Received: 12 July 2021 | Revised: 1 March 2022 | Accepted: 18 March 2022

DOI: 10.1002/fes3.382

ORIGINAL ARTICLE

Food and Energy Security Open Access WILEY

A technological quality control system for rice supply chain

Qi Tao[1,2] | **Zhenyu Cai**[2] | **Xiaohui Cui**[2]

[1]South China Normal University, Guangdong, China

[2]Key Laboratory of Aerospace Information Security and Trusted Computing, Ministry of Education, School of Cyber Science and Engineering, Wuhan University, Wuhan, China

Correspondence
Xiaohui Cui, Key Laboratory of Aerospace Information Security and Trusted Computing, Ministry of Education, School of Cyber Science and Engineering, Wuhan University, Wuhan 430072, China.
Email: xcui@whu.edu.cn

Funding information
The authors would like to acknowledge the support provided by the National Key R & D Program of China (No. 2018YFC1604000)

Abstract

Rice quality affects social stability, consumer health, and corporate brand benefit. The traditional supply chain traceability management system is centralized, monopolized, asymmetric, and opaque. It is the main factor leading to frequent food safety incidents. This paper proposes a technological quality control system for rice supply chain to protect rice products quality and safety. Firstly, it adopts risk assessment and traceability mechanism to prevent the hazard factors in the production and processing. Then, to prevent spoiled food from endangering the consumers' health and reduce food waste, it explores a shelf life model of rice products to predict the remaining shelf life of products. Finally, this paper constructs a decentralized traceability management system based on blockchain and IoT, which enables consumers to access the real information of rice products and helps supervisors to monitor the quality of products in the supply chain.

KEYWORDS

rice quality and safety, rice supply chain, risk control, shelf life, traceability

1 | INTRODUCTION

Rice is the grain that feeds more than half of the world population (Fukagawa & Ziska, 2019). A lot of rice varieties of different species exist with yields ranging from 1–3 ton/ha to 5 ton/ha (Abraham et al., 2016). Since the Japanese nuclear power plant leaked radioactive material in 2011 (WHO, 2014), many countries have imposed strict food controls on their food trade relations with Japan. Nearly, 7 million people in Europe suffer from foodborne diseases every year (Saltini & Akkerman, 2012). Food quality will affect the reputation and market value of enterprises (Cleeren et al., 2017; Kong et al., 2019). Both consumers and food companies would benefit from faster response times to food scandals and outbreaks of foodborne illnesses (Astill et al., 2019). But food safety incidents are slow to be handled due to low transparency and inefficient batch sorting, which leads to an inability to trace food items in the supply chain (Sarpong, 2014). The complexity and dynamics of rice supply chains is an important challenge to ensure food quality (Behnke & Janssen, 2020). Traceability has become critical in food supply chains as consumers expect higher levels for food safety (Tayal et al., 2020).

Some countries, such as the United States (He, 2018) and Finland (Lundén et al., 2021), have taken food quality and safety control (*from production to sales*) as a national strategy and established food quality traceability systems as shown in Table 1. It could help to ensure food safety and quality, as food is a perishable product and foodborne illnesses can originate from mishandling anywhere in a supply chain (Lucena et al., 2018). The traditional traceability systems applied to agricultural supply chains are centralized, monopolistic, asymmetric, and opaque,

TABLE 1 Traceability system in countries around the world

System name	Food	Nation	Features
Livestock traceability system[a]	Cow	Australia	Traceability by an electronic eartag; Data are stored in a central database;
Food traceability system for import and export[b]	Food	South Korea	Traceability by a food trace number; Central database;
Livestock identification and traceability system[c]	Cow	England	It belongs to a UK government department; Animal management;
Animal Traceability System[d]	Animal	United States	Traceability by animal ID; Full chain traceability and archiving system; A global database;
Animal Labeling Traceability System[e]	Sheep	New Zealand	Traceability by visual ID; Data in a central database;

[a]https://www.nlis.com.au/.

[b]https://www.tfood.go.kr/tfweb/FtmsMain.do.

[c]https://secure.services.defra.gov.uk/wps/portal/ctso.

[d]https://www.scoringag.com/scoringag/3/index.cfm?sfa=main.main.

[e]https://www.nait.co.nz.

leading to serious trust crisis (Xie & Xiao, 2021). In the past decades, a series of food safety risk events and scandals, such as mad cow disease (Berg, 2004), horse meat scandal (Premanandh, 2013), toxic milk powder (Xiao-Jin et al., 2015), and gutter oil (Li et al., 2016), have broken consumers' confidence (Liu & Ma, 2016). Trust is one of the most important factors when consumers purchase food (Kriegesteffen et al., 2010). Consumers are in urgent need of detailed information about foods from farm to fork (Gunst & Roodenburg, 2020; Lareke, 2007). There exist some problems to be solved: (1) How to build trust, transparency, and complete traceability system in the food supply chain (Caro et al., 2018); (2) How to meet consumers' expectations for food quality and safety (Bumbudsanpharoke & Ko, 2015).

Walmart constructed a modern traceability system based on blockchain technology to trace the food in North America (Sharma & Kumar, 2021). It helps Walmart to reduce time for tracking the origin of a specific food from seven days to 2.2 s (Kamath, 2018). Blockchain technology helped food company to create greater transparency, veracity, and trust in its food information (Kramer et al., 2021). Being built on a decentralized and distributed database (Tao et al., 2019), blockchain enhances transparency, accountability, trust, and traceability in supply chains (Tao, Chen, et al., 2021; Yiannas, 2021). The main advantage of blockchain technology is that transaction records are permanently recorded in data blocks and cannot be tampered with (Kumar & Mallick, 2018; Sun et al., 2016). Huang et al. (González-Amarillo et al., 2018; Huang et al., 2019) proposed a food traceability system based on RFID (Radio-Frequency Identification) and blockchain for helping markets to enhance food quality and safety. In their system, the RFID was used to collect and share data in the system, and blockchain technology was used to ensure the reliability and authenticity of shared data. Storøy et al. (2013) proposed a TraceFood method for exchanging trace information between systems. *Tian* (Tian, 2017) investigated a traceability system based on blockchain, IoT and HACCP (Hazard Analysis and Critical Control Point). In the proposed system, HACCP was used to prevent the occurrence of food risk, and massive real-time data are shared to each supply chain partner safely and efficiently based on blockchain and IoT. Biswas et al. (2017) proposed a blockchain-based traceability system in the wine supply chain, where each transaction is recorded as a data block that is visible to any participator in the system. System user can trace the wine's history information by the product ID. However, their work is only a study example, rather than a practical application of blockchain technology in wine. The application of blockchain technology in food is still in its infancy (Westerlund & Soham Nene, 2021). And there are few of comprehensive research schemes for guarantying the products quality and safety in rice supply chain (Xie & Xiao, 2021).

To protect rice quality and safety, we propose a technological quality control system for rice supply chain. The main work of this paper is concluded as follows:

- It constructed a risk assessment and traceability mechanism for hazardous factor, and discovered the potential risk factor in advance according to the quality and safety information in the rice supply chain.
- Combining Arrhenius model and Q_{10} model, it explored a shelf life model for rice products to predict the residual shelf life of products, which would help to reduce food waste. According to the shelf life of products, optimization of storage management and transportation routes

can help enterprises to prevent food spoilage (Scalia et al., 2017; Sharp & Timme, 1986).

- It constructed a traceability management system based on blockchain and IoT to prevent the risk of data tampering, and optimize the efficiency of product traceability and inferior product recall. In the system, the IoT devices (RFID and temperature sensor) are used to automatic collect and share data in each link of supply chain. Blockchain technology (consensus and smart contract) is used to achieve transparent data sharing and guarantee data reliability and integrity.

1.1 | The current status of agricultural economics

International trade in food accounts for 10% of total food sales, and the globalization of trade let the food to travel distance from farm to fork than ever before (Julian et al., 2010). Traceability is helpful to increase consumer confidence in food, and consumers regard verifiable evidence of traceability as an important criterion for the food quality and safety (Alfaro & Rábade, 2009).

Food quality risk control involves every link from raw materials to food retail, because risk incidents may be caused at any link in the food supply chain. Any food has a shelf life. Many illnesses are caused by spoiled food. Food spoilage is not only wasteful, but also adversely affects trade and consumer confidence. Food waste occurs throughout the food supply chain, from farm to fork (Parfitt et al., 2010). Reducing food waste minimizes the environmental impact of agriculture on climate, biodiversity, soil, water, and atmosphere. According to the International Institute of Refrigeration (IIR), about 300 million tons of agricultural products are wasted each year worldwide due to spoilage. In the United States, the food industry discards $35 billion worth of spoiled products each year (Flores & Tanner, 2008). Globally, the incidence of foodborne diseases is increasing (CAC, 2013). Unsafe food causes many illnesses such as diarrhoea and cancer. World Health Organization (WHO, 2015) estimated that foodborne and waterborne diarrhoeal diseases cause about 2 million deaths every year. More than 85000 cases of salmonellosis are reported in the EU each year, at a cost of 3 billion euros (WHO, 2015). Foodborne diseases not only seriously affect people's health, but also have affect economic consequences for individuals, families, communities, businesses, and countries. In 2010, *Robert L. Scharff*, an US Food and Drug Administration (FDA) economist, estimated that the overall national economic impact of foodborne illness totaled $152 billion per year (Scharff, 2010). As the consequence of food scandals and safety incidents, consumers demand high-quality food with safety assurance and transparency. Product quality and safety affect consumers' confidence in enterprises, and traceability of products can improve consumer confidence in product supply chain. The traceability scheme from farm to fork has become an important part of the product quality assurance system, which is helpful to rebuild public confidence in the product supply chain (Opara, 2003). A good traceability system helps to minimize the production and circulation of poor-quality products, which would minimize the economic losses caused by product recall (Aung & Chang, 2014).

It is a challenge to ensure food quality and traceability in agricultural supply chain. The researches (Pappa et al., 2018) showed that the application of blockchain technology could improve product quality by enhancing process transparency and efficiency in the agri-food industry. In particular, existing studies (Saurabh & Dey, 2021) have demonstrated the feasibility and practicability of blockchain technology in agricultural supply chain. Blockchain technology is useful to improve product tracking. The Mango and pork value Chain management system from Wal-Mart Corporation implemented product traceability based on blockchain and bar code technology (Kamath, 2018), where the system not only reduced product traceability time from 7 days to 2.2 s, but also improved supply chain transparency and efficiency. Kumar and Iyengar (2017) proposed a blockchain-based traceability system for rice value chains to monitor the quality of rice in transit. Carbone et al. (2018) designed a transparent and secure supply chain system based on blockchain and IoT, where it could obtain real-time air temperature, humidity, and soil moisture information. In agriculture, monitoring crop growth-based IoT devices would improve water efficiency, and monitoring greenhouse gas emissions such as carbon dioxide, methane, or hydrocarbons through sensor technology helps to promote environmental sustainability (Iqbal & Butt, 2020). Although blockchain technology has broad prospects in the agri-food supply chain, its application is still in the preliminary stage.

1.2 | Organization

The rest of this paper is as follows: Section 2 introduces a transparent rice supply chain, and rice product quality management. Section 3 introduces the construction of a risk assessment and traceability mechanism for hazard factors. Section 4 describes a shelf life model for rice products to manage the product quality. Section 5 describes a traceability management system based on blockchain technology and IoT. The conclusion and future work are in Section 6.

2 | PRELIMINARIES

It will introduce the rice supply chain, blockchain technology, and IoT technology. Then a rice product quality management method is described.

2.1 | A transparent rice supply chain

In the rice supply chain, the main participants are raw material suppliers, manufacturers, distributors, sellers, and consumers (Biswas et al., 2017; Caro et al., 2018). As the core role of the supply chain, rice manufacturers manage the most of supply chain information based on logistics by integrating upstream growers and the downstream sales departments (Talib et al., 2013). However, the enterprises in the rice supply chain have independent business systems, which only focus on the data and business processing in their respective fields. Due to the lack of unified system standard and data storage standard, it is difficult to share information among different enterprises, which seriously affects the information supervision and traceability of the rice supply chain (Farahmand & Farahmand, 2013).

Combining with the previous work (Biswas et al., 2017; Caro et al., 2018; Qi & Cui Xiaohui, 2018), we selected the main links of rice supply chain as shown in Figure 1, including planting, harvesting, drying, storage, processing, logistics, and consumption. The data of each link are stored in database. It mainly includes the material properties data (*the main ingredient composition and content of the key risk factors*), environmental data (*sanitary condition, temperature, humidity, et al.*), additive data (*product name, ingredients, inventory, et al.*), the control data (*technical parameters, temperature, concentration, et al.*), and other data (*time, location, batch, ID number, et al.*), and management data (*responsible person, management system, implementation standards, et al.*).

To construct a traceability management system, it should construct a transparent rice supply chain to share data (Tian, 2017). So, it needs to collect the data of each link based on IoT sensors. And, data collection for some nodes is shown in Figure 2. Then, it needs a transparent shared database to store data.

Collecting the data by IoT sensors can prevent data falsification and ensure data accuracy in the rice supply chain (Antonucci et al., 2019). IoT sensors enable each node in rice supply chain to track materials and environments in real time. The application of blockchain technology in the IoT industry is rising, as it derives from security and tracking of products (Antonucci et al., 2019). RFID is a wireless identification sensor in IoT (Zhou et al., 2016). With the development and application of RFID, the RFID tag technology is more standardized (Choi & Roh, 2006). RFID is normally used as a data carrier to establish a unique identification label for products to record the supply chain information (Stevenson, 2010; Tao, Ding, et al., 2021; Tian, 2017). Compared with QR code and Bar code, RFID has the advantages of waterproof, anti-interference, high temperature resistance, large storage capacity, and the rapid acquisition in real-time (Tian, 2016). Under the coverage of the wireless network, the RFID system can transmit the product-related data into the database, so as to realize real-time information acquisition and abnormal data alarm. The workflow of RFID is shown in Figure 3.

Blockchain is a distributed ledger system with the characteristics of transparent, consensus, decentralized, and tamper-proof (Yiannas, 2021). It ensures the reliable transactions of multi-parties and facilitates transparent data sharing (Tao, Chen, et al., 2021). It can be used as electronic forensics for transactions based on digital signatures algorithm (Zhou et al., 2003). smart contract is an intelligent and self-executing logic code, which can automatically execute the agreement between the two parties.

The participant, from the vendor to the consumer, can track and verify specific goods. The transactions are stored into data block based on Merkle tree as shown in Figure 4. The Version Number of data block is used to store version information for this block. The Previous Block Hash of data block stores the hash value of the front block. The Time stamp of data block stores the block generation time, ensuring the data is not tampered with.

2.2 | Rice product quality management

The market has more competition, product quality is an important way to improve the market advantage of enterprises (Paiva, 2013). According to the analysis of rice supply chain by the method of AHP (Analytic Hierarchy Process), it discovered that the main factors affecting

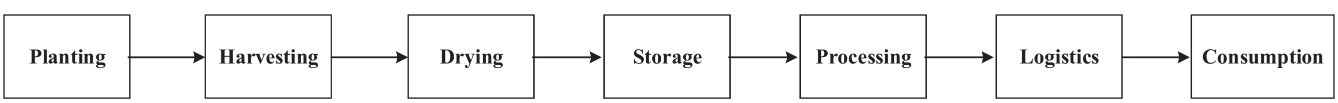


FIGURE 1 The main links of rice supply chain

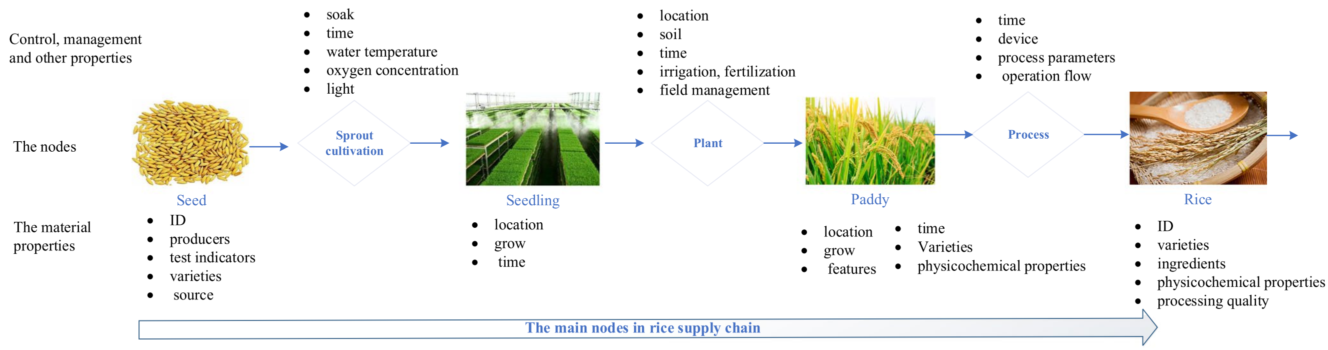
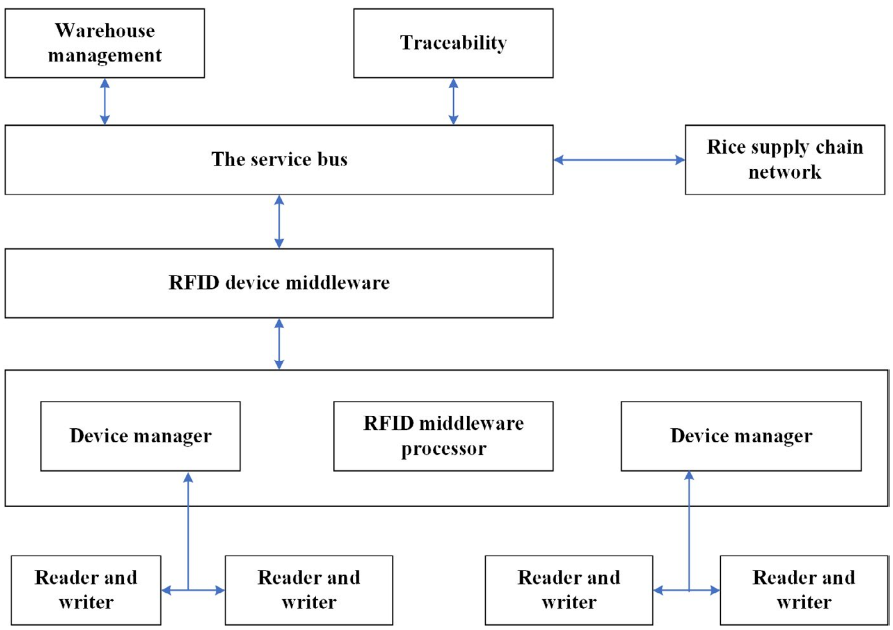


FIGURE 2 The main nodes information in rice supply chain

FIGURE 3 The workflow of RFID device



the quality of rice products were raw material, production process and circulation (Su et al., 2012). Based on the measures for the administration of sampling inspection of food safety (http://www.samr.gov.cn/spcjs/cjjc/qtwj/201908/t20190819_306097.html), a rice product quality management framework is constructed as shown in Figure 5. It is used to control the products quality in the production and processing, which includes production quality control, quality inspection requirement management, quality inspection process management, and quality inspection results disposal.

- **Production quality control**. Based on real-time process parameters, production operation specifications and raw material information in the production and processing, a rice product quality model is established to preliminarily evaluate the rice product quality (Su et al., 2012). Based on the national rice quality standards (https://www.renrendoc.com/paper/102345823.html), it can optimize the production process parameters in real time and improve the product quality.
- **Quality inspection requirement management**. It includes enterprise samples report for inspection, sampling inspection by government regulatory agencies, consumer complaints, and enterprise proved itself innocent. Then the rice products will enter the quality inspection process management and social crowdsourcing supervision.
- **Quality inspection process management**. Based on the food safety inspection measures (http://www.samr.gov.cn/spcjs/cjjc/qtwj/201908/t20190819_306097.html), it should establish a qualitative inspector library. Assign quality inspectors intelligently based on distance, inspection cost, product type and other factors, and retain the evidence of quality inspection process, including physical evidence (*such as samples submitted for inspection*) and electronic evidence (*such as key pictures reflecting the quality inspection process*, *quality inspection report*).
- **Quality inspection results disposal**. Based on the national laws (http://scjg.shangluo.gov.cn/post/5df9c05f2fa5e8505bd95155/5de77b5ba345d24b10381f24) and

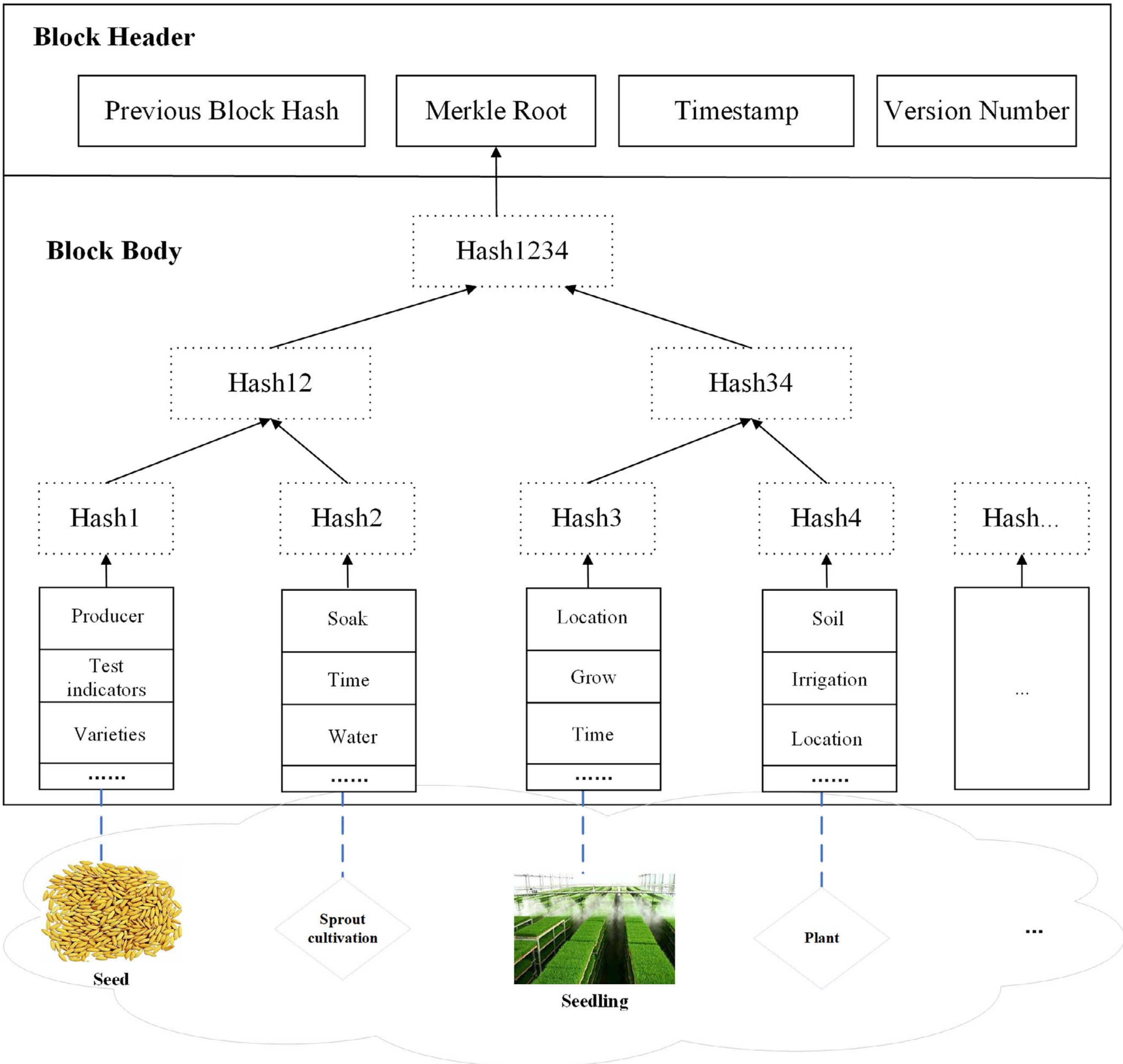


FIGURE 4 The data block structure model

regulations (http://std.samr.gov.cn/gb/search/gbDetailed?id=C3386C490C908B79E05397BE0A0AC288; http://std.samr.gov.cn/db/search/stdDBDetailed?id=C362C05F3E50A68DE05397BE0A0A9B00) on rice products quality and safety, regulator required manufacturers to compensate consumers and rectify the process parameters. If there is any objection to the quality inspection report, the manufacturer can apply to obtain the retained evidence of the quality inspection process to verify the results. After the production rectification, the manufacturer can apply for quality inspection again.

3 | RISK ASSESSMENT AND TRACEABILITY MECHANISM FOR HAZARD FACTORS

Hazard factors of rice products mainly come from raw materials, environment, and production operation (http://qikan.cqvip.com/Qikan/Article/Detail?id=7104794992). The quality of raw materials determines the rice product quality. **The raw material risk factor** is that quality problems of finished products caused by quality problems of raw materials. In the production and processing, if the manufacturer ignores the quality control

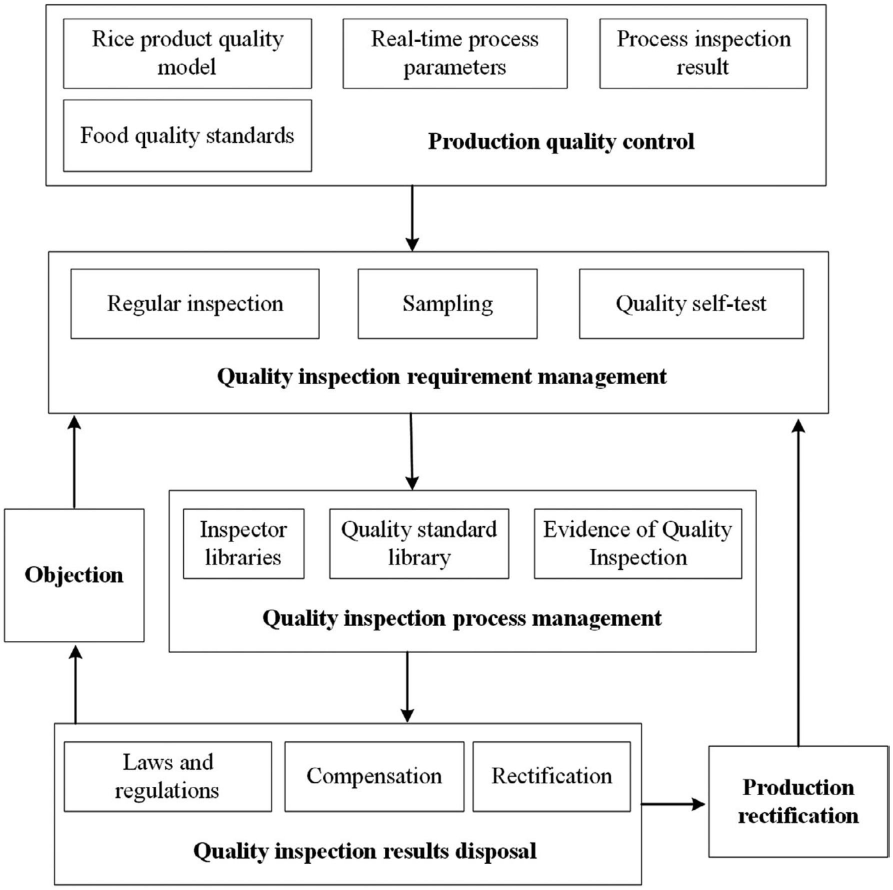


FIGURE 5 The workflow of rice product quality management

of raw materials, it may lead to the quality and safety risks of rice products due to the unqualified quality of raw materials. **The environmental risk factor** is caused by uncertain hazard factors in food production and processing environment. Environment factors such as temperature, humidity, water quality, and air quality may affect the products quality. Excessive storage temperature will lead to deterioration of raw materials (Zhou et al., 2016). In addition, some social environment factors, such as environmental hygiene, plant layout, business management, may affect product quality. Due to the unreasonable layout of the production plant, the material circulation is not smooth, resulting in material accumulation and deterioration. **The production operation risk factor** is caused by non-standard operation behavior in the process of product production. For example, in high temperature production environment, it is possible to produce toxic hazard factors such as acrylamide (Mitsuru, 2015).

Recently, the quality and safety control of rice products is mainly completed by sampling and testing the hazard factors of the finished products. But, there has problems such as long sampling and testing cycle, untimely detection of hazard risk and high potential risk of food safety. Therefore, this paper proposed a risk assessment and traceability mechanism to discover the potential hazard factor based on the quality and safety information in the rice supply chain, as shown in Figure 6. The mechanism includes hazard factors identification, hazard degree prediction, risk assessment and warning, and tracking and discovery of potential hazard factors. It realizes the automatic control of food safety risks, which is conductive to the discovery of potential risk factors. The specific operate steps include: identify sampling nodes and material input points, risk assessment, risk warning, track and discover the hazard point, and hazard risk disposal.

- The hazard factors in the sampling nodes were identified and the hazard degree was evaluated based on a rice product quality model (as shown in Section 2.2).
- According to the hazard degree and risk assessment results, it will prompt whether risk warnings such as hazard risk interception and disposal are necessary.
- It will determine whether risk management is necessary based on the results of risk assessment. If the hazard risk needs to be dealt with, it will track the hazard risk point in rice supply chain.
- Risk factor of the hazard risk point should be adjusted to a safe range according to the national food safety standards.

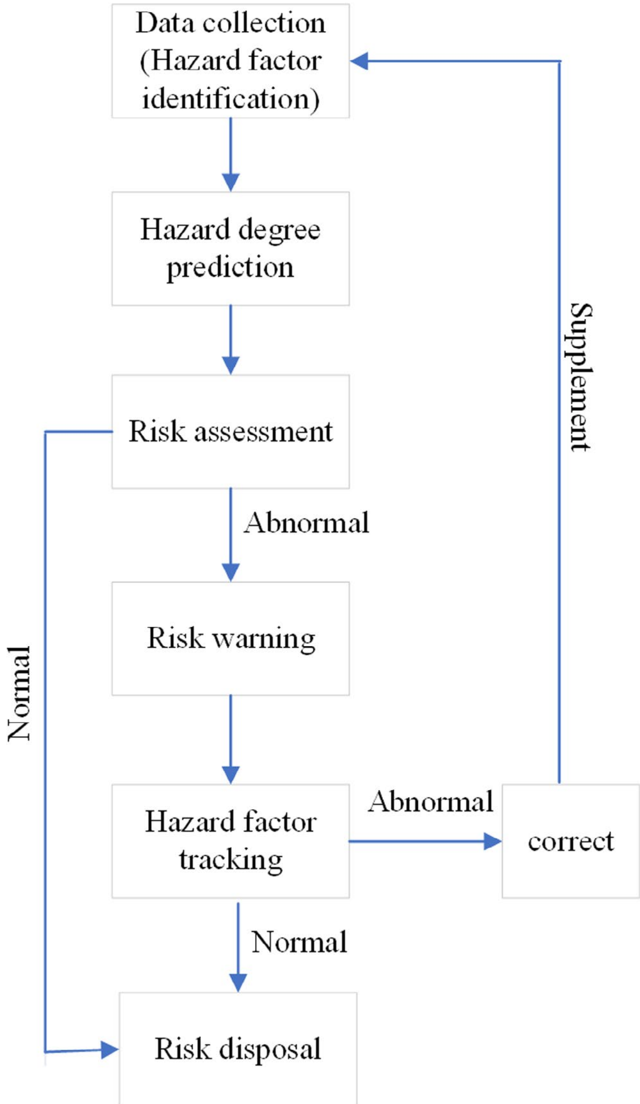


FIGURE 6 Risk assessment and correction mechanism for hazard factors

4 | QUALITY CONTROL OF RICE PRODUCT BASED ON SHELF LIFE MODEL

Physicochemical features such as hardness, stickiness, non-estesterified fatty acid, and appearance of rice products were always changed (Wiset et al., 2011). It is affected by storage conditions such as storage temperature and storage time (Zhou et al., 2003). The quality of rice products changes greatly at different temperatures. The optimal dates of milled rice stored at 25 and 5°C were 1 and 7 months, respectively (Yokoe, 2008). Rice spoilage first appears on a chemical level (Saikrishna et al., 2018). Aged rice is usually distinguished based on the features of texture, viscosity, and thermal properties (Mukprasirt et al., 2010), in which the texture features are rice grain adhesion, hardness, tooth tension, roughness, grain size, and looseness. These features are mainly affected by storage temperature and storage period, while the storage period of rice product is affected by storage temperature, as shown in Table 2.

In the rice product processing and storage, the change of product quality usually conforms to the zero-order reaction kinetics and first-order reaction kinetics (Labuza et al., 1978). The zero-order reaction kinetics is:

$$A = A_0 + kt \tag{1}$$

and first-order reaction kinetics is:

$$lnA = lnA_0 + kt \tag{2}$$

In the first-order reaction kinetics equation, it can reflect the relationship between the change of storage quality index and time t, where A_0 and A are the physicochemical characteristic of samples before storage and on the t day of storage, respectively; t is the storage time of the sample;k is a rate constant of quality change that can be estimated based on the sample data (A_0, A, t) via the least squares method using the Curve Fitting Toolbox of Matlab (https://it.mathworks.com/matlabcentral/fileexchange/10176-ezyfit-2-44).

Arrhenius model is widely used to predict lipid oxidation, Maillard reaction and protein denaturation (Kilcast, 2000).

$$k = k_0 \exp\left(-E_a/\mathrm{RT}\right) \tag{3}$$

The Arrhenius model can reflect the dependence of growth rate (k) on temperature (T) by the growth curve. The parameter k_0 is a frequency factor; R is gas constant (8.3144 J/mol·K); E_a is an activation energy (kJ/mol), which is a temperature sensitivity of the growth rate. When other conditions are the same, the higher the ambient temperature, the faster the deterioration of food. However, Q_{10} model is a food temperature sensitivity model that is mainly used to describe the impact of temperature on food shelf life (Choi et al., 2017).

$$Q_{10}^{(t_0-t)/10} = Q_s(\alpha)/Q_s(\alpha_0) \tag{4}$$

where Q_s is product shelf life (d); α is an experiential temperature of shelf life; α_0 is the target temperature of shelf life.

Q_{10} model is usually combined with Arrhenius model to improve the accuracy of food shelf life prediction. So, combination of Arrhenius Equation (3) and Q_{10} Equation (4), the effect of temperature on the rice product shelf life is as follows.

$$Q_{10} = \exp\left(10E_a/(\mathrm{RT}+10)\right) \tag{5}$$

TABLE 2 Analysis of influencing factors of rice quality

Influencing factors	Reasons	Researches
Longer storage (>16 months) of milled rice at 4 and 37°C results in decrease in peak viscosity and breakdown.	It has been attributed to the interaction between starch and non-starch components.	Zhou et al. (2003)
A significant increase in peak viscosity of rice during storage period of more than 4 months at 40°C.	This increase in peak viscosity was due to a decrease in α-amylase activity in rice grains.	Park et al. (2012)
The stored rice at 29°C for 6 months produced harder gels of higher viscosity, compared with starch from rice stored at 2°C.	Storage temperature changed the amylograph viscosity curve of starch paste of rice.	Zhou et al. (2016); Sodhi et al. (2010); Villareal et al. (2010)
Peak viscosity and setback of rice flour increased during storage period of 4 months at 25°C.	The setback increased during the storage period.	Wiset et al. (2011)
The best storage periods of milled rice at 25 and 5°C were 1 and 7 months, respectively.	The higher the temperature, the greater the quality degradation.	Yokoe (2008)
The stability of brown rice during storage can be improved through drying using infrared heating to temperature of 60°C followed by tempering for 4 h.	It could effectively inactivate lipase and improve the long-term storage stability of brown rice.	Ding et al. (2015)

The Equation (5) reflects the relationship between temperature and shelf life, where the shelf life of product at time T is calculated as follows:

1. k_0 can be calculated by the least squares method with sample data at different time in Equation (2);
2. Then, take k_0 into Equation (3), E_a can be calculated by regression analysis based on the sample data;
3. Take E_a into Equation (5), and calculate the shelf life of product at time T.

5 | TRACEABILITY MANAGEMENT SYSTEM BASED ON BLOCKCHAIN AND IOT

This paper proposed a rice supply chain traceability management system based on block chain and IoT, which avoided manual intervention on data and prevented the risk of data fraud. In the system, the combination of the IoT and blockchain technology helps to improve the level of system automation, optimize the efficiency of product traceability and inferior product recall, and reduce the cost of supply chain management. The following section focus on the discussion of the system model and its functions.

5.1 | System model

The traceability and quality control system in rice supply chain is mainly data collection module, data management network module, and application service module, as shown in Figure 7. Each node in the rice supply chain contains a large amount of data (*material data*, *management data*, *media data*). These data are collected by the data collection module (*IoT sensor devices*, *RFID*, *computers*, *mobile phones*, *and web crawlers*) and then uploaded to the data management network after data processing.

Data management network module uses a dual-mode storage mechanism based on consortium blockchain and traditional database (*MySQL database and Oracle database*). The uploaded data are checked and broadcast by invoking a smart contract deployed in the blockchain network. Each service node in the blockchain network makes consensus on the data, which is then converted into a digital digest by hash algorithm. The digital digest is packaged into a data block (as shown in Figure 4) and stored in a distributed ledger. At the same time, the data in the supply chain, and the mapping relationship between the data block and uploaded data, are stored in the traditional database.

Application service module is a comprehensive application based on the data collection module and data management network module. It mainly serves the consumers, production enterprises, and supervisors. System users can use corresponding function based on their roles in the module, such as consumers can trace products details (*manufacturer*, *planting information of raw material*, *logistics information*, et al.), enterprises can manage their products (analysis of sales performance of different products in different regions and different seasons), and supervisors can monitor the supply chain in real time (*product risk assessment and risk warning*). Smart contracts are used to monitor the mapping between distributed ledgers of blockchain and traditional databases to prevent data tampering.

5.2 | Product traceability

Smart contract is a digital protocol that supports content verification and automated execution. By setting execution conditions with smart contract, it provides information exchange and value transfer services for system users in the blockchain network (Tao et al., 2019). When the uploaded data from the service node in the supply chain meets the trigger conditions, the system will automatically invoke the related function in the smart contract, which can realize the intelligent monitoring of rice products in each link of supply chain.

Data collection devices (*sensors*, *mobile phone*, *barcode hand scanner*, et al.) are connected to the blockchain network through the device API interface. The preset response conditions of the smart contract are defined according to national rice industry standards. Consensus algorithm is adopted by the system service node to verify the data and transaction information submitted in the supply chain. Once the data are invalid, the smart contract will automatically trigger an alarm and send the alarm information to the enterprise and the supervisor. As shown in Figure 8, according to the national standard of milled rice (GB/T1354-2018; https://max.book118.com/html/2018/1225/6004005115001241.shtm), the preset response conditions in the smart contract are moisture content of japonica rice <15.1%, yellow rice <1%, broken rice <15%, impurities <0.4%. If the rice data through the current service node meet the preset response conditions, the rice product can flow into the next link of the supply chain; Otherwise, the system will prompt risk warning, and track the alarm source.

Due to the limitation of the length of the article, it selects some links to describe the working process of the traceability management system as follows.

- **Planting link**. The main role of this link is the farm. It selects the rice seed. The seed information, such as

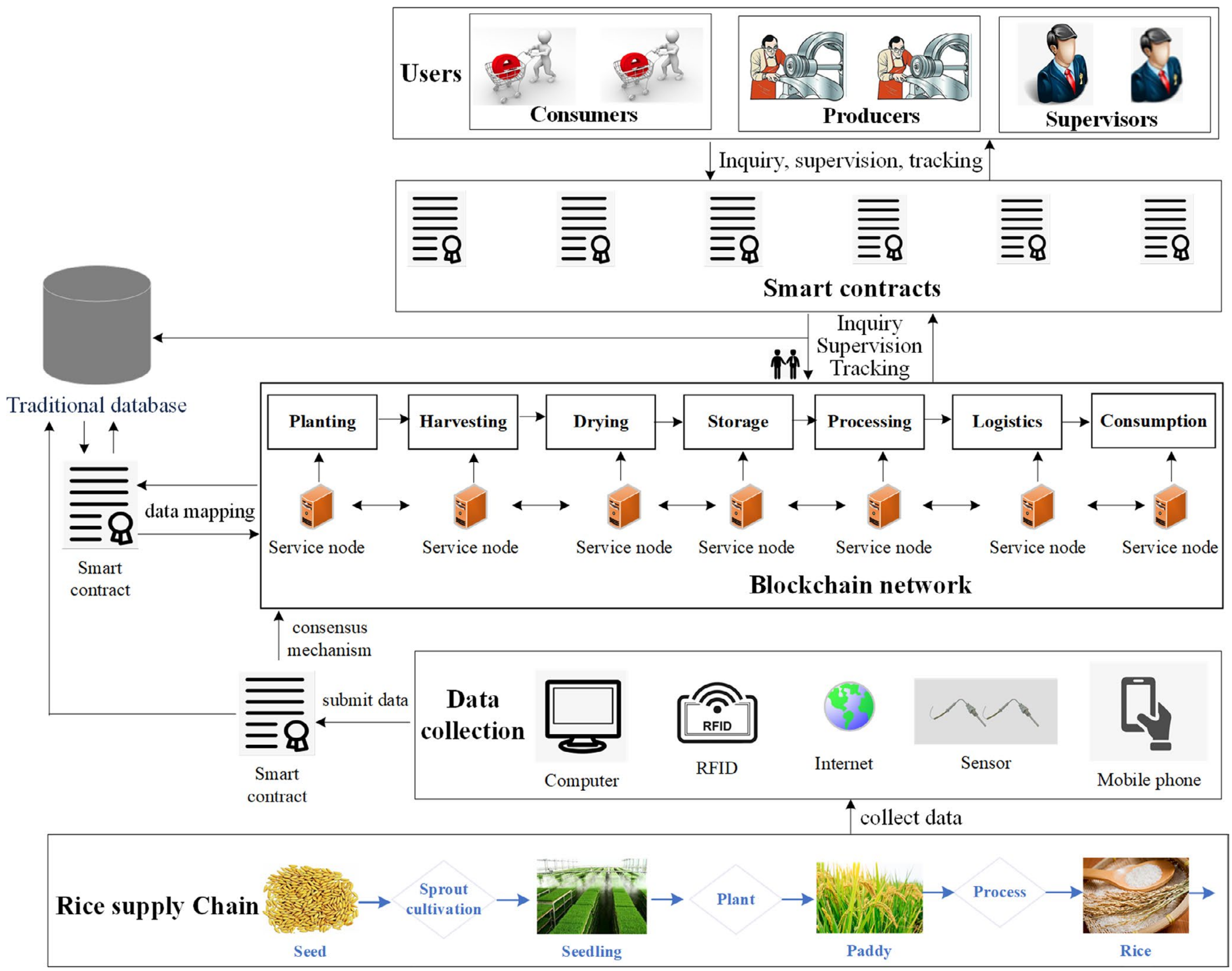


FIGURE 7 System model

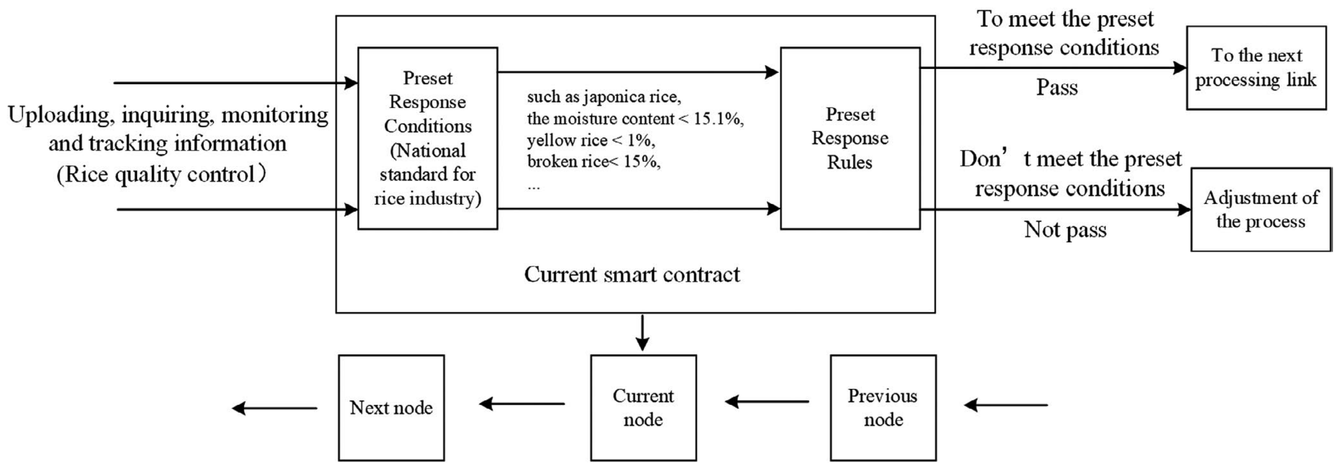


FIGURE 8 The tracking information management by smart contract

variety and source, is recorded in the blockchain. And, the system will automatically create a rice product data block chain as shown in Figure 4. The planting information also needs to be input into data blocks, including farm information (farm address, the name and contact detail of the farm manager), fertilizing information (the source, type, dosage, and use time of fertilizer), pesticide information (the source, type, dosage, and use time of pesticide), water quality, and soil PH. If the rice is sold to the next link (for example, the storage node S1), the farm node will initiate a trade request. While the system creates a smart contract containing the trade request and the node S1. If the trade is done, node S1 is responsible for the tracking and maintenance of rice product information. In addition, the rice quality needs to meet the national rice quality standards, so the regulators also should take part in this link. The supervisors have the right to spot check and ensure the rice quality. The spot check information of the rice also be recorded into the blockchain.

- **Storage link**. The main role is the storage. After receiving rice from the planting node, the storage node S1 maintains the data block chain of the rice product. It collects the data such as warehouse address, warehouse capacity, conservation and storage methods, responsible person, and storage temperature. Based on the collected data, the remaining shelf life of products could be predicted and informed to stakeholders.
- **Processing link**. The primary role is the rice products manufacturer. After receiving rice from the storage node S1, the manufacturer M1 is responsible for the maintaining the data block chain. It collects the processing information, including the raw material information, production standard, ingredients, product name, the shelf life and expiration of the product, product quality, product batch, nutrients, product identification number, responsible person, and the enterprise information. Supervisors will also participate in product sampling inspection to ensure the product quality. The system would record the sampling inspection information such as inspection agency, inspector, product, inspection results and time. According to the risk assessment and traceability mechanism, smart contracts are designed to assess the degree of risk based on the collected data. If the risk is abnormal, the risk warning will be sent to the manufacturer M1.
- **Consumption link**. The primary role is the retailer. The retailer can access the product source information based on the data block chain. In addition, to ensures the integrity of the product data block chain, the retailer needs to record the selling time and price of the product into the system. Regulators can participate in product sampling inspection to ensure the product quality. The sampling inspection information (inspection agency, inspector, product, inspection results and time) would be recorded into the blockchain.
- **Traceability**. The primary role is consumer and regulator. When consumers buy a rice product, they access the product information by scanning the food package code. When a food safety incident occurs, regulators can quickly determine the source of the incident by reviewing the entire process of the product from farm to fork. And accurately recall the product through detailed logistics distribution information in the system.

6 | CONCLUSIONS AND FUTURE WORK

This paper proposed a risk assessment and traceability method for hazard factor to track and deal with the risk point. It explored a shelf life model for rice product to predict the residual shelf life. Combining the characteristics of blockchain and IoT, we constructed a traceability management system in rice supply chain. The system automatically collected data by IoT devices and shared data in each link of the rice supply chain. Consumers could access the real quality information of rice products, and regulators could monitor the full supply chain.

In the future work, the system needs to be further optimized with application. In addition, combine blockchain technology with big data to explore a novel data platform for rice supply chain and help promote the healthy and sustainable development of rice industry.

CONFLICT OF INTEREST

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

AUTHOR CONTRIBUTIONS

Conceptualization and Investigation Tao Q.; Software, Cai Z.; Writing—original draft, Tao Q.; Writing—review and editing, Tao Q., and Cui X. All authors have read and agreed to the published version of the manuscript.

ORCID

Qi Tao https://orcid.org/0000-0002-8715-6969
Xiaohui Cui https://orcid.org/0000-0001-6079-009X

REFERENCES

Abraham, A., Mathew, A. K., Sindhu, R., Pandey, A., & Binod, P. (2016). Potential of rice straw for bio-refining: An overview. *Bioresource Technology*, 29–36. https://doi.org/10.1016/j.biortech.2016.04.011

Alfaro, J. A., & Rábade, L. A. (2009). Traceability as a strategic tool to improve inventory management: a case study in the food industry. *International Journal of Production Economics*, *118*(1), 104–110. https://doi.org/10.1016/j.ijpe.2008.08.030

Antonucci, F., Figorilli, S., Costa, C., Pallottino, F., & Menesatti, P. (2019). A review on blockchain applications in the agri-food sector. *Journal of the Science of Food and Agriculture*, *99*(14), 6129–6138. https://doi.org/10.1002/jsfa.9912

Astill, J., Dara, R. A., Campbell, M., Farber, J. M., & Yada, R. Y. (2019). Transparency in food supply chains: A review of enabling technology solutions. *Trends in Food Science Technology*, *91*, 240–247. https://doi.org/10.1016/j.tifs.2019.07.024

Aung, M. M., & Chang, Y. S. (2014). Traceability in a food supply chain: safety and quality perspectives. *Food Control*, *39*, 172–184. https://doi.org/10.1016/j.foodcont.2013.11.007

Behnke, K., & Janssen, M. (2020). Boundary conditions for traceability in food supply chains using blockchain technology. *International Journal of Information Management*, *52*. https://doi.org/10.1016/j.ijinfomgt.2019.05.025

Berg, L. (2004). Trust in food in the age of mad cow disease: a comparative study of consumers' evaluation of food safety in Belgium. *Britain and Norway. Appetite*, *42*, 21–32. https://doi.org/10.1016/S0195-6663(03)00112-0

Biswas, K., Muthukkumarasamy, V., & Tan, W. L. (2017). Blockchain based wine supply chain traceability system. Future Technologies Conference.

Bumbudsanpharoke, N., & Ko, S. (2015). Nano-food packaging: An overview of market, migration research, and safety regulations. *Journal of Food Science*, *80*, R910–R923. https://doi.org/10.1111/1750-3841.12861

CAC. (2003). *Basic texts on food hygiene* (3rd ed.). Codex Alimentarious Comission. http://www.fao.org/docrep/006/y5307e/y5307e00.HTM

Carbone, A., Davcev, D., Mitreski, K., Kocarev, L., & Stankovski, V. (2018). Blockchain-based distributed cloud/fog platform for IoT supply chain management. *Eighth International Conference on Advances in Computing, Electronics and Electrical Technology, CEET*, *2018*, 51–58.

Caro, M. P., Ali, M. S., Vecchio, M., & GiaFfReda, R. (2018). Blockchain-based traceability in Agri-Food supply chain management: A practical implementation. *IoT Vertical and Topical Summit on Agriculture - Tuscany (IOT Tuscany)*, *2018*, 1–4. https://doi.org/10.1109/IOT-TUSCANY.2018.8373021

Choi, J. Y., Lee, H. J., Cho, J. S., Lee, Y. M., Woo, J. H., & Moon, K. D. (2017). Prediction of shelf-life and changes in the quality characteristics of semidried persimmons stored at different temperatures. *Food Science and Biotechnology*, *26*, 1255–1262. https://doi.org/10.1007/s10068-017-0173-4

Choi, W., & Roh, B. (2006). Backward channel protection method for RFID security schemes based on tree-walking algorithms. *International Conference on Computational Science Its Applications*. https://doi.org/10.1007/11751632_30

Cleeren, K., Dekimpe, M. G., & Heerde, H. (2017). Marketing research on product-harm crises: A review, managerial implications, and an agenda for future research. *Journal of the Academy of Marketing Science*, *45*, 593–615. https://doi.org/10.1007/s11747-017-0558-1

Ding, C., Khir, R., Pan, Z., Zhao, L., Tu, K., El-Mashad, H., & Mchugh, T. H. (2015). Improvement in shelf life of rough and brown rice using infrared radiation heating. *Food Bioprocess Technology*, *8*, 1149–1159. https://doi.org/10.1007/s11947-015-1480-5

Farahmand, N. F., & Farahmand, N. F. (2013). Organizational business development of hospital by laboratory services. *Science and Education Publishing*, 119–127. https://doi.org/10.12691/jbms-1-6-1

Flores, S. E., & Tanner, D. (2008). RFID technologies for cold chain applications. *International Institute of Refrigeration, Bulletin*, *15*(4), 4–9.

Fukagawa, N. K., & Ziska, L. H. (2019). Rice: Importance for global nutrition. *Journal of Nutritional Science and Vitaminology*, *65*, S2–S3. https://doi.org/10.3177/jnsv.65.S2

González-Amarillo, C. A., Corrales-Muñoz, J. C., Mendoza-Moreno, M., Gonzalez Amarillo, A. M., Hussein, A. F., Arunkumar, N., & Ramirez-Gonzalez, G. (2018). An IoT-based traceability system for greenhouse seedling crops. *IEEE Access*, *6*, 67528–67535. https://doi.org/10.1109/ACCESS.2018.2877293

Gunst, A. V., & Roodenburg, A. J. (2020). Consumers' distrust about E-numbers: A qualitative study among food experts. *Proceedings of the Nutrition Society*, *79*. https://doi.org/10.1017/S0029665120002700

He, J. (2018). From Country-of-Origin Labelling (COOL) to Seafood Import Monitoring Program (SIMP): How far can seafood traceability rules go? *Marine Policy*, *96*, 163–174. https://doi.org/10.1016/j.marpol.2018.08.003

Huang, H., Zhou, X., & Liu, J. (2019). *Food supply chain traceability scheme based on blockchain and EPC technology*. Smart

Blockchain, Second International Conference, SmartBlock, October 11–13, 2019, Proceedings, 2019. https://doi.org/10.1007/978-3-030-34083-4_4

Iqbal, R., & Butt, T. A. (2020). Safe farming as a service of blockchain-based supply chain management for improved transparency. *Cluster Computing*, *23*(1), 2139–2150. https://doi.org/10.1007/s10586-020-03092-4

Julian, P., Mark, B., & Sarah, M. (2010). Food waste within food supply chains: quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*, 3065–3081. https://doi.org/10.1098/rstb.2010.0126

Kamath, R. (2018). Food traceability on blockchain: Walmart's Pork and Mango Pilots with IBM. *The Journal of British Blockchain Association*, *1*, 1–12. https://doi.org/10.31585/jbba-1-1-(10)2018

Kilcast, D. (2000). The stability and shelf-life of food. *ELSEVIER*, 1–22. https://doi.org/10.1533/9781855736580.1

Kong, D., Shi, L., & Yang, Z. (2019). Product recalls, corporate social responsibility, and firm value: Evidence from the Chinese food industry. *Food Policy*, 60–69. https://doi.org/10.1016/j.foodpol.2018.11.005

Kramer, M. P., Bitsch, L., & Hanf, J. (2021). Blockchain and its impacts on agri-food supply chain network management. *Sustainability*, *13*, 2168. https://doi.org/10.3390/su13042168

Kriegesteffen, A., Boland, H., Lohscheidt, J., Schneider, F., Transparent, S. M., & Food and Consumer Trust. (2010). *2010 International European Forum, February 8–12, 2010*. Innsbruck-Igls.

Kumar, M. V., & Iyengar, N. (2017). A framework for blockchain technology in rice supply chain management. *Advanced Science and Technology Letters*, *146*, 125–130.

Kumar, N. M., & Mallick, P. K. (2018). Blockchain technology for security issues and challenges in IoT. *Procedia Computer Science*, *132*, 1815–1823. https://doi.org/10.1016/j.procs.2018.05.140

Labuza, T. P., Shapero, M., & Kamman, J. (1978). Prediction of nutrient losses. *Journal of Food Processing Preservation*, *2*, 91–99. https://doi.org/10.1111/j.1745-4549.1978.tb00549.x

Lareke, A. (2007). *Tyrannical consumers – Initiate value creation in the food value chain*. Packaging Logistics.

Li, J., Cui, N., & Liu, J. (2016). Gutter oil: an overview of Chinese food safety issues and policies. *Global Health Promotion*, *24*, 75–78. https://doi.org/10.1177/1757975915623733

Liu, P., & Ma, L. (2016). Food scandals, media exposure, and citizens' safety concerns: A multilevel analysis across Chinese cities. *Food Policy*, *63*, 102–111. https://doi.org/10.1016/j.foodpol.2016.07.005

Lucena, P., Binotto, A., Kim, H. M., & Momo, F. D. S. (2018). A case study for grain quality assurance tracking based on a blockchain business network. Symposium on Foundations and Applications of Blockchain (FAB '18), 2018.

Lundén, J., Kosola, M., Kiuru, J., Kaskela, J., & Inkinen, T. (2021). Disclosed restaurant inspection results on food safety show regional and local differences in Finland. *Food Control*, *119*, 107462. https://doi.org/10.1016/j.foodcont.2020.107462

Mitsuru, Y. (2015). Acrylamide, a carcinogen formed by high-temperature processing and cooking in food such as wheat products. *Journal for the Integrated Study of Dietary Habits*, *26*, 55–58. https://doi.org/10.2740/jisdh.26.55

Mukprasirt, A., Herald, T. J., & Seib, P. A. (2010). Pasting characteristics of rice flour-based batter compared to wheat flour-based batter. *Journal of Food Quality*, *25*, 139–154. https://doi.org/10.1111/j.1745-4557.2002.tb01014.x

Opara, L. U. (2003). Traceability in agriculture and food supply chain: a review of basic concepts, technological implications, and future prospects. *Food Agriculture & Environment*, *1*(1), 101–106. https://doi.org/10.3168/jds.S0022-0302(03)73617-0

Paiva, C. L. (2013). Quality management: Important aspects for the food industry. *Food Industry*. https://doi.org/10.5772/53162

Pappa, I. C., Iliopoulos, C., & Massouras, T. (2018). What determines the acceptance and use of electronic traceability systems in agri-food supply chains? *Journal of Rural Studies*, *58*, 123–135. https://doi.org/10.1016/j.jrurstud.2018.01.001

Parfitt, J., Barthel, M., & Macnaughton, S. (2010). Food waste within food supply chains: Quantification and potential for change to 2050. *Philosophical Transactions of the Royal Society B Biological Sciences*, *365*, 3065–3081. https://doi.org/10.1098/rstb.2010.0126

Park, C., Kim, Y. S., Park, K. J., & Kim, B. K. (2012). Changes in physicochemical characteristics of rice during storage at different temperatures. *Journal of Stored Products Research*, *48*, 25–29. https://doi.org/10.1016/j.jspr.2011.08.005

Premanandh, J. (2013). Horse meat scandal – A wake-up call for regulatory authorities. *Food Control*, *34*, 568–569. https://doi.org/10.1016/j.foodcont.2013.05.033

Qi, T., Cui, X., Zhao, S., Yang, W., Li, W., Zhang, B., & Yu, R. (2018). The food quality safety management system based on block chain technology and the application research in rice. *Journal of the Chinese Cereals and Oils Association*, *33*, 102–110.

Saikrishna, A., Sayantani, D., Vijayalakshmi, S., Moses, J. A., & Anandharamakrishnan, C. (2018). Ageing of rice: A review. *Journal of Cereal Science*, 161–170. https://doi.org/10.1016/j.jcs.2018.04.009

Saltini, R., & Akkerman, R. (2012). Testing improvements in the chocolate traceability system: Impact on product recalls and production efficiency. *Food Control*, *23*, 221–226. https://doi.org/10.1016/j.foodcont.2011.07.015

Sarpong, S. (2014). Traceability and supply chain complexity: Confronting the issues and concerns. *European Business Review*, *26*, 271–284. https://doi.org/10.1108/ebr-09-2013-0113

Saurabh, S., & Dey, K. (2021). Blockchain technology adoption, architecture, and sustainable agri-food supply chains. *Journal of Cleaner Production*, *284*(15). https://doi.org/10.1016/j.jclepro.2020.124731

Scalia, G. L., Nasca, A., Corona, O., Settanni, L., & Micale, R. (2017). An innovative shelf life model based on smart logistic unit for an efficient management of the perishable food supply chain. *Journal of Food Process Engineering*, *40*, 1–13. https://doi.org/10.1111/jfpe.12311

Scharff, R. L. (2010). Health-related costs from foodborne illness in the United States. http://www.producesafetyproject.org/media?id¼40009

Sharma, M., & Kumar, P. (2021). Adoption of blockchain technology. *A Case Study of Walmar*, https://doi.org/10.4018/978-1-7998-8081-3.ch013

Sharp, R. N., & Timme, L. K. (1986). Effects of storage time, storage temperature, and packaging method on shelf life of brown rice. *Cereal Chemistry*, *63*, 247–251.

Sodhi, N. S., Singh, N., Arora, M., & Singh, J. (2010). Changes in physico-chemical, thermal, cooking and textural properties of rice during aging. *Journal of Food Processing and Preservation*, *27*, 387–400. https://doi.org/10.1111/j.1745-4549.2003.tb00525.x

Stevenson, R. A. (2010). Rfid detection and identification system for implantable medical lead systems. CA.

Storoy, J., Thakur, M., & Olsen, P. (2013). The TraceFood Framework – Principles and guidelines for implementing traceability in food value chains. *Journal of Food Engineering*, *115*, 41–48. https://doi.org/10.1016/j.jfoodeng.2012.09.018

Su, X., Li, L. I., & Wang, X. H. (2012). A study of comprehensive evaluation of agricultural product quality and safety based on AHP. 2012 International Conference on Management Science Engineering 19th Annual Conference Proceedings, 2012, pp. 359–366. https://doi.org/10.1109/ICMSE.2012.6414206

Sun, Z., Xiufeng, L. I., Wang, W., & Zhiqiang, J. I. (2016). Application prospect of block chain technology in food safety. *Agriculture Network Information*.

Talib, H., Ali, K., & Idris, F. (2013). Quality management framework for the SME's food processing industry in Malaysia. *International Food Research Journal*, *20*, 333–338. https://doi.org/10.1109/CCDC.2013.6560944

Tao, Q., Chen, Q., Ding, H., Adnan, I., Huang, X., & Cui, X. (2021). Cross-department secures data sharing in food industry via blockchain-cloud fusion scheme. *Security and Communication Networks*, *2021*, 1–18. https://doi.org/10.1155/2021/6668339

Tao, Q., Cui, X., Huang, X., Leigh, A. M., & Gu, H. (2019). Food safety supervision system based on hierarchical multi-domain blockchain network. *IEEE Access*, *7*, 51817–51826. https://doi.org/10.1109/ACCESS.2019.2911265

Tao, Q., Ding, H., Wang, H., & Cui, X. (2021). Application research: Big data in food industry. *Foods*, *10*, 2203. https://doi.org/10.3390/foods10092203

Tayal, A., Solanki, A., Kondal, R., Nayyar, A., & Kumar, N. (2020). Blockchain-based efficient communication for food supply chain industry: Transparency and traceability analysis for sustainable business. *International Journal of Communication Systems*, *34*(4). https://doi.org/10.1002/dac.4696

Tian, F. (2016). An agri-food supply chain traceability system for China based on RFID & blockchain technology. *IEEE*, 1–6. https://doi.org/10.1109/ICSSSM.2016.7538424

Tian, F. (2017). A supply chain traceability system for food safety based on HACCP, blockchain Internet of things. *International Conference on Service Systems Service Management*. https://doi.org/10.1109/ICSSSM.2017.7996119

Villareal, M., Resurreccion, M., Suzuki, M., & Juliano, B. O. (2010). Changes in physicochemical properties of rice during storage. *Starch Strke*, *28*, 88–94. https://doi.org/10.1002/star.19760280304

Westerlund, M., & Soham Nene, S. L. M. R. (2021). An exploration of blockchain-based traceability in food supply chains: on the benefits of distributed digital records from farm to fork. *Technology Innovation Management Review*, *11*, 1–13. https://timreview.ca/article/1446

WHO. (2014). FAQs: Japan nuclear concerns. *Humanitarian Health Action*. https://reliefweb.int/sites/reliefweb.int/files/resources/15AACC7649AA82DC8525785E00713110-Full_report.pdf

WHO. (2015). *Food safety*. https://euro.sharefile.com/share/view/s00d0e20abc046de9

Wiset, L., Laoprasert, P., Borompichaichartkul, C., Poomsa-Ad, N., & Tulyathan, V. (2011). Effects of In-bin aeration storage on physico-chemical properties and quality of glutinous rice cultivar RD 6. *Australian Journal of Crop Science*, *5*, 635–640. https://doi.org/10.1111/j.1445-6664.2011.00409.x

Xiao-Jin, Y. U., Wang, H., Yang, H. M., Guo, Q. L., & Shi, H. L. (2015). Simultaneous determination of seven kinds of toxic and prohibited substances residues in infant milk powder by LC-MS/MS. *Food Research and Development*.

Xie, C., & Xiao, X. (2021). Traceability of agricultural product quality and safety based on blockchain – Taking fresh E-commerce as an example. 2020 International Conference on Applications and Techniques in Cyber Intelligence.

Yiannas, F. (2021). A new era of food transparency powered by blockchain. *Innovations: Technology, Governance, Globalization*, 46–56. https://doi.org/10.1162/inov_a_00266

Yokoe, M. (2008). Determination of shelf life of milled rice stored at different temperatures (Part 2). *Journal of Jsam*, *70*.

Zhou, Z., Robards, K., Helliwell, S., & Blanchard, C. (2003). Effect of rice storage on pasting properties of rice flour. *Food Research International*, *36*, 625–634. https://doi.org/10.1016/S0963-9969(03)00013-9

Zhou, Z., Yang, X., Su, Z., & Bu, D. (2016). Effect of ageing-induced changes in rice physicochemical properties on digestion behaviour following storage. *Journal of Stored Products Research*, *67*, 13–18. https://doi.org/10.1016/j.jspr.2016.01.004

How to cite this article: Tao, Q., Cai, Z., & Cui, X. (2022). A technological quality control system for rice supply chain. *Food and Energy Security*, *00*, e382. https://doi.org/10.1002/fes3.382