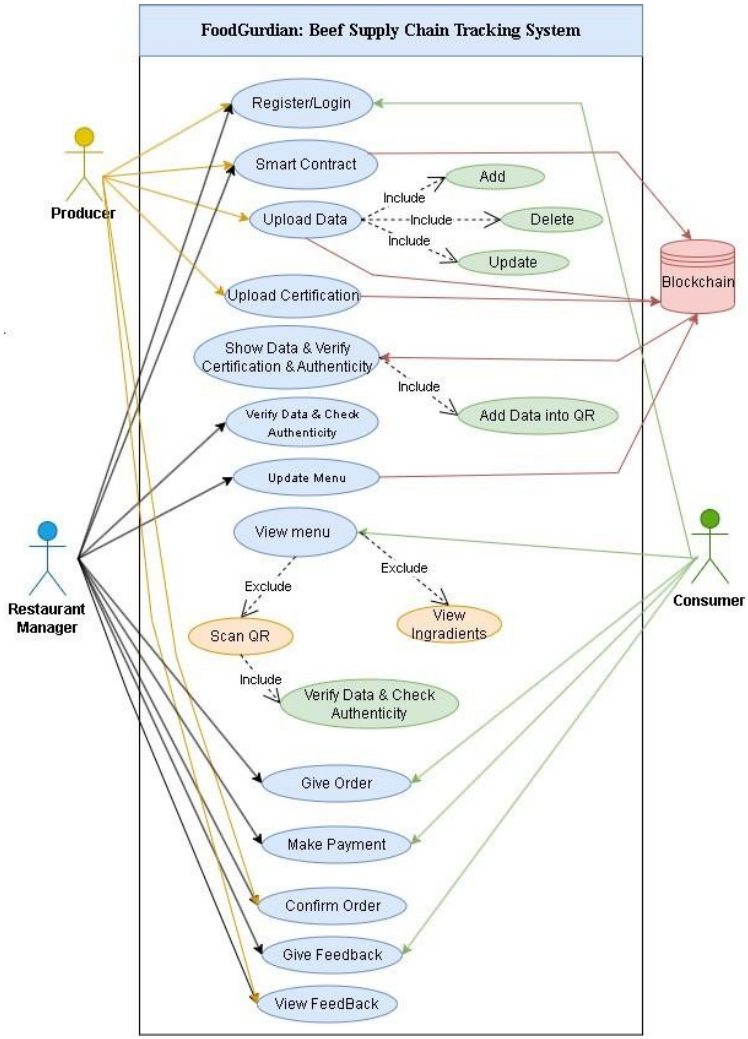
The system architecture shows a view of the data storage process within the IPFS file system and the operational dynamics of the supply chain. Within this framework, the producer plays a key role in the data storage process in IPFS. The roles and responsibilities of the various actors involved are clearly defined, and the architecture highlights the interactions and collaboration between these actors. This description emphasizes how these relationships contribute to the efficient functioning of the supply chain system.

3.2.5 Use Case Diagram

A Use Case Diagram is a modeling tool used to examine and represent the behavior of a system under development. It aids in identifying different users or actors associated with the system and their interactions. Actors in a Use Case Diagram are typically divided into

two categories: those external to the system and those who engage directly with it. In the case of a blockchain-based *halal* supply chain, a Use Case Diagram is constructed to visualize the different actors involved, outlining their roles and the interactions that occur within the system as in figure 7.

Figure 7: Use Case Diagram for *halal* supply chain tracking



Source: Authors' own work

Figure 7 shows the system involving three primary actors: the producer, the restaurant manager, and the consumer. Each actor is assigned different roles and responsibilities within the system. The use case diagram outlines the activities and interactions among these actors, showing their relationships and dependencies as they carry out different tasks and operations within the system.

3.2.6 Use Case Specifications

Table 3 outlines the procedure for the producer to upload cow details to the blockchain. The process begins with the producer logging into the system, after which a data submission form is presented. The producer completes the form with the necessary information and submits it. The system then verifies the data, displaying a confirmation message upon successful upload. If any errors are detected, an error message is shown to the producer. This process ensures that the cow details are securely uploaded to the blockchain, thereby enhancing transparency and reliability within the supply chain.

Table 3: Use Case Specification Upload Data for Producer

USE CASE ID	FG001	
USE CASE 1	Upload Data	
Goal in Context	Producer/supplier needs to add, delete, and update product data into blockchain.	
Preconditions	Producer/supplier needs to Register/ login first to access the system.	
Success End	Producer/supplier has uploaded their products' data	
Failed End	Producer/supplier is unable to access the system.	
Primary, Secondary Actors	Producer/supplier interacting with blockchain database	
Trigger	Upload request comes in	
DESCRIPTION	Step	Action
	1	Producer/supplier login/ register
	2	Producer/supplier upload their product data
	3	Data has been recorded by Blockchain system for verification.

Source: Authors' own work

Table 4 outlines the use case specification for the "Verify and Check Authentication" process, conducted by the manager. The process begins with the manager logging into the system and accessing the product details page. Here, the manager examines the beef details along with the associated authentication certificate. If the information confirms the product's quality, the manager can place an order directly from the page. Equally, if concerns arise or the product does not meet expectations, the manager can submit feedback. The system then sends a notification to the producer, highlighting any issues raised. This process enables the manager to thoroughly verify the beef's authenticity and quality, ensuring informed decision-making.

Table 4: Use Case Specification Verify data and check authenticity for Manager

USE CASE ID	FG002	
USE CASE 2	Verify data & check authenticity	
Goal in Context	Manager needs to Verify the data and check authenticity	
Preconditions	Manager needs to Register/ login first to access the system.	
Success End	Manager verified the data and checked the authenticity	
Failed End	Manager unsatisfied with the data and authenticity and notified the Producer	
Primary, Secondary Actors	Manager is interacting with Blockchain Database	
Trigger	Verify and Authenticity request comes in	
DESCRIPTION	Step	Action
	1	Manager login/ register.
	2	Manager verified the product data
	3	Manager has satisfied with the product data
	4	Product is authenticated by Manager.

Source: Authors' own work

Table 5 outlines the use case specification for the "Verify and Check Authentication" process from the customer's perspective. The

process begins with the customer logging into the system and navigating to the menu page to explore available food options. From this page, the customer can view details about the ingredients and trace the product by scanning a QR code. Upon scanning, the customer gains access to the product's details, including its authentication certificate. If satisfied with the information, the customer can confidently proceed to place an order. If not, they may select a different menu item and provide feedback on the product. This feedback is recorded by the system and immediately communicated to the manager, ensuring customer experiences are acknowledged. This use case provides customers with transparency and confidence in the quality and authenticity of the product, contributing to a more satisfying experience overall.

Table 5: Use Case Specification Verify data and check authenticity for Customer.

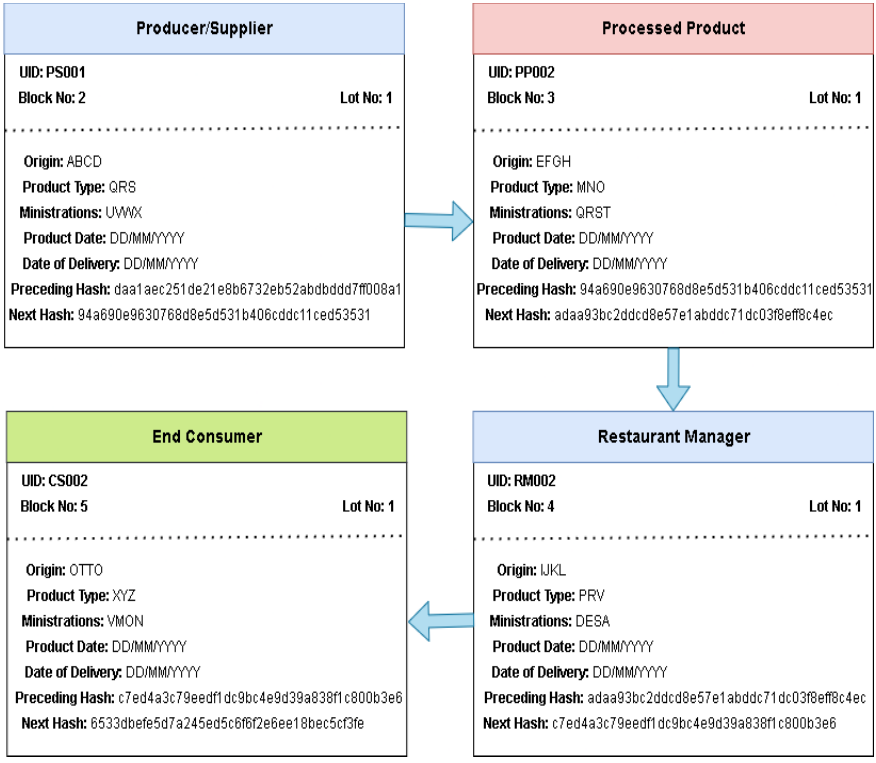
USE CASE ID	FG004	
USE CASE 4	Verify data & check authenticity	
Goal in Context	Consumer needs to Verify the data and check authenticity	
Preconditions	Consumer needs to Register/ login first to access the system.	
Success End	Consumer verified the data and checked the authenticity	
Failed End	Consumer unsatisfied with the data and authenticity and notified the Manager	
Primary, Secondary Actors	Consumer is interacting with Blockchain Database	
Trigger	Verify and Authenticity request comes in	
DESCRIPTION	Step	Action
	1	Consumer login/ register.
	2	Consumers see the food detail and scan the QR code for trace the beef supply chain details and verify with certificate
	2	Consumer verified the product data
	3	Consumer has satisfied with the product data
	4	Product is authenticated by Consumer.

Source: Authors' own work

3.2.7 Block Generation Process

Figure 8 presents a block diagram that shows the process of generating hashed blocks within a blockchain following each transaction. The diagram underlines the essential procedure of verifying the authenticity of data and transactions by comparing the hash of the preceding block. If the hash of the previous block fails to align with the expected value, the subsequent block will be invalidated, and an error message will be generated. This diagram highlights fundamental characteristics of blockchain technology, including its reliability and transparency, which collectively ensure that all participants in the network can trust the system's integrity.

Figure 8: Block Diagram of hashed block generation



Source: Authors' own work

4.0 Analysis of Results

4.1 Survey Results

The survey explored their familiarity with blockchain technology and its economic and financial implications for the food restaurant industry. The results, shown in figure 9, reveal that 55.9% of respondents are aware of blockchain technology, while 44.1% are not. The relatively high level of awareness may be attributed to their academic environment, which often emphasizes emerging technologies and their financial impacts. However, the notable percentage of students unfamiliar with blockchain suggests a gap in understanding its economic advantages and applications. This highlights the need for targeted educational initiatives that emphasize blockchain's potential to optimize financial operations and reduce costs in the food industry.

Figure 9: Respondents' familiarity with blockchain technology

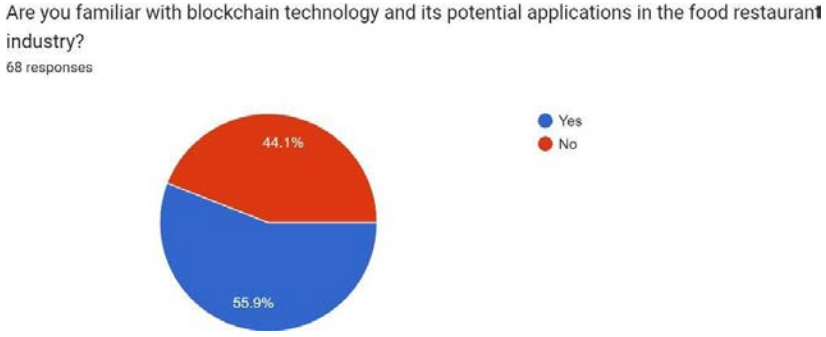
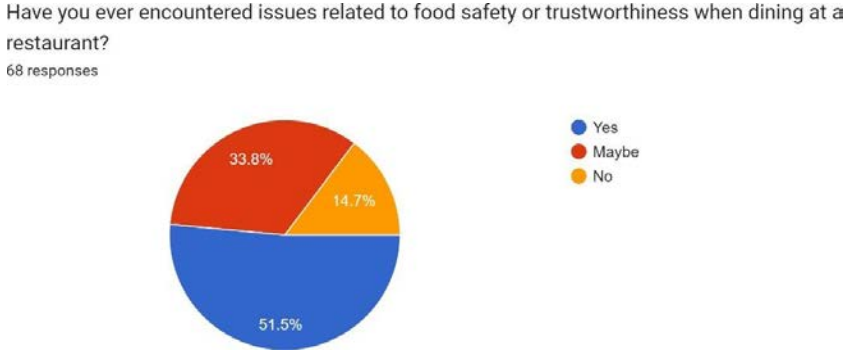


Figure 10 shows the results of asking about respondents' experiences related to food safety and trustworthiness in restaurant settings. The results reveal that 51.5% of respondents have encountered issues concerning food safety or trustworthiness when dining out, while 33.8% indicated that they might have faced such issues. The remaining respondents reported no such concerns. These findings highlight a significant level of worry among students regarding food safety and trustworthiness, reflecting an important issue that could impact their dining choices and overall trust in restaurant establishments. The considerable proportion of respondents who have experienced or are uncertain about food safety issues

highlights a potential area where blockchain technology could offer substantial economic and financial benefits. By enhancing traceability and transparency in the food supply chain, blockchain could address these concerns and improve consumer confidence, ultimately contributing to cost savings and increased financial efficiency in managing food safety.

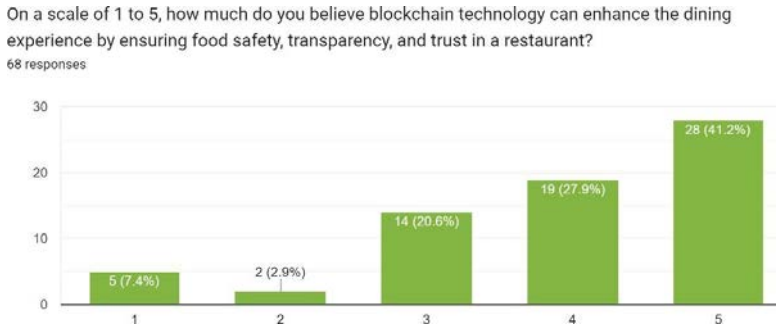
Figure 10: respondents' experiences related to food safety and trustworthiness



The respondents were also asked to rate on a scale of 1 to 5 the extent to which they believe blockchain technology can enhance the dining experience by ensuring food safety, transparency, and trust in a restaurant. The results shown in Figure 11 suggest a generally favorable view among most students regarding blockchain's potential to improve key aspects of the dining experience, such as food safety and transparency. The high percentage of respondents assigning ratings of 4 or 5 reflects a strong belief in blockchain's capacity to address these concerns.

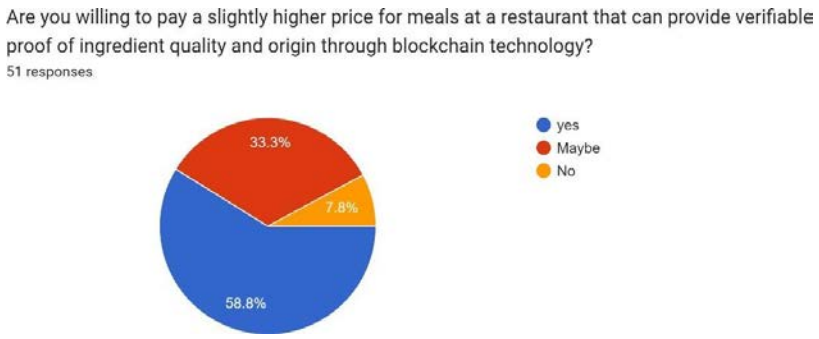
However, the 10.3% of respondents who rated their confidence lower may highlight doubt or a need for further understanding of blockchain's practical applications and benefits in the restaurant industry. This difference in opinions underscores the importance of addressing potential reservations and communicating the economic and financial advantages of blockchain technology in enhancing operational efficiency and consumer trust.

Figure 11: Respondents' beliefs regarding blockchain's potential to improve trust in food safety



The respondents were also asked whether they would be willing to pay a slightly higher price for meals at a restaurant that offers verifiable proof of ingredient quality and origin through blockchain technology. The results in Figure 12 indicate that 58.8% of respondents affirmed their willingness to pay a premium for such transparency, while 33.3% expressed uncertainty about their willingness. These findings suggest a significant portion of respondents values the enhanced assurance provided by blockchain technology regarding ingredient quality and origin, reflecting a readiness to invest in higher-priced meals for increased transparency.

Figure 12: Respondents' willing to pay for meals with verifiable proof through blockchain technology



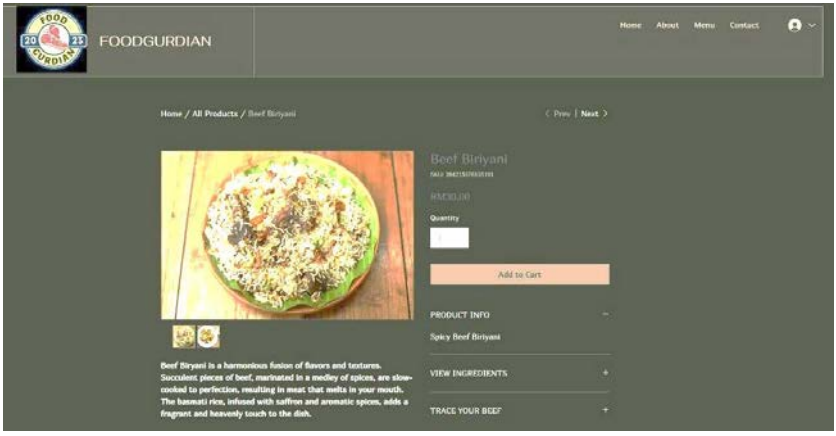
The considerable percentage of respondents who are uncertain or unwilling to pay more highlights potential barriers, such as price sensitivity or uncertainty about the practical benefits of blockchain in

this context. Addressing these concerns could be crucial for restaurants aiming to use blockchain technology to justify price increases and enhance consumer trust in their offerings.

4.2 System Prototype

FoodGuardian is a blockchain-based platform prototype designed to verify the authenticity of meals offered by restaurants. By using blockchain technology, FoodGuardian enables consumers to trace the origin, quality, and safety of ingredients used in their meals, offering a level of trust and verification that is increasingly required in the food service industry. This subsection presents the prototype of FoodGuardian, demonstrating its functionality and its potential to enhance consumer confidence by ensuring that meals served in restaurants meet high standards of authenticity and quality. Through this platform, restaurants can offer verifiable proof of ingredient integrity, fostering greater transparency and trust within the dining experience. In the FoodGuardian platform, the Meal Order Page for a restaurant menu, shown in Figures 13, enables users to efficiently place food orders by adding selected items to their cart. In addition to the ease of ordering, customers can view the ingredients of each dish and trace the source of the meat used. FoodGuardian emphasizes transparency, allowing customers to make well-informed decisions regarding their meals.

Figure 13: Prototype's Food Order Page Interface



Source: Authors' own work

By offering detailed information about ingredient sourcing, the platform ensures a higher level of consumer confidence. This page provides users with details about their food, including the ability to trace the origin of the meat, such as the breed of the cow and its medication history as in Figure 14. Furthermore, users can access certifications from veterinary authorities, farm inspections, and *halal* certification bodies as in Figure 15.

Figure 14: Prototype's View Details Interface

Source: Authors' own work

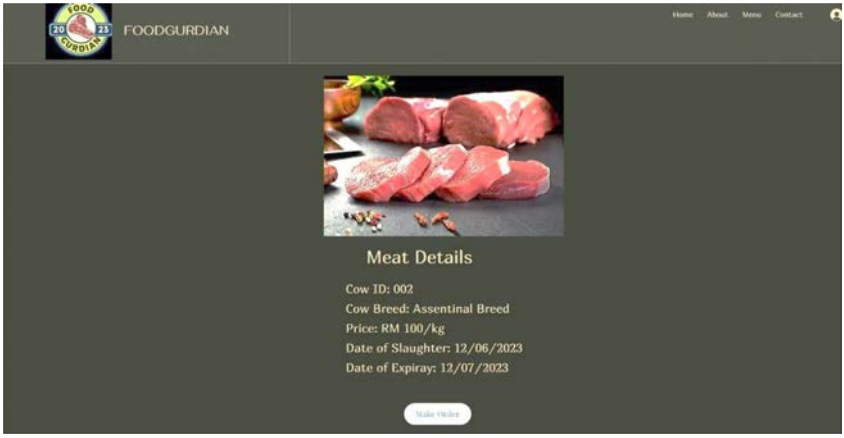
Figure 15: Prototype's View Certification Interface

Source: Authors' own work

On the other side of the system, food producers and restaurant managers play an important role in maintaining the integrity of the supply chain by uploading relevant data. Producers are responsible for providing detailed information about the livestock, including breed specifics, health records, and medication history. Additionally, producers submit veterinarian certifications and farm inspection reports to further validate the quality and safety of their products. Restaurant managers, on the other hand, input information about how the ingredients is sourced, stored, and prepared. They also ensure that the uploaded data includes certifications such as *halal* or organic labels to meet consumer expectations. Both parties collaborate through the system to ensure that the blockchain ledger is continuously updated, providing real-time, verified data that consumers can access. This process ensures that every step of the food production and preparation chain is documented, contributing to a transparent and trustworthy dining experience.

The system has Beef Order Page for Manager as in Figure 16. After the restaurant manager has reviewed the detailed information about the meat added to the blockchain by the producer, they have the option to place an order directly with the producer. This feature streamlines the obtaining process, allowing for efficient and seamless ordering of the desired meat for the restaurant.

Figure 16: Make Order Page Interface for Manager

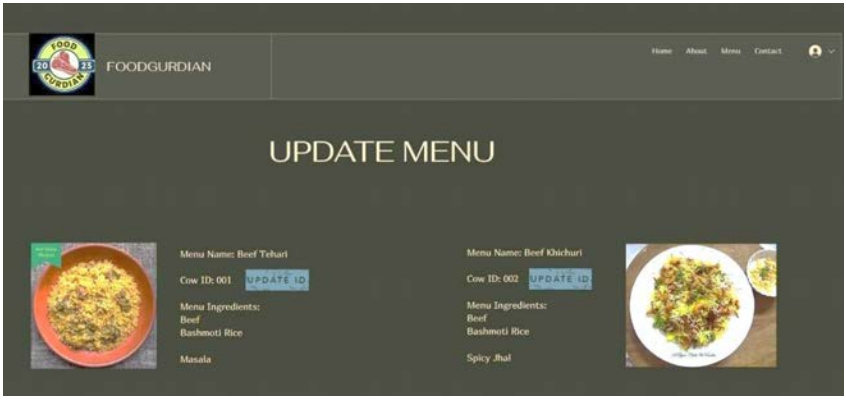


Source: Authors' own work

By integrating the review and ordering functions within the same platform, the system ensures that managers can make informed purchasing decisions based on verified data, while also minimizing delays in the supply chain. This enhances the overall operational efficiency of the restaurant.

The restaurant manager can update the menu by associating each item with a specific CowID, Figure 17. This unique identifier links the beef used in the dish to its origin, ensuring full traceability. Customers can later scan a QR code connected to the CowID, allowing them to verify the source of the beef they are consuming. This process promotes transparency and provides customers with confidence in the authenticity and quality of the food, reinforcing trust in the restaurant's commitment to ingredient integrity.

Figure 17: Prototype's Update Menu Page Interface for Manager



Source: Authors' own work

This prototype demonstrates how consumers can trace the origin and quality of meat by scanning QR codes linked to a unique CowID, providing access to critical information such as breed, medication history, and most importantly, *halal* certification. This feature is particularly significant for Muslim consumers in non-Muslim countries, who often face challenges in verifying the authenticity of *halal* food in the markets.

The platform enables both producers and restaurant managers to upload key data on the meat's source, including verification from *halal* certification authorities. Restaurant managers can ensure that their menu items meet *halal* standards by associating the CowID with the meals, providing Muslim customers with confidence in the religious compliance of their food. The system not only guarantees transparency and traceability but also empowers Muslim consumers to make informed dining choices, having greater trust and assurance in the availability of authentic *halal* options in restaurants.

5.0 Discussion

The integration of blockchain technology into *halal* food supply chains presents a significant opportunity to enhance transparency, traceability, and the authenticity of certifications. The survey results revealed that 55.9% of respondents were familiar with blockchain technology, while 44.1% had little to no knowledge of it. This finding aligns with existing studies, such as Hussain et al. (2021), which also observed varying levels of awareness about blockchain in the context of food supply chains. The relatively high level of awareness among Malaysian university students may be attributed to their academic exposure to emerging technologies, consistent with the findings of (Rejeb et al., 2021), who noted that younger, more educated consumers tend to have higher levels of technological awareness. However, a notable portion of respondents (44.1%) lacked familiarity with blockchain's economic and operational advantages, showing concerns raised in other studies regarding the limited understanding of blockchain's full potential in food systems (Ellahi et al., 2023).

Blockchain technology offers a robust solution to address key challenges in the *halal* food supply chain, particularly in enhancing transparency and verifying the authenticity of *halal* certifications. The immutability and traceability of blockchain have been emphasized in previous literature, such as in the works of Chang et al. (2020) and Adetunmbi et al. (2021), who highlighted blockchain's ability to securely document each stage of the supply chain from production to consumption. This capability is crucial for maintaining consumer trust, especially in *halal* markets, where following religious standards is paramount. The survey results similarly reflect positive consumer

perceptions of blockchain's potential for enhancing food transparency, with many respondents recognizing the value of immutable records for verifying *halal* compliance.

However, while blockchain offers significant benefits, the study participants identified several challenges, including the complexity of the technology and the need for more user-friendly interfaces. This is consistent with findings by Sunmola and Burgess (2023), who also noted usability concerns as a barrier to broader blockchain adoption in supply chains. The complexity of blockchain systems can slow down adoption, especially among non-technical stakeholders, which reinforces the need for simplifying interfaces and ensuring that all users can effectively navigate the system. Addressing these concerns is critical for the successful implementation of blockchain in *halal* food supply chains, as highlighted by Ellahi et al. (2023).

The challenge of scalability also emerged as a significant concern. Blockchain's ability to handle large volumes of transactions while maintaining efficiency and data integrity is still an area that requires further development. Azizi et al. (2021) similarly noted that traditional blockchain architectures face limitations in terms of scalability, particularly in IoT-integrated systems where high transaction volumes are common. Although the performance testing in this study demonstrated blockchain's ability to maintain data integrity, more refinement is needed to ensure that the system can operate effectively across various network conditions and transaction loads. This shows the scalability challenges highlighted by Chang et al. (2020), emphasizing the need for more robust blockchain infrastructure to support large-scale applications in global supply chains.

On the consumer side, blockchain's ability to provide reliable verification of *halal* products holds substantial promise, especially in regions where access to authentic *halal* food options is limited. Previous research by Rejeb et al. (2021) similarly found that blockchain can significantly enhance consumer confidence by offering verifiable proof of food origin and certification. The survey results underscore the importance of this feature, particularly in Western countries where concerns about *halal* authenticity are heightened due to the fragmented nature of supply chains. By providing transparent

and traceable certification records, blockchain can play a key role in building consumer trust, as supported by both the survey findings and prior studies.

6.0 Conclusion

This study examines the application of blockchain technology in the *halal* supply chain, highlighting its potential to significantly improve transparency and authenticity. The research demonstrates that blockchain's decentralized and immutable ledger system offers substantial benefits in tracking ingredients and verifying *halal* certifications, thereby reinforcing consumer confidence in the integrity of *halal* products. By providing verifiable proof of *halal* certification, blockchain solves important issues related to food authenticity, particularly in markets where reliable *halal* options are often limited. However, the study also identifies several implementation challenges, including the need for considerable changes to existing supply chain practices and addressing scalability issues. While blockchain technology effectively maintains data integrity, its performance in managing high transaction volumes and various network conditions requires further enhancement. Overall, blockchain technology represents a major advancement for improving transparency and authenticity in the *halal* supply chain. Continued research and development are important to overcome these challenges and fully use blockchain's potential to ensure the integrity of *halal* products. As the technology advances, integrating it with matching systems will be important for maximizing its impact and effectiveness in the *halal* sector.

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