Chapter 10
Blockchain in Food Traceability

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Abstract Blockchain is a transformational, paradigm-shifting technology impacting multiple industries. Starting in 2009 with the creation of Bitcoin, the applications of the technology have expanded to a wide range of use cases including food traceability (Abeyratne SA, Monfared RP, Int J Res Eng Technol 5:1–10, 2016). Described briefly, a blockchain is a decentralized, distributed ledger verified through consensus of the network (The Economist, The great chain of being sure about things. 2015). Due to the relative immaturity of the technology, it is difficult to predict how and in what ways it will transform the food sector, but it is clear that Blockchain will be a key technology for improving food traceability systems (Abeyratne SA, Monfared RP, Int J Res Eng Technol 5:1–10, 2016). More broadly, Blockchain is shifting how and what data is shared throughout the food supply chain, moving from siloed, opaque data traditionally held on paper or internal, centrally controlled databases to a more open, transparent system.

Food supply chains have unique challenges which make blockchain data architectures particularly attractive, such as disparate trading partners, hyper globalized supply chains, and unequal adoption of digital technology. The intention of this chapter is to briefly introduce the concept of blockchains and delineate use cases and advantages for food traceability, not to delve into technical computer science. Many traceability-related examples are drawn from current pilots and early implementations of blockchain in the food sector, which include seafood, produce, and meat/poultry.

Keywords Blockchain · Internet of things · Ethereum · Hyperledger · Cryptology

Note: For the purposes of this chapter, blockchain is referring to the spectrum of technologies based on Nakamoto's basic premise of a decentralized ledger connected through Merkel trees.

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J. McEntire, A. W. Kennedy (eds.), *Food Traceability*, Food Microbiology and Food Safety, https://doi.org/10.1007/978-3-030-10902-8_10

Introduction to Blockchain

The history of blockchain starts in the financial technology and e-commerce sectors, an important disclaimer when applying blockchain to other use cases [1, 4]. Originally, blockchain technologies needed no other verification than the network itself, because the assets accounted for by the blockchain only existed on the blockchain [4]. Blockchain technologies were begotten out of an experimental manner of exchanging value, known as cryptocurrencies. The term "blockchain" was first used by Satoshi Nakamoto, a pseudonymous person or entity, in a 2008 paper conceptualizing chronological blocks of data linked through a networked cryptologic chain [12]. The following year, Nakamoto created Bitcoin based on this concept, which is still the most prominent cryptocurrency [4, 12]. Nakamoto's intention of Bitcoin was to create an entity wherein transactions are made without an established intermediary (i.e. banks), which made transactions more transparent and less easily corruptible [12]. Cryptocurrencies have functionalities akin to other currencies but are not tied to nation-states, as fiat currencies like the U.S. Dollar or Euro are [4]. The underlying architecture, blockchain, is able to leverage the capability of a global, open network combined with a cryptologic methodology for generating a secure, trust-less means of exchanging value or information [4, 12].

Since blockchain technology is essentially a database system, it has vast applications across other industries, including product traceability, logistics, and other financial applications [1, 4]. Innovations by subsequent blockchain oriented organizations, such as IBM, the Linux Foundation and the Ethereum Network, quickly developed blockchain platforms with the flexibility to harness blockchain for supply chains [4, 13].

Blockchain technologies are new iterations of an existing concept. Ledgers are an inherent tool of business, and blockchain uses technology to improve on some of the disadvantages of private ledgers, namely by reducing reliance on external institutions in favor of cryptologic proof [4, 12, 13]. In the context of food traceability, blockchain technologies are seen as a formidable tool to enabling whole-chain traceability and transparency rather than the traditional, opaque 1-up, 1-down traceability [17].

With blockchain distributed on a mutually shared network, all stakeholders of a supply chain can be on the same page with traceability information [1]. But more revolutionary is the potential for this information to be available for all segments of the supply chain including end consumers.

What Is Blockchain?

Although the initial iteration of blockchain technologies concentrated on creating non-institutional currency, the technology is essentially a ledger with a wide potential of features, depending on the architecture [1, 4, 13]. For the purpose of this chapter, a *transaction* is any addition or manipulation of information on the blockchain. In food traceability, a food item may undergo an internal transformation and would then be noted on the blockchain. For our purposes, this may still be referred to as a transaction, although no money has exchanged hands.

A blockchain uses hash-based cryptology to assure security and trust [12, 13, 17]. A hash is an encrypted version of a string, or sequence of characters, wherein it is computationally impossible to derive the original without a key [13]. The blockchain has three essential pieces of data: the transaction timestamp, transaction details, and a new hash combining the hash and details of the previous transaction [12, 13]. Each transaction is then distributed throughout the network [12, 13]. Through this process, a continuous encrypted record of the transaction is kept and becomes immutable once added to the blockchain [12, 13].

To verify changes to the blockchain, a resolving algorithm audits the pending transaction after which it is then distributed throughout the network to the shared ledger [4, 12, 13]. Once a transaction has become finalized through this validation process, it becomes a permanent part of the chain [4, 12, 13]. The nodes at which transactions are verified are known as "miners" [4, 12, 13]. Blockchain architectures primarily differ in their choice in resolving algorithms and the degree of openness to miners. Some algorithms prioritize decentralization and anonymity while other prioritize throughput and rapidity [9]. Public blockchains reward miners with tokens, such as Bitcoin or Ether, for performing calculations to resolve new transactions [12].

Users of the blockchain have two keys: private and public. The public key is the means for sending material to a specific individual on the blockchain and publicly verifying their actions. The private key authenticates transactions from the individual holder (Fig. 10.1).

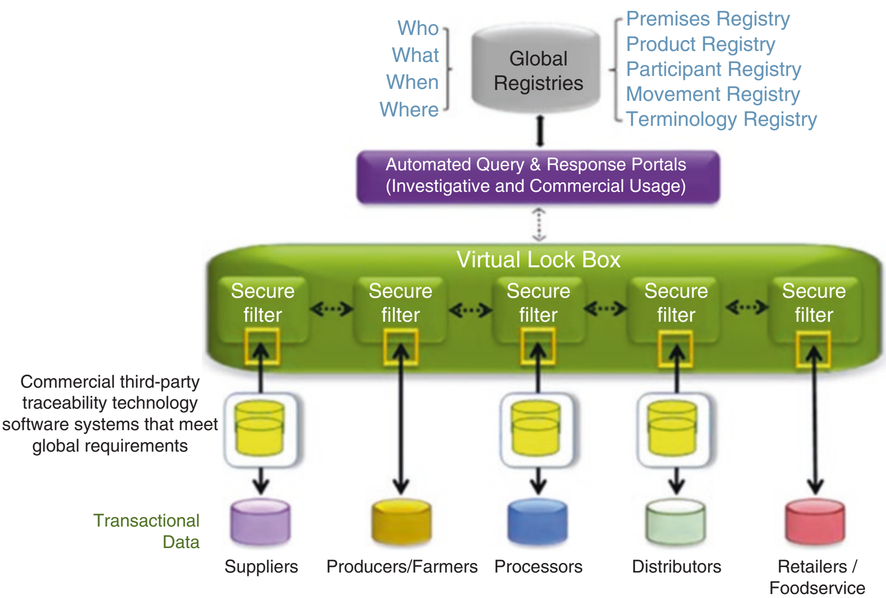

Fig. 10.1 Interoperable architecture in food traceability systems [I1]

Although many blockchain applications have been devoted to cryptocurrency exchange, the framework can theoretically be applied to any scenario requiring assured/verified information, including food supply chains [1, 6]. The technology has heavy interest among diverse sectors, for its ability to rely on peer-to-peer networks rather than centralized institutions [6]. By having a more transparent and decentralized system, companies along the supply chain will be able to input data into the system with a degree of anonymity and control that may spur universal adoption [1, 6]. Data verification derived from its cryptologic structure is another attractive quality of blockchain systems.

Blockchains are epitomized by three major components: cryptology, networks, and computation [12]. The mathematics behind blockchains have existed for some time, but widespread high-speed internet connectivity combined with the general increase in computational power have made it possible for blockchain networks to be feasible [1, 12]. By being distributed among peer-to-peer nodes, it is very difficult to usurp the record among all of them [1, 12, 13]. This makes the record immutable, time-stamped, and secure while being trustless in the system ownership [6, 12]. In food supply chains, the distributed nature of blockchains makes it advantageous for food recalls due to the speed with which information is linked.

The value of blockchain use in traceability systems is predicated on the rapidity of querying the system, the simultaneous capabilities of anonymity and transparency, and the immutable and shared nature of the system. The concern with a centralized system for traceability includes a single point of breakdown, the opacity of such a system, and basis on the trust of the provider [1, 6, 19]. Blockchain has the potential for disparate parts of the food supply chain to input data into a shared ledger that reaches both ends of the market, from producer to consumer [1]. Companies can input traceability information while keeping important proprietary or business-competitive information hidden [3].

As of 2018, supply chain and traceability solutions using blockchain technologies have mostly been explored in pilot studies and early implementation [1]. Several companies have started to explore using open-source blockchain bases, such as Ethereum or IBM's Hyperledger, for usage in supply chains [8, 9, 14]. Some of these pilot studies combine other technologies, such as internet-enabled sensors [2, 17].

Many of the benefits touted for blockchain enabled systems are not necessarily exclusive but are rather attributes of strong traceability systems. By using a distributed system that is not implicitly owned by a particular entity, adopting common Key Data Elements [KDEs] may be easier. However, it is possible to have KDEs that are harmonized across an industry while using more piecewise approaches to data collection and dissemination.

Use Cases for Blockchain in Food Traceability

The use cases for blockchain in food traceability are nearly the same as those for general traceability initiatives, which is a primary reason it is so aggressively being pursued by many industry leaders. Food traceability initiatives and technologies are mainly trying to address five primary use cases: food fraud, food safety and recalls, regulatory compliance, social issues, and consumer information. Blockchain in food traceability has the most utility in food commodities (e.g. produce) and disparate, fractured supply chains (e.g. seafood). The utility of blockchains among vertically integrated operations is diminished due to the ability to leverage existing tools in inventory management to accomplish traceability goals.

Food fraud affects all food sectors and has been steadily growing in interest with improved detection methods and greater traceability information being required and available. Michigan State's Food Fraud Initiative describes food fraud activities as "adulteration, misbranding, tampering, overruns or licensee fraud, theft, diversion, simulation, and counterfeiting" [11]. Though food fraud can be unintentional, economic incentives often lead to food and/or information tampering in the supply chain [6, 10, 17]. Blockchain has been seen as a potential tool for combatting the informational side of food fraud [2, 6]. Because blockchain creates a time-stamped, unalterable, distributed record of transformation, transport and depletion, it enables a more straightforward auditing process to investigate food fraud. Previously, obtaining this information would require some compelling reason, such as a food safety outbreak investigation. A blockchain can much more easily be queried and accessed to authenticate transactions or to find the culprits. A particular use case in food fraud relates to seafood, specifically the sale and consumption of Illegal, Unreported, and Unregulated (IUU) fishing [14]. Vulnerable species and ecosystems are being fished to extinction, and over several decades, international agreements have shaped policy on where and when to appropriately fish certain seafood species [14]. However, it is difficult to have a single or interoperable record accompanying seafood as it goes through the supply chain. There are current efforts to use blockchain to resolve these issues, with Provenance being a prominent example [14]. These efforts combine several emerging technologies, like IoT to help solve several issues at once in combatting seafood fraud [6, 17].

Though food traceability has many aspirational use cases, regulatory compliance is the first consideration when devising a food traceability system [17]. The risk of noncompliance can result in unsellable product, fines, and loss of reputation. As regulatory requirements for traceability of food products increase globally, blockchain has a flexibility that would ease and anticipate them [10, 17].

The use case that blockchain most directly addresses are food recalls and safety. As addressed elsewhere in this book, a foodborne outbreak can eviscerate even the largest companies' reputations. Additionally, the commodity killer effect is well known to the industry wherein consumers lose confidence in a particular type of food across the board even against companies and regions that were unaffected by the outbreak. Blockchain provides a decentralized, but unified framework for tracking food as it goes through the supply chain [1, 7, 17]. To support this ideal of whole-chain traceability from source to retailer, a data architecture must be constructed so that there is low cost to each individual supply chain partner, shared responsibility in data stewardship, straightforward interoperability, and security of the record [17]. Blockchain has all of these characteristics, especially public blockchains, such as Ethereum, where transactions can be batch submitted for pennies, reducing a supplier's (whom most often has lowest margins and least amount of resources for purchasing new technology) financial hurdles to enabling traceability. Interoperability between supply chain partners can still be a challenge, especially if they do not agree upon a common platform. However, data import and export out of blockchains are fairly trivial. And most importantly, the auditability and security of the architecture gives them rapid access to the record and can automate much of the often manual process for recalls.

Social issues in food supply chains have existed for millennia, but the power of data access and dissemination have empowered the opportunity to address them. In food supply chains, there are wide-ranging social issues that are as abhorrent as forced labor and slavery to ensuring labor laws are followed to assuring legality of employment [10]. Mainly, food companies are interested in obtaining more information on their ingredients as globalization increases their suppliers and sources [10]. Though blockchain has more limited value in tracking information that doesn't want to be tracked, the advantage of more information is it gives a starting point to investigating social issues. For instance, seafood has vast problems with forced labor in aquaculture farms. Requiring information assuring legal labor (most likely through an external audit) carrying forward on the product through the blockchain would help address this issue [14].

One of the strongest use cases in the startup space on blockchains is increasing end consumer information on food products. The clean label movement and industry data show that consumers are increasingly concerned with the origin, production, and supply chain of the products they consume. Clean labels accomplish this through assuring certain ingredients or additives weren't used, but mostly it is a marketing tactic. However, it does exemplify the consumer's desire to have information on their product. Smart labels are another instance of increased consumer information [16]. Blockchain, by unifying the ends of the supply chain, can give companies the ability to educate their consumers on their product's origin and production [7, 10].

The use cases for blockchain in food traceability are not limited to these instances only, but to expand on all possible use cases would be an exercise in imagination rather than on the current technological landscape. Other possibilities include combining payment and traceability data or NGO certifications (e.g. Marine Stewardship Council, Rainforest Alliance).

Blockchain Configurations

The most visible blockchain environments are known as public blockchains, which are open for any to participate in, provided that they have tokens to post transactions to the blockchain. Most all cryptocurrencies work as public blockchains, such as Bitcoin or Ethereum. However, consensus and private configurations have been implemented which have different properties [18].

There are competing priorities which determine the efficiency and privacy of blockchains [8, 18]. Blockchains have competing priorities based on the use case. To have a truly decentralized blockchain, access is not restricted and transactions are mined based on awarding a token like Bitcoin or Ether. However, as the blockchain grows, transactions take longer and longer to be completed [10]. For supply chains, it may not be advantageous for any person or entity to participate in the network.

For these reasons, consensus and private blockchains have been developed. These architectures retain some of the desirable features of blockchains: immutability, time stamped, and auditability. However, becoming private or semi-private detracts some of the groundbreaking aspects of blockchain and makes it merely another type of database [10]. For many use cases, that is fine, but it increases costs due to having to maintain central nodes, usually at the behest of the service provider [10]. Reduced is that democratization of data responsibility and deinstitutionalization that blockchain promises.

For food supply chains, not having a truly decentralized blockchain network is not critical [6, 10]. Many of the current implementations of blockchain in the food sector are supplied by vertically integrated, large corporations. They have the resources to contract with a service provider to coordinate, convene and host the trusted nodes of the network. These corporations also have the resources to work directly with supply chain partners to ensure best practices and technologies are adopted to effectively carry out the initiative.

Other food supply chain initiatives using blockchain have consensus configurations. So rather than sole ownership of the blockchain being controlled by one entity, the blockchain is shared among supply chain partners. This shares the responsibility of maintaining or paying for transactions to be added to the blockchain.

When considering whether to keep information "on-chain" or "off-chain", the two main concerns are privacy and performance [10]. The architecture of blockchain applications is optimized for assurance of information and decentralization, and thus has a sacrifice when it comes to uploading and transmitting large files. Additionally, in public blockchains, all transactions are visible, so if supply chain partners wish to share business sensitive traceability information, storing information "off-chain" (i.e. in a more traditional, permissioned database) with some linkage on the blockchain may be more advantageous.

Current Blockchain Environments in Food Traceability

Blockchain architectures differ mainly on the way consensus is arrived when adding transactions to the ledger. The two main environments that will be discussed are the Ethereum network and Hyperledger, as those are the two most advanced and useable blockchains for food supply chains.

The Ethereum network is a blockchain environment with wide-ranging potential applications [5]. Though set up as a public blockchain similar to Bitcoin with a token known as Ether or gas, Ethereum can be used to configure networks and even Decentralized Autonomous Organizations [5]. It was created by Vitalik Buterin as an improvement to the Bitcoin concept. He envisioned a blockchain network on which any conceivable application can be created on it. This was one of the first instance of blockchain being used in supply chains.

IBM and the Linux foundation joined together to create a suite of blockchain applications collectively called Hyperledger [9]. There are currently 5 frameworks of Hyperledger, of which sawtooth and fabric are used most frequently with food supply chains. Hyperledger works differently than the Ethereum network, having different resolving algorithms [9]. It uses a lottery-based system rather than proof of work [9]. Therefore, it is better to be used for consensus or private blockchains rather than as a public system.

To Whole Chain Traceability, Transparency, and Beyond

Blockchain is more than a technology, it is also a movement towards greater transparency in commerce [1, 7, 15]. It is important to keep that in mind because the development of blockchain technologies comes from the area of Financial Technology or Fintech and not supply chain, food or agricultural sectors. There are some ideological divides between those developing base blockchain platforms and those whom wish to use it for business operations [15].

Food and agricultural production are among the oldest human activities. Consequently, there are customs and attitudes around the agricultural sector that may not immediately occur to non-food technologists. Agricultural and food production is often dependent on trade secrets: fishing grounds, production methods, etc.

Smart Contracts

Smart contracts are one of the most transformational aspects of a blockchain data storage strategy versus traditional systems such as ERPs [1, 3]. While the idea of smart contracts is not new, with blockchains being tied to value, the value of smart contracts is self-evident. Contracts rely on the exchange of service or goods for currency or some other value [3]. Smart contracts combine the action and motivation for the business relationship.

Smart contracts are programmed to exact financial transactions and business actions to certain conditions [1, 3]. For instance, paying out a purchase order may be able to be executed on the blockchain with minimal human interaction.

Drawbacks and Challenges

The popularity of blockchain applications has revealed some drawbacks that will need to be addressed before being broadly applicable to industries like logistics or food traceability. One is the inherent compromises that exist in blockchain, such as limited transactions per second, which has created bottlenecks in exchanging information on public blockchains [9, 12, 17]. To scale a public blockchain schema for an industry that processes thousands to millions of transactions a second, these types of bottlenecks are unacceptable [17]. There is also an issue with latency, or the time needed to append a block of data to the chain [17].

As with any technology innovation, interoperability will be instrumental in ensuring implementation. For blockchain, that will mean agreeing on a common platform to be used throughout a given supply chain. After all, blockchain is merely enhancing the existing business and transactional relationships in an industry. There will also still be a need for standardizing KDEs.

As with any new technology, there are bound to be speculative businesses using blockchain technology as a dubious value-added service. For an analogy, e-commerce companies proliferated in the 1990s during the dotcom boom, but many made poor business decisions while too heavily relying on the promises of new technology, an infamous example being pets.com. Therefore, if one is investing in a blockchain technology to enhance traceability, it is important to have healthy skepticism on how effective blockchain is being implemented as a supply chain solution. Be wary of any promises that seem extraordinary. Cryptocurrencies are not strictly necessary to using blockchain in supply chains, so be especially skeptical about companies asking to invest in cryptocurrency.

Digitization and Combination with Other Technologies

Blockchains in supply chains are only the data architecture component. To track goods throughout the supply chain, other technologies are often combined with blockchain to accomplish traceability. As has been stated, blockchains in the fintech sector only had to account for assets that only existed on the blockchain, such as Bitcoins. For recording and accounting for goods in the physical world, other technologies have to exist to cover that “first” or “last” mile [1, 2, 17, 19].

Much of the advantages to blockchain stem from the mere digitization of records. There are still many sectors of food production that heavily rely upon paper-based traceability, and in order to have a blockchain system, a company would first have to digitize these records [1]. Data collection technologies, such as embedded sensors or voice capture, are being used in combination with blockchain to accomplish this [1]. There are also robust efforts to use near field communicator (NCF) tags to authenticate and have a physical presence of the blockchain [2].

Conclusions

Blockchain is not a silver bullet solution, especially to the sector of food traceability. Virtually every venture that is using blockchain technologies is still in its infancy, and there are many factors not dictated by technology that are affecting adoption.

However, the potential for improved traceability by way of increased transparency, interoperability, and deinstitutionalization may prove invaluable to finding solutions among the issues in food traceability.

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