Emerging Crop Traceability Systems in Smart Farming: A Review

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Abstract. Traceability is the ability to retrieve the history, use, location or activity of an identified item, hence crop traceability system is a system that provides unique identification to the crop and tracks all information from the seed until the end product in the market. Crop traceability is beneficial to agri-business owners, farmers and consumers as it enables the production of quality crops. This paper aims to study the emerging crop traceability technologies in smart farming and present the possible solutions to improve the crop traceability system based on the ICT perspective. Some of the technologies involved are barcode, QR code, RFID, IoT, artificial intelligence and blockchain. Among these technologies, blockchain is seen to be the future technology suitable to improve the crop traceability system. However, the integration of blockchain into the existing system is still in the infancy stage.

Keywords: Blockchain · Farm Management · Food Safety · Quality Traceability · Smart Agriculture

1 Introduction

The agriculture industry has exponentially expanded in recent years and is anticipated to continue evolving, especially in this era of IR4.0. It is projected that by 2050, the world food production needs are to increase by 70% to feed 1 billion people [1]. If the traditional farming method is still widely used, this will be detrimental to food security [2]. Failure to meet the food supply-demand will lead to food shortage, malnutrition and food price inflation. Hence, to meet the ever-growing food demand, the farmers and agribusiness owners must adopt relevant measures to be more efficient and productive.

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Due to that, conventional farming has now begun to shift towards smart farming. Smart farming transformed conventional farming by capturing data and interpreting the data using ICT-based technology to make farm operations more efficient, productive and sustainable. Nevertheless, as crop quantity can be maximized through smart farming, there should not be any compromise on the quality of crops and agri-products. Hence, the demand for a solution to keep track of the quality of crops and the safety of food in each part of the supply chain is on the rise.

Due to that, a crop traceability system is of importance to any smart farm. By definition, crop traceability is the monitoring of crops from the farms to the market to promote food safety in the supply chain. Crop traceability is important to farmers and agribusiness owners due to the following reasons: (i) ensures the quality of agricultural products and achieves disease-free crop production [3], (ii) enables export to many countries through compliance with standards and policies [4] and (iii) discriminates real agri-products from counterfeits [5, 6] also highlighted that the traceability system allows connection between farmers to the end consumers, without any intervention of a third party, which will build the consumers' trust in the product and strengthen the product brand. Hence, this paper reviews the available crop traceability system in smart farming and discusses possible solutions to improve the crop traceability system in smart farming based on the ICT perspective.

The rest of the paper is structured as follows. Section Literature Review includes the general information on smart farming and the roles of ICT in smart farming. Next, we present the review on the crop traceability system in smart farming, providing an ICT perspective for further discussion. Then, the last section concludes the work with potential future directions.

2 Agriculture Farming

2.1 Farming: Conventional Versus Smart Farming

Conventional farming is practiced since the olden days to allow crop and food production. Hence, this farming method occupies fertilization, pest control handling and fulfillment of crop growth requirements by depending heavily on the farmers' knowledge and experience. As agriculture is one of the important sectors not only in Malaysia but worldwide, the landscape of conventional farming begins to change toward smart farming as a more sustainable approach in the long run. According to El Chami et al. (2020), for an agricultural practice to be sustainable, it needs to meet these criteria;

(i) fulfill the demand of people through its production, (ii) is economically viable and (iii) preserve the environment in the long run. Table 1 compared the characteristics of conventional and smart farming to highlight how smart farming can revolutionize the agriculture sector.

2.2 Roles of ICT in Smart Farming

2.2.1 Automate Tasks

One of the important roles of ICT in smart farming is to automate tasks that are often handled manually in conventional farming practices. For example, activities such as

Table 1. Comparison of conventional and smart farming characteristics

	Conventional Farming	Smart Farming	References
Definition	Farming that practices uniform resource inputs such as fertilizers, pesticides and excessive irrigation without much consideration of the conditions between and within the fields as well as commonly focuses on frequent, single-crop planting to grow food.	Farming focuses on capturing data and interpreting them using ICT technologies to make farm operations more predictable and efficient.	[7, 12, 13]
Aim	• Growing food as economically as possible • Ensure that food is affordable for all • Allow farmers to make a living through minimum earnings	• Reducing the need for human resources and efforts • Making maximum utilization of the available resources • Improving monitoring capabilities and farming efficiency • Ensure maximum profitability through increased quantity and quality of agricultural production • Allow farmers to obtain maximum earnings	[13, 14]
Emphasis	Localization, biodiversity, shared genetic resources and a cultural appreciation for many different crops	Emphasize production, capital gain, input intensity and crop consistencies	[15]

(*continued*)

water irrigation and placing fertilizer on crops can now be automated using drones and autonomous robots. A study by [7] mentioned that smart farms with auto foggy spray or auto dosing systems ensure that favorable farming conditions can be automatically kept in check, hence reducing human efforts that are more prone to error.

Table 1. (*continued*)

	Conventional Farming	Smart Farming	References
Practices	• Often performed by experienced farmers on instinct • Based on wisdom passed from generation to generations • Practices result in incomplete, ambiguous, and sometimes even inaccurate, information being received by the next generation	• Automated collection of data and monitoring of farming parameters using IoT sensors/WPNs • Crop collection and monitoring using robots and autonomous vehicles • Data visualizations to inform on decision making	[7]
Output	Depend on the capability of the farmer	Depend on the capability of the ICT technologies integrated into the farm management	[16]
Issues	• Knowledge transfer problem • Loss of data due to manual handling • Limited data collection method	• Difficult integration with current legacy system • Higher cost for inclusion of ICT technology	[17, 18]
Technology involved	Traditional and currently available technologies	Integrates the latest technology such as IoT sensors, cloud servers, autonomous robots, gateways and drones to control agricultural production through mobile or computer platform uses	[19]
Added value	Not much	Agricultural e-commerce, food traceability and anti-counterfeiting, agricultural leisure tourism, and agricultural information services	[20]
Sustainable	No	Yes	[13, 20]

2.2.2 Allow for Real-Time Monitoring

In conventional farming, data collection is often conducted manually. For example, farmers record environmental parameters and the crop production information on paper records, which then need to be keyed in into the spreadsheet software by the agri- business workers [7]. This manual practice does not only cause delays in data summary but also increases data inaccuracy and restricts data analysis. Meanwhile, ICT in smart farming enables real-time data collection through the usage of IoT sensors [8]. Hence, with the availability of all data from environmental conditions parameters (water irrigation, humidity, temperature, fertilizer, soil pH and etc.) in real-time, farming conditions can be adjusted quickly to guarantee the quality and quantity of their crop production [9].

2.2.3 Curate Meaningful Data Visualizations

In conventional farming, the data collection method cannot integrate both data and images. Yet, these variations of data forms are important to translate into meaningful information. Hence, another role of ICT in smart farming is to curate meaningful data visualizations [10] from the collected data. This can be done in many visualization platforms such as dashboards, mobile or web platforms, which can demonstrate the meaningful data visuals according to the need of its users and aid in their decision making [11]. For example, a smart farm dashboard can provide data visuals to facilitate farmers in monitoring their smart farm conditions, allow the agri- business owners to keep track of the whole crop production from multiple farms and enable consumers to get more information about an agri-product by scanning the product QR code.

2.2.4 Enables Crop Data Traceability

One of the added values of smart farming is the potential of crop traceability features. In conventional farming, it is difficult to trace back the information of a particular crop once it is on the market. However, in smart farming, crop traceability is getting more attention as data starting from planting, harvesting and processing to distribution and delivery are captured [21]. Many ICT- based technologies are embedded in the smart farming system to improve crop traceability such as IoT [22, 23], QR code, artificial intelligence, RFID and many more [6, 17, 24, 25]. Crop traceability is important mainly due to its potential as quality control, export compliance and brand awareness tools.

3 Crop Traceability in Smart Farming

By definition, traceability is the ability to retrieve the history, use, location or activities through a registered identification [26]. Hence, crop traceability involves the monitoring of crops from the farm to the market, passing through distributors and wholesalers, to consumers. According to [27], there are four pillars to an agri-product traceability system which are product identification, data to be traced, product touting, and traceability tools. As mentioned earlier, crop traceability is important for ensuring product quality, safety and optimizing the supply chain process which indirectly impacted the consumption of resources and labor. Due to this, an ideal traceability system needs to have: (i) the complete history of a particular crop, from seed to product on the shelf, (ii) environmental information for each farm from planting to harvesting and (iii) information on agricultural inputs and treatments (e.g. seedling, growth, insecticide spraying, fertilizing, and harvesting) and (iv) digital records on each supply chain process such as distributions and delivery.

González-Amarillo et al. [24] mentioned that traceability can be internal or external. Internal traceability trace crop from the seedling stage to harvest to guarantee the quality and safety of the crop while external traceability keeps track of the crop from harvest, production of agri-product to distribution in the market. The following subsection will provide an overview of the crop traceability system in smart farming.

3.1 Crop Traceability Systems in Smart Farming

As crop traceability had highlighted its importance in the agriculture industry, it is also important to understand how far the systems had evolved in smart farming. Table 2 listed the current crop traceability systems in smart farming while Fig. 1 depicted the overview of the technologies involved in the crop traceability system in smart farming.

In general, most crop traceability systems are made of a combination of multiple technologies. However, most of the systems are often centralized. Centralized systems tend to monopolize, be asymmetric and opaque [37]. This lead to a more vigorous study on the potentiality of crop traceability systems using blockchain technology to change the landscape towards a decentralized system to address the issues of data accuracy and data validity. Yet, an in-depth and more thorough venture into the blockchain technology is needed for it to be fully implemented in the smart farms.

4 Discussions

Recalls *of* agri-products due *to s*afety and sanitation issues have been never-ending, leading to the increasing concern about food safety and questions about the quality of the agri-products that enter the market. If not addressed, this issue will debilitate consumer trust in the food markets [38]. Even more, with the growing world population, the need and demands of the food market are not sufficiently met. Hence, a reliable traceability system has become necessary. Tracing the crop supply chain is the process of tracking the movement of a particular crop in the entire process starting from planting. In smart farming, crop traceability is an important quality management tool. Unqualified agri-products can be identified quickly within any part of the supply chain and smart farm owners can effectively curb the circulation of the agri-products before they reach the market. Should there be any safety or sanitation issue that occurred after the agri-products hit the market, a quick recall of unqualified products and identification of the causative agent can be performed immediately using a crop traceability system. From the consumers' perspective, the crop traceability system enables them to trace the agri-product quality information effortlessly [17].

According to [24], a traceability system is very likely to be adopted, especially in smart farming, due to the huge benefits that it brings. One of the benefits is the ability to estimate the shelf-life of a product post-harvest. From the system, variables to the farm

Table 2. Crop traceability systems in smart farming

Technology	Cost	Sector of use	Efficiency	Features	References
Barcode	Low cost	Fresh products, pesticide administration	Less efficient	2-dimensional code image, Limited data traceability	[21, 28], 29
Quick response (QR) code	Low cost	Track across the supply chain	Fairly efficient in all sectors	Simple with the use of smartphone devices and in combination with other technology such as IoT	[7]
Radio frequency identification (RFID)	Slightly higher than the barcode/QR code. Huge investment leads to the descaling of RFID to only be used in certain processes in the supply chain	Bigger production scale	Fairly efficient in all sectors	Simple and versatile, sensor-based data transmission	[27, 30]

(*continued*)

Table 2. (*continued*)

Technology	Cost	Sector of use	Efficiency	Features	References
Artificial intelligence (AI)	Costly	Early warning system, food safety & traceability, augmenting entire supply chain, health monitoring of crops	Fairly efficient in all sectors	Complex algorithms that constantly analyze the data captured from various sources to assist in the production of healthier crops, the control of pests, the monitoring of soil and growing conditions and the improvement of a wide range of agricultural tasks throughout the supply chain.	[31]
Internet of Things (IoT)	Costly	Regulation of water in the smart farm field, monitoring of crops	Fairly efficient in all sectors	Sensors to detect the environmental data in the smart farm in which the entire data was computed and presented using a traceability system	[7, 27, 32]
Blockchain	Costly	Smart contract	Conceptual, not fully implemented	Enable real-time tracking Decentralized, verification system to provide data transparency	[33–36]

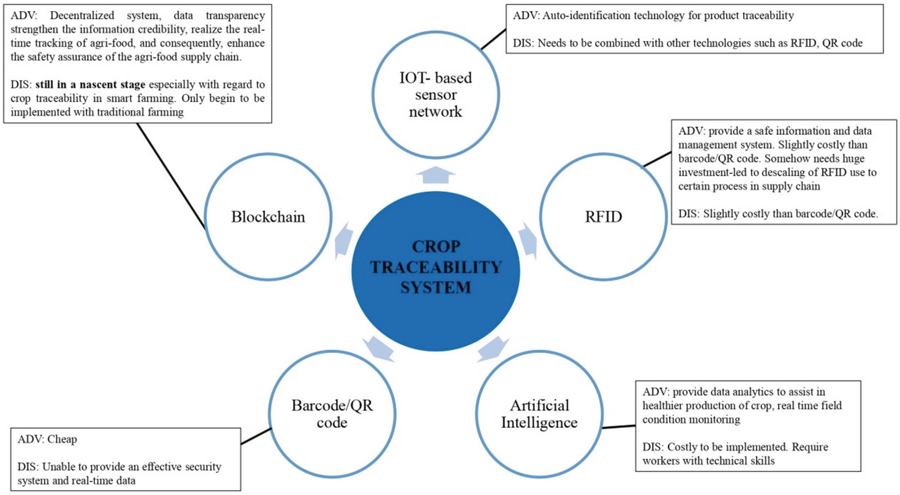

Fig. 1. Overview of the technologies involved in the crop traceability system in smart farming. *Note* ADV = advantage, DIS = disadvantage

conditions, which may include humidity, temperature, water irrigation consumption, crop growth pattern, seedling behavior and the timeline for crop harvest can be accurately tracked. This is then translated to the best quality and yield of the smart farm agri-products.

With regard to ICT technology, the crop traceability system has previously occupied barcodes technology for more than 30 years. It is simple to use and is low in cost. However, barcode stores limited information which can only be obtained when prompted using the scanner. Hence, the traceability system using barcodes may suffer from data loss and inconsistent data storage. Next, the barcode technology is advanced to QR code. QR codes are highly used over a group of applications, especially to log information across the supply chain. Due to its versatility in providing direct information and details, QR codes are often used to convey information to the end- users of the supply chain.

Besides that, RFID technology contributes to the crop traceability system through automatic data capture and exchange using wireless sensors or tags. RFID is capable of massive data storage, sufficient data reading speeds and reusability to a point it can help reduce production and distribution costs in smart farming. However, the cost of RFID tags is higher than barcodes. Hence, adopters of RFID in smart farms often descale the use of RFID to only certain processes of the supply chain. With the explosive IoT development, this technology has now been favored in crop traceability systems in smart farms due to its effectiveness in gathering real-time information within the crop life-cycle and supply chain, with less human effort.

However, the current practice of crop traceability in smart farming, or agriculture at large, suffers from data fragmentation and centralized controls which makes it vulnerable to data modification, fraud, tampering and falsifying of information. Hence, it is necessary to ensure that the data contained in crop traceability is accurate, valid and can be trusted. Due to this, research to embark on blockchain technology in crop traceability systems in smart farming has begun to capture much attention.

Sneri et al. [6] mentioned that blockchain technology helps establish a consensus mechanism in which the data is recorded openly, in sequence and maintained by the players of the peer-to-peer network, to make up a decentralized system. The use of this disruptive technology creates trust between customers and the agri- producers as the information related to the crop is transparently provided. Due to the blockchain technology, customer understood that the information is valid and cannot be changed without the permission of both seller and customer [39].

Hence, a crop traceability system using blockchain technology creates a fraud-proof system that is not only trustworthy, but with high degree of data integrity [40]. In short, this will be beneficial for regulation and compliance with the policy with crop export [41]. Another highlight of how blockchain can revolutionize the crop traceability system is through the implementation of smart contracts. Smart contracts are script technology that allows one to build trustworthy applications that support the existing *blockchain* technologies [18]. As example, to allows transactions to be performed immediately with no intermediaries involved and to ensure real agreement between farmers and business owners.

5 Conclusion

In conclusion, the basic function of any traceability system is as a way of communication, making all information available to be able to track product information at any point in the supply chain so that corrective actions can be implemented quickly and effectively. To design a sufficient crop traceability system, these data need to be captured and stored; (i) the complete history of a particular crop, from seed to product on the shelf, (ii) environmental information for each farm from planting to harvesting and (iii) information on agricultural inputs and treatments (e.g. seedling, growth, insecticide spraying, fertilizing, and harvesting) and (iv) digital records on each supply chain process such as distributions and delivery. Although there are many technologies available to develop a crop traceability system, blockchain technology seems to be a promising panacea in providing a long-term, sustainable decentralized solution. However, it can be very costly and blockchain has yet to seamlessly integrate with existing organizational systems.

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