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Article

FoodSQRBlock: Digitizing Food Production and the Supply Chain with Blockchain and QR Code in the Cloud

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Abstract: Food safety is an important issue in today's world. The traditional agri-food production system does not offer easy traceability of the produce at any point of the supply chain, and hence, during a food-borne outbreak, it is very difficult to sift through food production data to track produce and the origin of the outbreak. In recent years, the blockchain based food production system has resolved this challenge; however, none of the proposed methodologies makes the food production data easily accessible, traceable and verifiable by consumers or producers using mobile/edge devices. In this paper, we propose FoodSQRBlock (Food Safety Quick Response Block), a blockchain technology based framework that digitises the food production information and makes it easily accessible, traceable and verifiable by the consumers and producers by using QR codes. We also propose a large-scale integration of FoodSQRBlock in the cloud to show the feasibility and scalability of the framework, as well as give an experimental evaluation to prove this.

Keywords: food production; supply chain; blockchain; QR code; cloud computing; food safety; barcode; traceability system; agri-food; agriculture



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1. Introduction

Over the decades, the food production system—the way to get food from farm to table—has evolved to a complex network. Today's food production system provides the consumers more variety and convenient, economical and healthier sources of food; however, such a system comes with its own challenges, such as the case where ingredients produced by one producer could end up in thousands of other products distributed in many different shops [1,2]. This challenge is an issue of food safety, which is potentially detrimental to consumers' health and seriously damages the consumer's trust of the food market. For example, some immoral food producer could use trench oil to produce cooking oil, which is then distributed to thousands of shops, which is retrospectively bought and consumed by the consumer, making them sick in the process. Several cases of such accidents or food safety scandals such as the "horse meat scandal", "Sudan red", "clenbuterol", "Sanlu toxic milk powder" and "trench oil" [3] have happened all over the world. These scandals do not just harm the economy of the food market, but at the same time threaten the safety and stability of society as well. Although there are standards available such as the General Food Law in the EU [4] and the Food Safety Modernization Act (FSMA) in the U.S. [5], which try to standardize the traceability of the digital information of food production in some of the stages of the food supply chain, these standards are regional, and currently, there is no holistic standardization of the tracking and recording data for food traceability purposes in all stages of the food supply chain across the globe. Therefore, in order to deal with such a challenge related to food safety, Blockchain Technology (BT) [6,7] may play a vital role in the traceability of food ingredients

in recent times such that consumers can trace the source of the food ingredients that they are buying/consuming.

Traditionally, many producers still record the data of their production on paper, whereas some producers digitise the production data, which does not enable interaction with other parties in the food system. Moreover, traditional food production systems are centralized in nature and could result in a trust problem, such as fraud, corruption, tampering and falsifying information. During a food-borne outbreak, sifting through thousands of documents (digital or paper) to trace food ingredients could be slow and complicated. In recent times, several methodologies [2,3,8,9] based on BT have been proposed to solve the challenge of food traceability for food safety purposes. The key strengths of utilizing BT is its decentralized, distributed and trusted nature, which could be advantageously used for food traceability and transparency for consumers at any point of the food production system. However, all the proposed BT frameworks [2,3,8,9] only deal with the effective traceability of food supply chains, but not with technical solutions to make the food traceability more accessible to consumers such that they can verify and track their bought food items, may be with an easy-to-access device such as a mobile phone.

On the other hand, a popular way to store food data digitally is by using 1D barcodes such as the Universal Product Code (UPC) barcode [10,11]. The UPC barcode consists of 12 numeric digits that are uniquely assigned to each trade/food item. Every region or country maintains a database that holds the record of these trade/food items along with the unique UPC, which are capable of storing the following data: the type of product, size, manufacturer and country of origin of the food item. Therefore, if a consumer wants to know more about the bought food item, he/she has to use a barcode reader (using a mobile phone application), which will fetch the unique UPC from the barcode and then fetch the information from an online database using the UPC. Although the information is fetched from an online database, the amount of information available on the item is limited to the type of product, size, manufacturer and country of origin based on the type of database. Therefore, no accurate traceability of the item throughout the supply chain is available for the consumer to verify. For example, Figure 1a represents a typical 1D barcode, which accompanies Tropicana juice's product label [12] and only reflects the following information (see Figure 1b) about the product: UPC number, European Article Number (EAN), Amazon Standard Identification Number (ASIN) product category, brand, model and, last, scan date-time, as fetched from BarcodeSpider.com (accessed on 21 March 2021). It should be kept in mind that the 1D barcode in Figure 1a only allows storing the 12 digit UPC and no other information; therefore, if the correct database is not used to fetch the information on the product using the UPC, then the information might not get retrieved at all. Moreover, if the consumer is not connected to the Internet, she/he might not even retrieve any information based on the UPC by scanning the traditional 1D barcode since a lookup of the online database using the UPC is necessary.

Another issue is that many food products have a shorter shelf life such as fresh vegetables and fruits, which should be consumed within a few weeks of being produced, and the expiry/best before date are printed on the label of the food item during the packaging and, hence, are not available in the UPC barcode information. Many food management applications [13,14] are now being offered to remind the consumer of the expiry/best before dates of the food products to reduce food waste in the household. In these applications (apps), a consumer can record the bought food items along with their expiry/best before dates, to create a reminder to consume the items before they expire. These applications offer barcode scanning to automatically enter the bought food items into the apps; however, given the lack of information stored in the barcode, the consumer still has to enter the expiry/best before date of each item individually. Therefore, this calls for a technology that enables the consumer not just to be able to verify the source of the bought food items throughout the supply chain for food traceability purposes, but also automatically fetch the respective expiry/best before date.

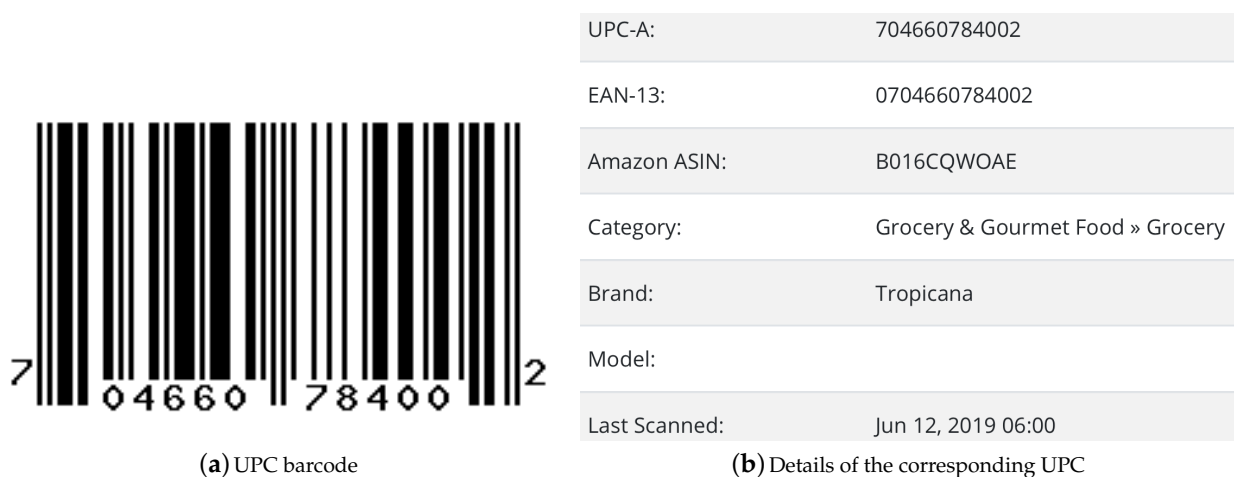


Figure 1. UPC barcode for Tropicana Trop50 Blackberry Cherry juice as fetched from [BarcodeSpider.com](#) [12] (accessed on 21 March 2021). EAN, European Article Number; ASIN, Amazon Standard Identification Number.

To resolve these challenges, we propose *FoodSQRBlock* (Food Safety Quick Response Block), a BT based framework that digitises the food production information such that the consumers and producers can trace the food produce at any point of the food production system and make the information easily accessible using the Quick Response code (QR code) such that the information can be retrieved and verified easily by the consumers and producers. In this paper, we also provide a proposal for a large-scale integration of *FoodSQRBlock* in the cloud such that the framework could be adopted easily given the improvement and accessibility of cloud technology. To this extent, the main contributions of this paper are as follows:

1. We propose *FoodSQRBlock*, a BT and QR code based framework to digitise food production information and retrieval;
2. A large-scale integration of *FoodSQRBlock* in the cloud and related experimental evaluation in the Google Cloud Platform.;
3. The analysis and limitations of the large-scale integration of *FoodSQRBlock* in the cloud.

2. Preliminaries

2.1. Blockchain Technology

When Satoshi Nakamoto [7] released the technology named Bitcoin, he revolutionised the industry not because he had invented a new currency system, which does not require the intervention of an institutional mediator while transferring money from one entity to another, but because he had gifted one of the most disruptive technologies that has come to life in decades. With the introduction of Bitcoin, blockchain was introduced to the world, which is a digital ledger in which all transactions are recorded chronologically and publicly. Therefore, the application of blockchain is not just limited to crypto-currencies [15,16] such as Bitcoin and has proven to be useful in tracking ownership, provenance of documents, digital assets, physical assets, voting rights, etc. The blockchain network is traditionally of three types as follows:

1. **Public:** In this network, everyone can check and verify the transaction made. The network is also open to anyone who wants to participate in the consensus process.
2. **Private:** In this type of network, strict restrictions are applied on data access, and the nodes (user/entity) have restricted access to specific block chains, which are monitored by a governing body.
3. **Consortium:** Nodes in this type of network can form a partnership with businesses or other authorities. This type of network may be public or private, and hence, this could be seen as a hybrid approach as it is partly decentralized.

Blockchain technology is popular because of its design features, which are composed of six key elements as follows:

1. **Decentralized:** Blockchain data can be recorded, stored, updated and distributed without dependence on a central authority or node.
2. **Transparency:** Data recorded and stored are transparent and visible, therefore leveraging trust among its users.
3. **Open source:** The source code, as well as most of the blockchain dependent systems are open to view, free to use and provide the ease of extension to other applications.
4. **Autonomous:** Blockchain updates are consensus based, and thus, data can be updated securely from a single user to the whole system. This feature provides autonomy to the system to update data securely.
5. **Immutability:** All data in the blockchain are reserved forever.
6. **Anonymity:** Blockchain also provides anonymity to its users and makes the system more trustworthy by only using the users' blockchain addresses instead of their personal information.

2.2. QR Code

The QR code [17–19] is an effective information transmission medium, which is widely used in product traceability, advertising, mobile payment, passport verification and other fields. The QR code is defined as 40 symbol versions (to carry various data payloads) and four user-selectable Error Correction Levels (ECLs): L, M, Q and H, which can correct up to 7%, 15%, 25% and 30% of the error codewords respectively when attacked by defacement. The larger QR version can offer higher data payload where the QR code can hold a maximum capacity of 2956 bytes for a 40 code version. The error correction capability of the QR code is one of the key features of this type of barcode introduced by the QR code standard and allows the barcode reader to retrieve the data correctly if portions of the barcode are damaged. The QR code utilizes the Reed–Solomon error correction algorithm to realize this fault tolerance, where the error correction codewords would be generated by the Reed–Solomon algorithm and added to the tail of QR code data codewords [20–23]. Usually, two error correction codewords can be used to correct codeword data error. Obviously, the larger the QR code version and the error correction level, the more it can offer higher data payload and reliability. Figure 2 represents a QR code in which a simple, “Hello, World!” message is embedded.

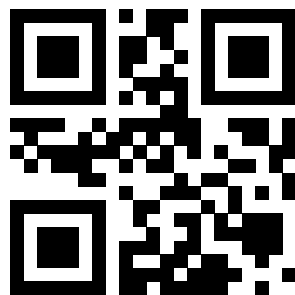


Figure 2. Representational QR code with the “Hello, World!” message embedded.

2.3. Cloud Computing

Cloud computing (cloud) [24,25] is a model to enable ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources such as networks, servers, storage, applications and services, which can be rapidly provisioned and released with minimal management effort or service provider interaction [26]. The essential characteristics of cloud computing are summarized as follows:

1. **On-demand self-service:** For cloud computing, capabilities can be provided automatically when needed, without requiring any human interaction between the consumer and the service provider.
2. **Broad network access:** In this type of service, computing capabilities are available over the network and accessible through several mechanisms disposable for a wide range of consumer platforms such as workstations, laptops and smartphones.
3. **Resource pooling:** In the cloud, computing resources are pooled to accommodate multiple consumers, hence dynamically allocating and deallocating them according to the consumers' demand. Moreover, the provider resources are location independent, i.e., the consumer does not have any knowledge or control of their exact location.
4. **Rapid elasticity:** In the cloud, the computing capabilities can be provided flexibly and released to scale in and out according to the consumer's demand. Therefore, the consumer has the perception of unlimited, and always adequate, computing capabilities.
5. **Measured service:** In the cloud, resource usage can be monitored and reported according to the type of service being offered. This is particularly relevant in pay-per-use or pay-per-user services because it grants great transparency between the provider and the consumer of such services.

Cloud services can be provided to consumers in a variety of ways, and one such service is Software as a Service (SaaS) [27], where the software and its related data are centrally hosted in the cloud computing environment such that the software can be provided to numerous consumers.

3. Related Work

Agri-food production and supply chains [2,3,8,9] have been studied extensively. Li et al. [28] developed a dynamic planning method for the agri-food supply chain. This methodology minimizes the losses of agri-food products while simultaneously maximizing the profits for agri-food supply chain members. In 2015, Foroglou et al. [29] produced a study on the applications of blockchain, which included an electronic cash system. In the same study, Foroglou et al. also showed the applications of blockchain in different domains in the future such as contracts, voting, intellectual property rights, smart property and finance. In 2016, Tian [3] proposed an agri-food blockchain framework using RFID technology to implement data acquisition, circulation and sharing in the production, processing, warehousing, distribution and sales links of the agri-food supply chain. In [2], Zhao et al. foresaw the storage capacity of BT being one of the most pressing challenges for applying BT to the agri-food supply chain. Another challenge for implementing BT, pointed out in [2], is the demanding computational power of utilizing such a framework. In [8], Astill et al. mentioned the use of the Internet of Things (IoT) (by using sensors embedded in different stages of food production) for data acquisition of food production and the supply chain and utilizing BT to create transparency for such data.

In [30], Bogner et al. proposed a decentralized application to share everyday objects/devices based on a smart contract using the Ethereum blockchain and QR code. In this application [30], a smart contract hosted on the blockchain, the local Ethereum client and a web app are used to identify each object or device based on the QR code, which is unique to each device. Although this approach utilizes the QR code and BT together to share devices in a decentralized manner, the logistics of the food supply chain are much more complex and hierarchical, which requires a more holistic approach specific to the agri-industry. In [31], Kumar et al. proposed an approach to stop counterfeit products in the medicine supply chain using BT and an encrypted QR code such that the consumer can trace each active ingredient in the medicine. In this approach, each ingredient is traced using BT and then embedded as encrypted data in the QR code for further verification by the consumer. The approach in this method [31] is complex in terms of the implementation in the agri-industry, especially given the distributed nature of the food supply-chain. Moreover, tracking each ingredient in the product also means additional storage memory usage

to trace the ingredients. On the other hand, in [32], Baralla et al. proposed an approach to trace the European food supply chain by using BT and the QR code; however, the approach utilizes Hyperledger Sawtooth, which is suitable for enterprises while discouraging individual and small farmers with small production capacity from utilizing such a technology. Additionally, this approach does not encourage recovery and verification of data such as the expiry date of the food product during the shopping phase of the food supply chain. The multi-level system architecture proposed in [32] also generates the QR code at every step of the supply chain, which also makes the QR codes more redundant and unnecessary.

From the published aforementioned studies, two important challenges arise from using BT in the food production system:

1. Improving the storage capacity of blockchain data while not increasing the computational power requirement.
2. Making the BT based food production framework more accessible to consumers such that the food items can be verified easily at any point in the supply chain.

In this paper, we propose, FoodSQRBlock, a BT based framework to make food production data more traceable and then make them available/accessible to the consumers using the QR code. Since, the whole framework is implemented at a large scale in the cloud, which offers flexible scalability as per the consumer's demand, the challenge faced due to storage capacity is not an issue.

4. Proposed Framework: FoodSQRBlock

In order to design the BT based framework to make food production data more traceable and accessible, first, we have to analyse the different phases and activities present within a generic food supply chain. In our proposed framework, we focus our research on the farm-to-fork supply chain, which has five main phases [32] characterizing a generic food supply chain as follows.

- **Production:** This is the primary production phase, which represents all the activities related to agriculture within the farm.
- **Processing:** In this phase, harvesting the produce and turning it into products are performed. The preparation and packaging of the produce is also performed in this phase, where each package is uniquely identified through a production batch code.
- **Distribution:** In this phase, once the product is packaged and labelled, it is released for distribution to different warehouses and other distribution centres for product storage.
- **Retailing:** In this phase, the products are delivered to the retailers, who sell the products to the consumers, from the distribution centres.
- **Consumption:** The consumer is the end user of the food supply chain, where she/he buys the product, requires the quality standards verifying the traceability and accesses other relevant data about the product such as the expiry date.

In our proposed framework, FoodSQRBlock, we focus on digitizing data from the first four phases (production, processing, distribution and retailing) and then use these data in BT for traceability and accessibility by the consumer in the consumption phase. All digital data regarding the first four phases are recorded and maintained in the blockchain in the cloud.

System architecture: To design our BT framework, we propose a multilevel system, whose architecture is represented in Figure 3. Our system has three layers as follows.

- **Physical layer:** This layer consists of different food products from different farmers and producers within the supply chain.
- **Digital data layer:** This layer includes digital data associated with the produce belonging to the physical layer, which will be used for traceability and accessibility. One example of the data of the produce could be the expiry date of the food product.
- **Cloud layer:** In this layer, the digital data are processed in the cloud using BT, which is used for traceability and accessibility.

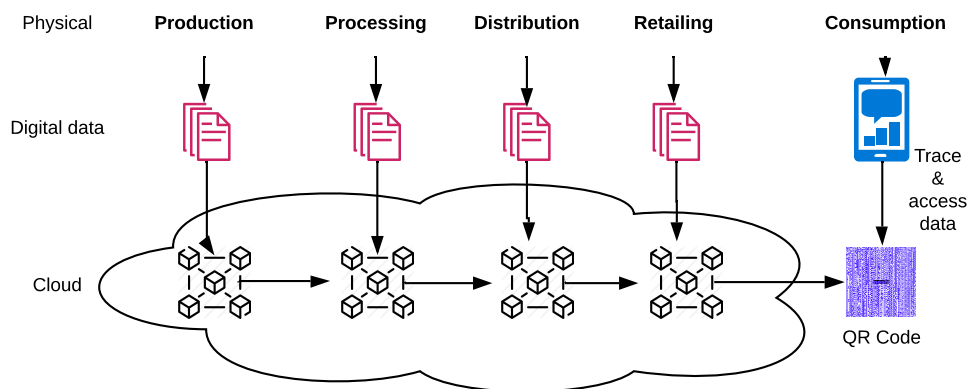


Figure 3. Overview of the system architecture of Food Safety Quick Response Block (FoodSQRBlock) based on the farm-to-fork supply chain.

Now, we introduce our FoodSQRBlock framework with an example to digitise the food production data in the four different phases (production, processing, distribution and retailing) of the supply chain and make the data available and accessible to consumers (consumption) for verification purposes using the QR code. Figure 4 shows the exemplar conceptual FoodSQRBlock framework of an agri-food supply chain traceability system. For this exemplar supply chain, we considered the production and processing phases to happen at the farm, whereas the warehouse represents the distribution phase and the shops the retail phase. In Figure 4, the food item is produced and processed at a farm, where the relevant information is digitised and stored in a block (genesis block/Block 0), and then, the item is transported to a warehouse/distribution centre, from which the item is finally transported to a shop for consumers to buy. In each step/phase of this supply chain, a new block is created that stores the hash of the previous block such that at any point the item (produce) could be tracked and traced. We utilize the SHA256 algorithm [33], which is very popular in BT currently, for the hash function to generate the hash of the previous block. In our FoodSQRBlock, we utilize SHA256 for the hash function since it provides the required security for the associated computational cost on the cloud. If we utilize a different hashing algorithm such as SHA512, it is computationally more expensive and takes longer to compute on the cloud, which ultimately increases the computational cost, especially if thousands of digital data of the produce are processed on the cloud every day.

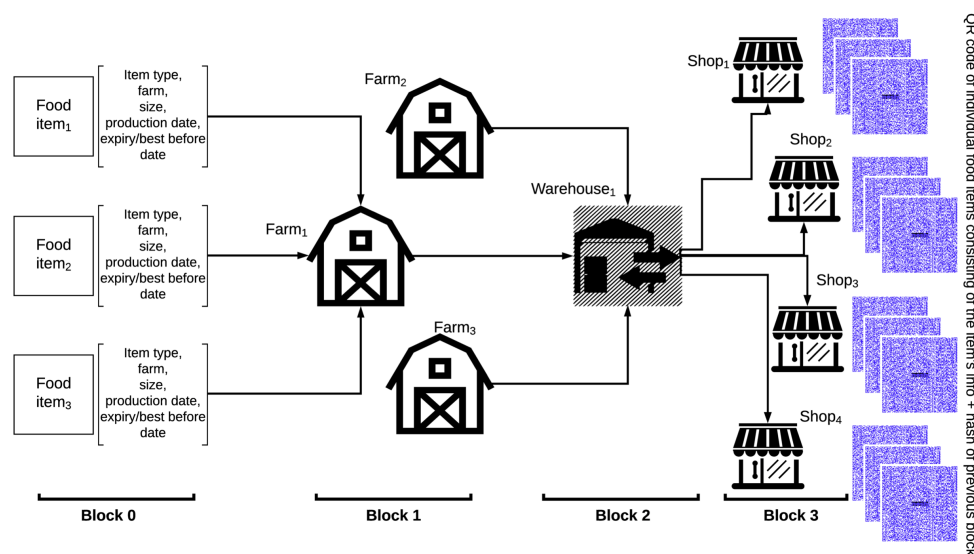


Figure 4. Conceptual FoodSQRBlock framework of an agri-food supply chain traceability system based on the QR code and blockchain technology.

Within the FoodSQRBlock, we have two modules: *Encoding* and *Decoding*. The Encoding module digitises the produce information, generates the blocks and also generates the QR code holding the information. The Decodemodule, which is an open source software (algorithm), enables the consumers to fetch and verify the information about the produce. The program source code for the Encoding and Decoding modules is provided in Section 7.

Encoding module: If we consider f_i as the i_{th} instance of the food item being produced at a farm or manufacturing plant, then the following information ($info(f_i)$) about the produce: produce name (p_i), type (t_i), farm/manufacturing plant id ($farm_i$), size of produce (s_i), production date ($pdate_i$) and expiry/best before date ($edate_i$), can be digitised such that this information can be passed along with the block for traceability and verification purposes by the consumer. Therefore, the digitised information can be represented as follows:

$$info(f_i) = \{p_i, t_i, farm_i, s_i, pdate_i, edate_i\} \quad (1)$$

In $info(f_i)$, the unique farm id ($farm_i$) is stored, which correlates with the farm data (farm name, geo-location of the farm), stored in a database maintaining records of all the farms/manufacturing plants. Here, the unique farm id is also generated using the hash function on the stored details of the farm/manufacturing plant, hence ensuring that the farm id is unique for each farm. In the genesis block (Block 0), $info(f_i)$ is stored. Whenever the produce is transported or processed by an entity in the supply chain, a new block is generated, which holds the original $info(f_i)$, as well as the hash of the previous block. The QR code could be generated at any point in the supply chain, and it holds the information passed in the block ($info(f_i)$) and the hash of the previous block). Figure 5a shows the QR code generated at the shop when the produced milk is transported to the shop (from farm to warehouse/distribution centre to shop).

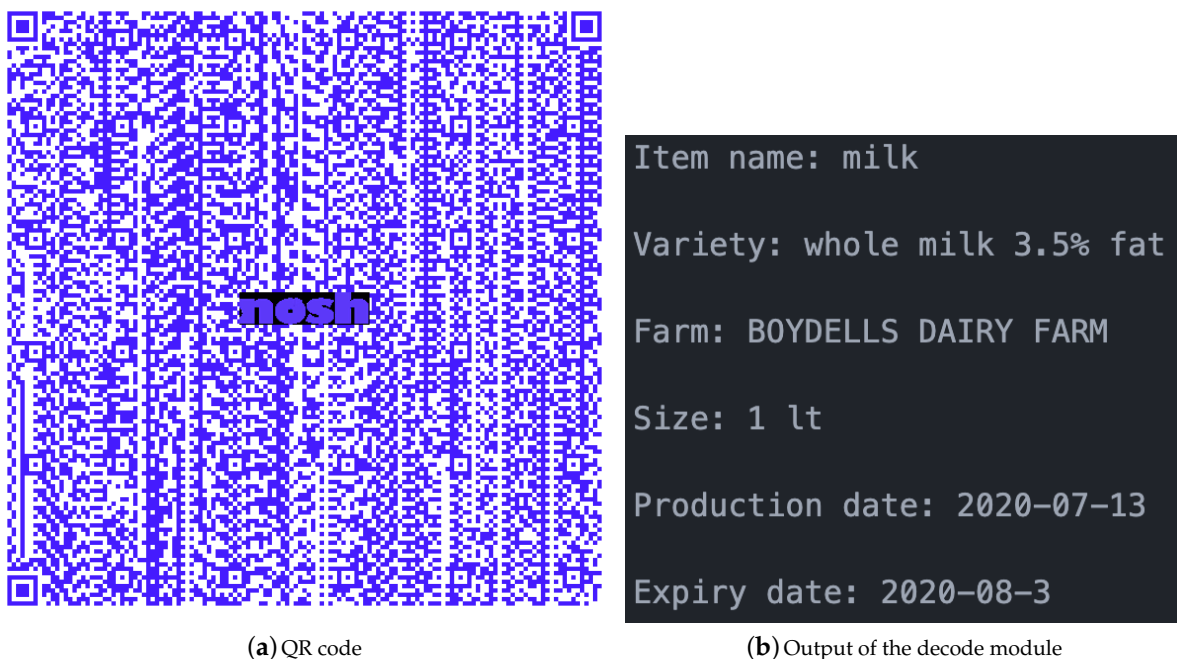


Figure 5. QR code holding the information of a dairy product, which is produced at Boydells Dairy Farm in the U.K., generated by FoodSQRBlock.

Decoding module: In this module, the information ($info(f_i)$) and the hash of the previous block are fetched using a QR code scanner (smartphone) from the QR code. Since, the information of the previous block is made available online for the consumers to verify, the Decode module performs a hash function on the information from the previous block and compares the value with the hash value fetched from the QR code. If the hash values match, then it means the information about the produce is authentic (leveraging

the immutability characteristic of BT). A reverse search on the unique farm id fetched from the QR code is performed to fetch the details of the farm/manufacturing plant where the produce originated, and the information is displayed to the consumer along with other information about the produce ($p_i, t_i, s_i, pdate_i, edate_i$). Since the details of the farm/manufacturing plant are stored in a database, a reverse search on the database can be performed using the unique farm id. Figure 5b shows the decoded information about the dairy product, fetched from the QR code in Figure 5a.

Note: Given the storage capacity of QR codes, more information could be stored/embedded in the QR code in the Encoding module. As a proof of concept and to test run the FoodSQRBlock framework, we found $info(f_i)$ embedding $p_i, t_i, farm_i, s_i, pdate_i, edate_i$ is most suitable for our purposes.

5. Experimental Evaluation: Case Study and Large-Scale Integration of FoodSQRBlock

In order to implement and evaluate FoodSQRBlock in the cloud, we chose Google Cloud Platform's (GCP) [34] Compute Engine service, which is a virtual machine consisting of 8 vCPUs, 16 GB RAM memory and 500 GB disk memory space, to setup our cloud server. The Compute Engine was running on Debian GNU OS (Linux) Version 10 (code name "buster"). We chose the following two food items to test run our implementation: milk and pumpkin. Milk is sourced from a local farm (Boydells Dairy Farm in Essex, U.K.), and pumpkin is also sourced locally (Foxes Farm Produce in Essex, U.K.). The milk is sourced from the farm and then sold directly at the farmer's market, whereas, the pumpkins are moved to a warehouse distributing facility after being sourced from the farm and then are sold at the farmer's market. We implemented the FoodSQRBlock as a web service (SaaS) on the GCP Compute Engine server to process the blocks and generate the QR codes, containing all the relevant information, for individual produce. We simulated the production in the aforementioned farms (Boydells Dairy Farm and Foxes Farm Produce) in the cloud platform to replicate the scenario of a real-world food production system. For a batch of milk being sourced around the same time, it is accumulated into the same block and blockchain consisting of two blocks (genesis block and hash of genesis block) generated for each individual batch. For pumpkins, every one hundred pumpkins are accumulated into the same block, and since each batch of pumpkin made it to the farmer's market (shop) via the distribution centre, each batch was processed to consist of three blocks in the chain (genesis block, the hash of genesis block when it went to the distribution centre and the hash of the block from the distribution centre after making it to the farmer's market).

5.1. Experimental Evaluation

In GCP's Compute Engine, the web service of FoodSQRBlock processed (generated the hash of the block along with the stored information as mentioned in the Encoding module in Section 4) different numbers of produce to find the time taken for processing such information. Figure 6 shows the processing time in seconds for 1, 10, 100, 1000, 10,000 and 100,000 items of produce on GCP's Compute Engine.

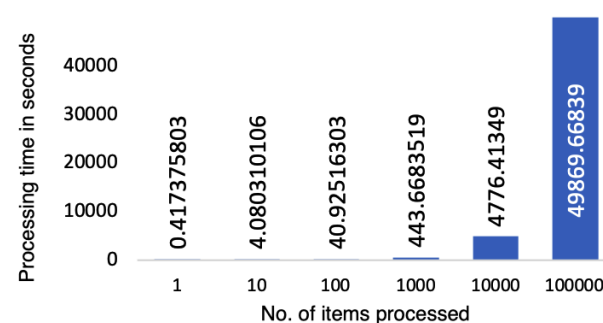


Figure 6. Time taken to process different number of items (using FoodSQRBlock) in Google Cloud Platform's Compute Engine.

5.2. Analysis and Discussion

From Section 5.1, it is evident that given the resources of GCP's Compute Engine, ten-thousand items could be processed easily under 80 min. However, if a farm or manufacturing plant produces more than 10,000 items in a day, then a more computationally powerful cloud server is required to be able to process the items within a reasonable time. Because GCP allows flexible ad-hoc computation resources for its Compute Engine, it is easy for us to scale up or down based on the number of items to be processed, therefore solving the storage capacity issue of BT, as mentioned in Section 3.

It should also be kept in mind that currently, there are no standards or regulations on standardising the traceability of the digital information of food production across the globe, and therefore, the implementation of the proposed FoodSQRBlock would require collaboration across regions.

6. Conclusions

In this paper, we propose FoodSQRBlock, a blockchain technology based framework, which digitises the food production information and makes it easily accessible, traceable and verifiable by the consumers and producers by using QR codes to embed the information. We also implement FoodSQRBlock in Google Cloud Platform to replicate a real-life food production scenario using milk and pumpkins as produce examples from real farms in the U.K. Experimental evaluation proves the feasibility and scalability of the FoodSQRBlock implementation in the cloud.

7. Code Availability

The program source code to implement the FoodSQRBlock (Encoding and Decoding modules) can be accessed from <https://github.com/somdipdey/FoodSQRBlock-Digitizing-Food-Supply-Chain-Using-Blockchain-And-QR-Code> (accessed on 21 March 2021).

Author Contributions: Conceptualization, S.D.; methodology, S.D.; software, S.D.; validation, S.D. and S.S.; formal analysis, S.D.; investigation, S.D.; resources, S.D. and S.S.; data curation, S.D.; writing—original draft preparation, S.D.; writing—review and editing, S.D., S.S., A.K.S. and K.M.-M.; visualization, S.D.; supervision, S.D. and A.K.S.; project administration, S.D.; funding acquisition, S.D. All authors read and agreed to the published version of the manuscript.

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Informed Consent Statement: Not applicable for this study as it did not involve humans.

Data Availability Statement: Not applicable.

Conflicts of Interest: This research was pursued such that part of the proposed methodology could be implemented as a feature in the commercial mobile application named nosh-Food Stock Management <https://nosh.tech> (accessed on 21 March 2021).

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