Blockchain-Based Traceability System From the Users’ Perspective: A Case Study of Thai Coffee Supply Chain

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ABSTRACT We explored the use of blockchain technology for traceability to improve the safety and value of food, focusing on the coffee supply chain as a case study. The main goal was to evaluate the feasibility in terms of design, perceived benefits, and challenges of applying blockchain and traceability from the users’ perspective. We implemented a prototype using a user-centered iterative interface design. Then we used the prototype to answer our research questions in mixed-method research, including in-depth interviews (10 participants) and a survey (350 participants) with stakeholders in the coffee supply chain in Thailand. The results showed that timeline-based design was preferred over map-based or text-based design for the visualization of traceability information and that blockchain was a promising technology, as 67% of the survey participants saw a positive influence of blockchain on the adoption of applications. The most notable benefits were origin checking and increasing product trustworthiness. The most notable challenges were inaccurate or incomplete information and the disclosure of trade secrets. More work is required to address the challenges for everyone in the supply chain ecosystem to adopt the proposed traceability system, including (1) providing trustworthiness and completeness of information by cross-checking with third parties or other users, (2) protecting sensitive information by aligning users’ interests or allowing control of information disclosure, and (3) educating and giving producers the motivation for the difficulty and the extra work.

INDEX TERMS Blockchain, coffee, supply chain, traceability, user-centered design, interview, survey.

I. INTRODUCTION

Food safety has become a major concern around the world, raising the need for better information management through the food traceability system. Stakeholders record their activities and send them along with their products down the supply chain. When problems occur, we can trace back and pinpoint where the troubles lie, which helps minimize damage and reduce food recalls. Traditionally, each party stores information, some on paper, and rarely shares it with everyone in the supply chain. Although digital technology has the potential to address the issue of information sharing, a centralized system allows an authority to view, manage, and delete data, making recorded data less trustworthy.

Blockchain is a decentralized technology that records data among participating entities with proper access control, but no single party has control over the entire system. Furthermore, properties of blockchain, such as immutability (ensuring that no one can modify the data) and transparency (providing access to the involved parties), make the
blockchain a promising technology for solving the problems of traceability systems [1]. Numerous companies have explored the use of blockchain in their supply chain, such as IBM Food Trust [2] and Walmart [3]. The research community has also increased interest and investigated various aspects of blockchain for food traceability, as can be seen in numerous review papers [4], [5], [6], [7]. However, the majority of papers emphasized technical viewpoints and infrequently addressed human issues, which are an important aspect of technology adoption.

Adopting blockchain-based food traceability in the real world is challenging in many aspects. For instance, the transparency property of blockchain could hinder the adoption as businesses want to protect their confidential information [8]. There exist several studies related to technology adoption, such as Saberi et al. [9], Chen et al. [10], and Duan et al. [11]. Still, relatively few works have gone into understanding users’ perspectives on the benefits, challenges, as well as possible solutions in adopting blockchain-based food traceability systems. There is still no study of blockchain-based traceability systems from the user’s perspective in Thailand.

This paper aims to explore the benefits, challenges, and possible solutions to ease the adoption of a blockchain-based traceability system through user interviews and a survey. The goal is to help researchers or practitioners better understand factors that influence people to practically use a blockchain-based traceability system. We focus on the coffee supply chain, which has a strong potential use case for blockchain-based food traceability, as seen in many ongoing projects (such as Hondurus [12] and Netherlands [13]).

Our contributions include:
- the user interface design of a blockchain-based coffee traceability system, iteratively guided by in-depth semi-structured interviews with prospective users of the system;
- the studies of the perceived benefits and challenges of the blockchain-based traceability system adoption for coffee beans, as well as suggestions to ease the adoption from prospective users in Thailand;
- the discussions of how our findings support or differ from existing global knowledge and implications to guide future development of blockchain-based agri-food traceability systems.

The remainder of this paper is organized as follows: Section II gives the background and a review of the literature; Section III explains the overview of the method used in this research; Section IV explains the design of our system; Section V and Section VI present the results of our interviews and survey, respectively. We then discuss the results in Section VII and conclude the paper in Section VIII.

II. RELATED WORKS
This section reviews related works on blockchain and traceability, coffee supply chain, coffee traceability, and the adoption of blockchain technology in the traceability of the agri-food supply chain.

A. BLOCKCHAIN AND TRACEABILITY
Blockchain is an innovative combination of computer technology to create a distributed database management system. It is designed for the transparency and integrity of the information, allowing multiple parties to transact without a central authority. Blockchain started in 2008 as the technology behind the first successful cryptocurrency, bitcoin [14]. The main purpose of bitcoin was to be a peer-to-peer cryptocurrency transfer application. The blockchain technology behind bitcoin stores the data in a block-based data structure, chained to the past blocks to create a linked history of data. The peer-to-peer network of bitcoin computer nodes reaches consensus using the Proof-of-Work algorithm.

Although bitcoin has proven to be very successful and has operated for more than a decade with millions of users, the original blockchain technology was not suitable for scaling to other applications. The Bitcoin blockchain has many limitations, including low throughput, high energy consumption, security issues, and privacy of data. Therefore, blockchain technology has become an active research area, with many researchers aiming to improve various technical aspects of blockchain, such as scalability [15], security [16], scalable integration with other technologies [17]. The technology is still in its infancy and remains an active area of research to date.

In terms of application domains, blockchain started in the financial sector but later expanded to other sectors, including agriculture and supply chain. Several researchers have worked on the topic of blockchain and traceability, such as supply chain traceability systems with blockchain and RFID technology in China [18], applications of blockchain or distributed storage technology for agricultural commodity markets [19], and others [20], [21], [22]. Trace Thai is another blockchain-based traceability system for Thai produce [23], [24]. However, Trace Thai was designed for generic products, which may not be optimized for coffee traceability in Thailand.

B. COFFEE SUPPLY CHAIN
Coffee is an agricultural product with a high market value (US$3,185.00m in 2022 for Thailand) and is likely to continue to expand annually by 11.99% [25]. In 2018, Thailand had 57 new companies registered for coffee production [26], and in 2022, Thai people consumed an average of 0.59 L of coffee per person [25].

The coffee supply chain is complex, involving many steps and stakeholders that could vary depending on the country, as seen in the illustrations by Ibrahim and Zailani [27], Grabs [28], Fakkhong and Yamsa-ar [29], Plengplang and Khutrakun [30]. In Thailand, the supply chain also depends on the business model. For instance, Lapato Coffee divided the supply chain into three main processes (sourcing, processing, and delivering) and involved
entrepreneurs, government sectors, private sectors, and civil society [30].

In general, the coffee supply chain consists of the following steps: planting, picking, processing, milling, grading, roasting, and packaging. There could be other steps such as grinding and distribution, but this paper focuses on roasted coffee beans. The details of each step in coffee production affect the taste and, consequently, the price of coffee. Farmers can take various actions in their process to improve their beans. For example, farmers can practice standard recommendations (e.g., Good Agriculture Practice or GAP [31]). Among practices and attributes, customers are willing to pay more for coffee with traceability [32]. Therefore, we considered coffee an interesting case to investigate the adoption of blockchain-based traceability systems.

C. COFFEE TRACEABILITY

Several research studies discussed the benefits of coffee traceability. For Thailand, traceability is part of the Common Code for Coffee Community (4C) standard, which could increase the price of coffee by 3 – 5% and benefit the producers [33]. According to Miatton and Amado [34], their traceability system allowed users to (1) check the freshness of coffee, which affects the taste of coffee, (2) increase transparency in information about the quality and origin of coffee, which increases consumer confidence, and (3) help meet the needs of consumers who want manufacturers to care about the environment. In Thailand, Doi Saket Coffee employed a cloud-based traceability system (QR Trace on Cloud) and claimed that it was well-received in the market [35].

As blockchain is seen as a promising technology for solving several problems of traceability systems, it has been adopted for coffee traceability. Pradana et al. [36], for instance, analyzed system requirements and proposed blockchain modeling for the coffee traceability information system. Miatton and Amado [34] adopted blockchain in the coffee value chain to make it effective, transparent, and capable of producing win-win business solutions. However, these works focused on technical aspects and did not explicitly involve users in their research. One blockchain-based system that involved users was not exactly for traceability but consumer-controlled coffee machines [37], [38]. The research explored perceptions of data collection and sharing, as well as expected benefits of the machine, such as dividends for farmers and the donation of part of the profit. Nonetheless, they did not survey the opinions of producers. Existing research on coffee traceability provided very limited details on stakeholders’ views on the proposed system.

Recently, Bager et al. [39], [40] implemented an event-based modeling framework for the coffee supply chain, using blockchain to increase traceability and transparency. Their work was based on fieldwork involving stakeholders, and they reported barriers and opportunities for technology adoption. They suggested that blockchain has great potential to solve issues in agro-food supply chains, but more study is required to evaluate the solutions in practical contexts.

D. TECHNOLOGY ADOPTION

In addition to Bager et al. [40] mentioned in the previous subsection, we found only one work that studied the adoption of blockchain-based coffee traceability systems in business. Thiruchelvam et al. [41] analyzed comments from stakeholders and proposed the Technology Acceptance Model (TAM) of blockchain technology in the Burundi coffee industry.

In a more general context, several works studied the adoption of blockchain technology in agri-food supply chain traceability. Chen et al. [10] conducted a thematic analysis of the literature to identify the processes, benefits, and challenges of the adoption of blockchain technologies in food supply chains. Similar works studied the adoption in the literature using content analysis [11] or analyzed review articles [42]. As a key factor in technology adoption is prospective users, works such as Behnke and Janssen [8], Yadav et al. [43], and Saurabh and Dey [44] involved users to identify the boundaries or challenges to be addressed before the technology can be put into practical use. However, as seen in Table 1, which summarizes their method and notable findings, the key factors for technology adoption could differ depending on the type of product and the country in which the study was conducted. The study of technology adoption in the Thai coffee supply chain is lacking and therefore our focus.

This paper investigates the adoption of technology by involving prospective users through mixed-method research. Furthermore, we formulate questions in a way that made participants aware of ‘blockchain’ since the opinion of the system might lie in the digitized supply chain rather than the blockchain [40]. We discuss how our findings conform or vary from other works in Section VII. Additionally, we include reports of the possible solutions from users’ perspectives, which have not been studied sufficiently globally.

III. METHODOLOGY

We adopt mixed-method research to investigate the benefits, challenges, and suggestions in adopting a blockchain-based traceability system. Following an exploratory sequential design [45], we first conducted semi-structured interviews with coffee producers and customers to collect qualitative data, which informed subsequent quantitative data collection using a questionnaire survey. The interviews and survey were reviewed and approved by the Institutional Review Board, and informed consent was obtained at the beginning of the studies. To ensure the feasibility of the procedure and the questions, we tested both the interview and the survey with one pilot participant each. The pilot results were not included in the final result but served as guidelines to make the final refinement of the questions.

The interview and survey questions were formulated to answer the research questions: (1) what factors influence the adoption of our application and (2) does blockchain affect their opinions about providing the data or adopting the system. For the survey, we also included (3) how information disclosure affects their opinions about adopting the system. The last research question was used to address one
of the main concerns of the participants we found during the interview.

Figure 1 provides an overview of our methodology. As a blockchain-based traceability system is relatively new in Thailand, we included a system prototype in the interviews and survey to ensure participants understand the system. We first briefly explain how we came up with the prototype and then explained the interview and survey procedure.

**A. DESIGN AND PROTOTYPE ITERATIONS**

We used a user-centered iterative design to develop our system prototype. We first designed the system using information from literature, used the design to conduct user interviews, then used findings from the interviews to refine the design. Each phase involved a few sub-iterations and 3 - 5 design alternatives. We interviewed 10 participants in total. There were also pilot studies before the formal studies. The main questions in the interviews included (1) what information users were interested in and (2) how to present the information to users. By involving users when designing the system, we reduce the effect of poor designs on the willingness to adopt the system.

**B. INTERVIEW**

The interview was semi-structured and mostly done online due to the Covid-19 situation. As it was difficult to let participants try our application, we used a recorded video describing the application and shared our screen when we clicked through each design. The questions included participant information and their opinions after seeing the demonstrations, as listed in Appendix A.

We used video-conferencing applications that the participant was familiar with. The interviews were conducted in Thai. Participants could turn off their video if showing their video was uncomfortable or inconvenient. Each session involved one or two researchers and one or two participants. Each interview took about 30 - 120 minutes. We recorded the conversations for later analysis and compensated participants for their time.

After summarizing the recordings into text, we analyzed the findings for the coffee production information flow and visualization, then used them to improve the design. The first author performed an inductive thematic analysis [46] of the interview content to identify the willingness to adopt our system, benefits, challenges, and suggestions. The findings from the interviews informed our questionnaire design.
The benefit and challenge categories from the interviews appeared in the questionnaire as choices to confirm and investigate the degree of the findings. Note that the suggestion categories reported in this paper were later revised to match with coding from the survey to ease the discussion.

### C. Survey

The survey used a questionnaire with questions similar to those of the interviews, as listed in Appendix B. We distributed the questionnaire to the National Science and Technology Development Agency, Thailand, and multiple Facebook groups of coffee producers in Thailand. We opened the questionnaire from August 2021 to September 2021 and awarded the participants with a lucky draw.

We calculated the statistics for closed-ended questions and quantified open-ended questions using content analysis [47]. We adopted guidelines to establish reliability for the open-ended questions [48]. As one answer might contain several points and the informal Thai language does not have clear indications such as a period at the end of a sentence, the first author first divided each answer into smaller units. Then, the first author came up with initial codes using an inductive method. Next, the first and the second author discussed and agreed on the code of each question. Two authors independently applied the code to 20% of the answers in each question and checked the level of agreement. We revised the codes before independently applying the code to the rest of the data.

Finally, we determined the reliability of our codes. We adopted Krippendorff’s alpha [47], which provides a higher adequacy for opinion research [49]. As one answer might have multiple codes, we calculated the agreement using the Measuring Agreement on Set-valued Items (MASI) [50] with the NLTK toolkit [51]. The codes and number of answers tagged with each code that two coders agreed on are reported in Section VI.

### IV. Design and Prototype

We designed how users can record, pass, and see transactions. The designs were informed by literature reviews [27], [28], [30], documentaries [52], [53], other online resources [54], [55], [56], and user interviews.

When users logged in to our system, they would see a menu according to the processing steps: planting, picking, processing, milling, grading, roasting, and packaging. In each step, the user filled out the information in a form, then the system recorded the information and automatically generated a QR code to forward the information to the next step. QR code made the information passing convenient. The user could scan the code to see the information of the previous steps, then they could continue the production immediately or at the desired time.

Our design included three interesting features.

First, users could mix beans from multiple sources, allowing the mixing of coffee beans from multiple farmers as well as the blending of multiple coffee species. Information from the previous step was listed with the checkbox, so users could select one or multiple sources to continue, as shown in Figure 2a.

Second, we allowed partial usage of beans. Users could specify the quantity to be used, as shown in Figure 2b, and the system would automatically calculate the remaining quantity to be used later. This feature provided flexibility, for example, for roasters when they blend coffee beans.

Third, users could use either a QR code or progress to the next step without a QR code, as shown in Figure 2c, so one person could have multiple roles. This feature might not be thought about without the interview, as other studies of the coffee supply chain seemed to suggest a dedicated role for each user, while the interview revealed otherwise for Thai coffee producers.

There were also minor design features. For example, we did not directly ask about the chemical used. Instead, we used the term “remark” to allow organic farmers to explain their specialty while not discouraging normal farmers. Users could optionally add a taste note after the packaging step, as all participants mentioned the taste of coffee during the interview. This information should be useful for supporting purchasing decisions.

For the visualization of traceability information, the designs were mainly informed from our previous work [42]. We analyzed 14 blockchain-based agri-food traceability applications and 10 non-blockchain-based agri-food traceability applications, then classified ways to visualize tractability information into 5 approaches: text, table, timeline, graph, and map. Since the preferred approach remains an open question, we decided to explore all alternatives by coming up with a design for each visualization type. Each design presented similar information but featured different pieces of information. In all designs, the users could click on an icon after the information to see additional information, such as certificates or map location, in a pop-up window.

Allowing mixing beans surprisingly made the visualization complicated. The scalability of the design was a major challenge, especially on mobile applications. The issue existed even when we used a simple case where we blended arabica and robusta from four farmers. Thus, we eliminated the table-based and graph-based design because of their poor scalability and limited benefits.

We continued with text-based, timeline-based, and map-based design. We found that the map-based design was the most intuitive to scale, as the visibility of places already depends on the zoom level. The timeline-based was the most problematic since both lines and text created visual clutter. In the end, we decided to use collapsible interaction for both text-based and timeline-based design, to highlight the most important information (i.e., the blending of arabica and robusta).

**Text-based Design**, as shown in Figure 3a and 3b, placed information in collapsible panels. The information was first grouped by coffee species and then by the owner of the information. The header of each panel included (1) the species...
name, (2) location, (3) step names, and/or (4) the most important step-specific information so that users could see the important information even in the collapsed panels. Each piece of information came after its bold label, so the users could easily visually scan for information.

### Timeline-based Design

As shown in Figure 3c and Figure 3d, highlighted the transaction date on the left of the lines, facilitating users to check the freshness of the product. The design collapsed information of each species into one item, used a big circle to indicate the blending, and used an arrow in a circle to indicate expandable information. We used color to highlight the difference in species. Important information about each item appeared in bold font size while other information appeared in smaller font sizes.

### Map-based Design

As shown in Figure 3e, pinned the location of each owner as an icon on a map and connected each location with a line with a direction arrow to show the flow of transactions. We used color to highlight the difference between species. We could not put other information on the map as they created visual clutter and occluded map features.
Hence, this design also incorporated formatted text in a pop-up panel. Users could click the icon to see information from the corresponding owner as text with a label. Other important information, such as roast level, was above the map in a similar format.

We implemented a proof-of-concept (POC) system for design #1 based on Hyperledger Fabric [57], an open-source private blockchain technology supported by the Linux Foundation and IBM. Hyperledger Fabric provides a layer of access control to identify users in each organization and allows custom smart contracts (i.e., chaincode) to be written for our use case. The architecture of the system is shown in Figure 4. Our system shared the information on the machines of the participants across the network. The users would access our application through their platform (i.e., farmer, miller, roaster, and customer page). The implementation of this POC allows us to ensure that what we designed is technically possible.

The POC was used at the beginning of the interview. However, since our main goal was to explore the designs and most users did not focus on technical details, we iterated through the designs by creating clickable prototypes of our designs in Figma (https://www.figma.com). This reduced the implementation time, and we also note that the iterations of designs do not alter the technical back-end beyond the possibility of implementation of the system by Hyperledger Fabric. We also created a presentation to better demonstrate how users record and pass information. The video recording of the presentation is at https://youtu.be/U3IeYYpGht0 (in Thai, with English subtitle). We showed the traceability information visualization using Figma (for the interview) and animated pictures (for the survey).

V. INTERVIEW RESULTS

During the iterative design process, we conducted interviews with 10 participants. The main objectives were to investigate the prototype issues and to gain insight into the willingness to adopt the system, the benefits, the challenges, and the suggestions to ease the adoption. We used the insights to inform the questionnaire design, which is explained in the next section.

A. PARTICIPANTS

Our participants included five producers (P1 - P5) and five consumers (C1 - C5), aged between 21 and 59. Table 2 lists the profile of our participants. Most of the participants had basic knowledge of blockchain technology, but only C1, C2, and P4 knew about traceability systems. Note that C1 - C3 and P1 saw the earlier design than the rest. P4 and P5 were managers in a coffee-production-related department in the same company. They were interviewed in the same session, as per the participant’s request.

B. PROTOTYPE FEEDBACK

We asked participants whether the system reflected the practical production process. Most suggestions about coffee information flow in early design came from C2, who studied coffee production. We incorporated them into our design, which was later confirmed by other producers. There are three notable findings from the interview, which did not stand out when we reviewed other materials.

First, mixing or blending beans from multiple sources is crucial. Farmers in the same area might sell to intermediaries or companies as a group (C3), in large quantities in some cases (P5). The blending is still needed even for single-origin coffee, as roasters might mix beans from multiple batches to control the taste (C2). Second, the role of stakeholders in the Thai coffee supply chain may be overlapped. Finally, there are a lot of details in coffee processing, and some of them do not have standards widely adopted by Thai coffee producers. For instance, there is no standard grading, and roasting level could differ from roaster to roaster (C2). P5 suggested that the current form was fine and could leave other details in one optional remark text box.
We asked participants what design(s) they prefer. Overall, participants preferred the timeline-based design, while having a map provided additional information. Meanwhile, P2 did not like any designs as they were hard to understand. He suggested that all information should be in one picture without too many clicks. Other comments about each design are as follows.

1) TEXT-BASED DESIGN
C2, C4, and P1 liked this design for its detailed information. C3, however, commented that text-only design is unpopular nowadays.

2) TIMELINE-BASED DESIGN
Most participants liked this design. It was easy to understand (C1, P1) and simple (C1). This design allowed seeing the overall production process (C4) while providing details on demand (P1, C5, P5). A user could see the date or interval (C3, C5, P4) in order (C5). The timeline was deemed as a self-telling story (C4) and not confusing (P5).

3) MAP-BASED DESIGN
Participants had different opinions about this design. P3 liked its ease to understand. P5 deemed the design interesting and modern. The map allowed an overview of the overall process (C2) but required many clicks to see details (C3).

It was deemed confusing (P5) and too much clutter (C5). C1 complained that some icons did not reflect the production process and suggested using animation to illustrate the time order. A clearer illustration of time order was also suggested by C2. C1 and C3 suggested that it should appear as additional information on other designs.

C. WILLINGNESS TO ADOPT THE SYSTEM
We asked participants whether they would use the system if the system works. The answers generally depended on their views on the benefits and challenges. Most customer participants would try our application as it looked useful (C3, C4, C5) or fun (C1). C3 said he would continue using it if the information could reflect the quality. C2 commented that if everyone in the supply chain agreed to disclose the information, it would be good and beneficial to the community. However, producers’ willingness was deemed a challenge.

All producers seemed reluctant to adopt our system, mostly because of a lack of perceived benefits or motivation for them (P1, P4, P5) and the lack of functionality they need (P3). P2 would not adopt as he did not want to disclose information, though he agreed that our system would be good for customers. Similarly, P5 commented that their company would not use this detailed information but agreed that our system was good for recording information. C2 would not

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**TABLE 2. Profile of participants in the interview. Mobile refers to the number of hours per day that the participants use mobile applications. Trace refers to the level of knowledge of traceability systems. Blockchain refers to the level of knowledge on the blockchain. All data are self-reported by the participants.**

| ID | Gender | Age | Education | Occupation | Experience | Mobile | Trace | Blockchain |
|----|--------|-----|-----------|------------|------------|--------|-------|------------|
| C1 | F      | 39  | Master    | Research Assistance | Drink 1 cup of instant or brewed coffee every few days for 20 years. | 6      | Basic | Basic |
| C2 | M      | 36  | Master    | None       | Drink coffee for 16 years. Studied coffee production. Has a barista certificate and a plan to open a coffee shop. | 3      | Basic | Basic |
| P1 | M      | 34  | High vocational certificate | Programmer, part-time farmer | Plant coffee trees for 2 years in a 1,600 square meter area. | 3      | None | Basic |
| C3 | M      | 59  | Master    | Company employee | Drink 1 cup of coffee every day since 10 years old. Now either drink at a coffee shop or roast and brew by himself. | 5      | None | Basic |
| P2 | M      | 42  | Bachelor  | Roaster    | Learn roasting for 5 years and sell roasted coffee beans for 4 years. | 8 - 12 | None | None |
| C4 | M      | 34  | Bachelor  | Programmer | Drink 1 cup of drip coffee every few days for 1.5 years. Previously drink instant coffee. | 3      | None | Basic |
| P3 | M      | 26  | Bachelor  | Contracted farmer | Do everything from planting to roasting for 3 years. | 1 - 2  | None | Basic |
| C5 | M      | 21  | High school | Undergrad Student | Drink a few cups of cold brew or drip coffee every day for 3 - 4 years. | 12 - 16 | None | None |
| P4 | M      | 37  | Master    | A manager in a coffee company | Work on promoting coffee production and collaborating with other organizations for 3 years. | 8 - 10 | Basic | Basic |
| P5 | M      | NA  | NA        | A manager in a coffee company | Work on purchasing raw coffee and promoting coffee for 6 years. | NA    | NA   | NA |
adopt our system since the current system already has all the needed information.

D. PERCEIVED BENEFITS OF THE SYSTEM
Both producers and customers could benefit from our system to check the origin of coffee. The participants could see the benefits to customers clearly, while benefits to producers were not very clear and were mostly speculated by customers.

1) ORIGIN CHECKING
Although the system might not be able to control quality, the system could prevent secretly mixing registered or certified sources with unknown sources, which could benefit traders and roasters (C2). P1, C4, and C5 deemed our system could help customers identify the origin of coffee.

2) PRODUCTION IMPROVEMENT
P3 commented that keeping the history could help farmers revisit the process, resulting in more consistent output. C3 thought that our system could provide flexibility in production. Usually, the millers would provide funding to the farmers and control the coffee quality. Our traceability system could be used, so there would be no need to have a planting location near the millers. Although this could cause conflicts between competitors, C4 thought our system could encourage good competition.

3) SALE ENHANCEMENT
P3 speculated the benefit of our system in promoting products specialized in each location. Similarly, P4 said our system might help a coffee shop sell the story of each location and inspire customers. C3 commented that the system could help farmers sell their products directly and promote coffee exporting if people acknowledge the quality of Thai farmers, thus could increase income and sales.

We were particularly interested in whether tractability could add financial value to the product. Hence, we specifically asked the customer participants about the additional price they could afford. C3 thought the traceability could add 20 - 30% value to premium Thai coffee and 10% to imported coffee. He normally would not drink expensive coffee, but the system could ensure the origin, so he might try expensive coffee occasionally. However, C2 thought the traceability itself would not add financial value, but a good system and certificate would. C1 would buy a cheaper one first but might try the traceable one if the price difference is less than 20%.

We observed that the participants seemed reluctant to pay the additional price for traceability. Hence, we instead asked for the value added in general. C5 thought the price should relate to the quality of the coffee itself. However, traceability would increase the sales volume (C4, C5) and build a reputation for producers (C4).

4) PRODUCT AUTHENTICITY AND TRUSTWORTHINESS
The product would look more authentic (C1). Our system could help ensure the product origin that the seller claimed (C3). C5 believed it was good that the information could not be edited. Additionally, it would be fair, as the blockchain has no central party.

5) PRODUCT SATISFACTION
Our system could help customers make the decision (C1) and get the coffee they want (C4). C5 said he would use the system because he liked finding new coffee. The system could help him understand and be more confident in the product.

E. PERCEIVED CHALLENGES OF THE SYSTEM
While C5 thought there should not be any challenge in adopting our system, many participants raised issues that originated from producers.

1) DIFFICULTY OR EXTRA WORK IN INFORMATION FILLING
C4 worried that producers might not use the system as it required extra work. P5, who bought a large number of coffee beans from hundreds of farmers, said it would be difficult to input all information. A company could not ask the farmers to fill in the information before settling the deal while retroactively filling in information is difficult.

This problem particularly burdened farmers. Coffee farms might be in areas with no electricity and internet (C2, P4). Most farmers might not carefully keep a record, such as the age of each tree (C2). Farmers might be illiterate or not know how to use technology (C2, P2, P4). Furthermore, P3 also concerned an older generation who may have issues in recording data, although he had no concern as a young farmer.

2) DISCLOSURE OF TRADE SECRETS
P1, P3, and P5 agreed that they could disclose the information that the system asked for. P2 explained that he could input the publicly available information such as the date. However, information such as his supply chain and blending methods, are sensitive and would never be disclosed. P2 explained that poor-quality substances are released into the mass market. This is a problem, but no one wants to solve it, since it is deemed a mutual benefit. The producers could make more money while the customers could get affordable coffee. Similarly, P5 would not disclose price information. The farmers might not want to disclose substances in soil (C2) or be traced back (P2). C4 also mentioned the system disclosing seller information, which might cause conflicts, cutting price competition, and benefit loss. However, he thought it could be a good competition.

3) PROBLEMS BETWEEN PEOPLE IN THE SUPPLY CHAIN
P2 commented that if customers knew the type of beans the roasters used for blending, they would think the final price is more expensive than the cost of the beans, without thinking that there would be other costs besides the beans. Thus, disclosing sensitive information could affect sales and the relationship between people in the supply chain. C3 worried
that bad reviews might ruin farmers, especially when the review could not be deleted.

4) PROBLEMS WITH THE REVENUE DEPARTMENT
P2 explained that, when the information is public, roasters might be afraid of being tracked. Although they pay taxes correctly, this information might force them to pay more taxes. Our system might not help producers and even make it worse.

5) INACCURATE OR INCOMPLETE INFORMATION
Many participants worried that the filled-in information might be incomplete, inaccurate, or false (C1, C3, C4, C5, and P4). Interestingly, these answers were not mentioned unless we specifically ask about the concerns regarding the blockchain system.

F. SUGGESTIONS TO EASE THE ADOPTION
The suggestions ranged from ways that might help them adopt our system to additional functions that make our system more useful.

1) SUGGESTIONS RELATED TO PROCESS OR PRODUCT
Producer participants suggested features for the farming process. P1 commented that a new generation of farmers has become interested in coffee planting. It would be great if our system could recommend planting methods for those who have just started planting. Similarly, P2 suggested that a system that helps in farming would make the supply chain happier.

Customer participants suggested having additional information: information about each location (C1), moisture during processing (C2), weight loss during milling (C2), price after packaging (C4), and coffee extraction methods for brewing (C5).

2) SUGGESTIONS RELATED TO COMMERCE
The system should provide functions for selling and promoting products for the benefit of producers. The system could show the daily coffee bean price (P1, P3). Allowing producers to promote their coffee could increase the diversity of coffee beans in the market (P3). P3 might adopt the system to directly sell the product to customers. Similarly, P1 and P2 suggested allowing intermediaries to buy coffee beans through the system.

For customers, the system should provide functions for browsing and searching for products. Customer participants suggested a search function based on location (C1) and coffee taste (C3), which should help in purchasing coffee. P2 thought that matching customer needs with taste notes would be useful and would greatly help in selling. Rosters would be happy with the increase in sales. They would gradually adjust and begin to help in traceability. P2, C3, and C5 suggested a review and rating system, which is commonly found in e-commerce platforms to increase confidence in the information.

3) SUGGESTIONS RELATED TO INFORMATION OR VERIFICATION
C1 suggested that the system should be more useful if user identity is verified. A taste note should be recorded by certified Q graders (C5), as there were differences between trained and untrained tasters (P2). P4 suggested that our system should have people who are trustworthy to verify or approve the information. C1 commented that the information would look more reliable if everybody, including competitors, had that information.

4) SUGGESTIONS RELATED TO BUSINESS AND MOTIVATION
P4 and P5 commented that a company in a mass market would not adopt the system. However, he recognized that small and medium enterprises (SMEs) and large enterprises might have different interests and practices. Our system could have dual models for each type of business. Additionally, the system should be suitable for small coffee shops that promote single-origin coffee. Aiming at companies that own the completed supply chain (from planting to packaging) first should ease the system development and deployment.

C4 and P5 suggested that producers might use it if they see the benefit, so we should educate producers and give them motivation. Additionally, P2 commented that if we could bring the government to talk with roasters and draft the policy together, the system would be completed and good for the Thai coffee community.

VI. SURVEY RESULTS
We confirmed and expanded the findings from the interview by surveying users for their opinions using a questionnaire. From the interview, one major challenge was the disclosure of sensitive information. We deemed the need to address this challenge before further system development since the measure could affect the architecture and user experience. The selected proposal was providing an option for users to control information access by themselves, which could compromise the transparency property of blockchain. To investigate our proposal, we added related questions to the questionnaire. The notable additional question was “How does allowing relevant parties to choose to disclose information by themselves affect your decision to use the system?”

A. PARTICIPANTS
We received answers from 350 participants. Modal values of the participant’s profile included female (56%), age group between 40 - 49 (38%), with master’s degree (46%), and using mobile applications more than 5 hours per day (37%). Figure 5 reports the participant statistics. Six participants did not specify their gender. Most participants did not know of or knew but never used traceability applications or blockchain applications, as illustrated in Figure 6.

Table 3 reports participants’ experience. The majority of the participants (79%) had only consumption
experience, while others had experiences in multiple areas. Unexpectedly, the distinction between producers and consumers was difficult. For example, 53 participants indicated their experience in planting or harvesting coffee, but only 8 participants indicated their occupation as farmers. One possible reason is that participants had multiple occupations, like the participant from the interview (P1) who was a programmer and a part-time farmer. Similarly, 50 participants had experience in roasting, but only 2 participants indicated occupation as roasters. Note that 7 participants did not indicate any experience, but one of them identified themselves as a producer in the comment.

### TABLE 3. Experience of the participants.

| Experience       | Planting | Processing | Roasting | Consuming |
|------------------|----------|------------|----------|-----------|
| No experience    | 297      | 311        | 300      | 8         |
| Less than 1 year | 13       | 13         | 22       | 15        |
| 1 - 5 years      | 16       | 15         | 21       | 59        |
| 6 - 10 years     | 14       | 6          | 2        | 71        |
| 10+ years        | 10       | 5          | 5        | 197       |

As we could not distinguish the producers and consumers, for the rest of the analysis, we report the statistics of all participants, then investigate the answers of professional producers (who indicated their occupation as farmers and roasters) and extreme cases.

### B. PROTOTYPE FEEDBACK

After learning about our application, 181 participants (52%) thought our application was following the current practice. However, 119 participants were unsure about the process and 50 participants indicated the need to improve the flow. One reason was that most of the participants were consumers with limited knowledge about the coffee supply chain. In addition, some participants had issues with the survey (e.g., unclear questions or unclear demonstration).

Most participants preferred timeline-based visualization, as illustrated in Figure 7. For others, four participants suggested an option to choose visualization, while two suggested a mixture of visualizations. One professional producer and one participant, who had experience in planting, suggested more details in the visualization. One participant suggested an overview first, then detail on demand. One participant, who had more than ten years of experience in all production processes, indicated that all visualizations were not understandable.

### FIGURE 5. Statistics of participant information, including: (a) age group, (b) education level, and (c) number of hours spent on mobile applications in a day.

### FIGURE 6. Statistics of participant experience with (a) traceability application and (b) blockchain application.

### FIGURE 7. Number of participants who preferred text-, timeline-, and map-based visualization. Note that participants might prefer multiple types of visualization.
C. WILLINGNESS TO ADOPT THE SYSTEM
On average, participants would like to use our application. The overall average score was 3.96, where 5 was “definitely use” the system. The Pearson correlation results indicated that there is a significant medium positive relationship between the experience with the traceability application and experience with blockchain application, \( r(348) = .337, \ p < .001 \). There is a significant small positive relationship between the experience with traceability application and the willingness to adopt the system, \( r(348) = .11, \ p = .039 \). However, there is a non-significant very small positive relationship between experience with blockchain applications and the willingness to adopt the system, \( r(348) = .0262, \ p = .625 \).

The average score from professional producers was 4.40, with the lowest score as 2 from one participant. The participant, who was a farmer, was concerned about who would verify the information and how the system could prevent interference from various groups of people. Another participant, who had experience in all steps of coffee production and gave a score of 2, commented that without follow-up data, it would be difficult to use this information to improve the production process. For other participants who gave a low score (1 or 2), we found comments on information verification and unclear benefits of the blockchain and the system.

D. PERCEIVED BENEFITS OF THE SYSTEM IN GENERAL
Figure 8 shows the benefits of the overall system seen by participants. Most participants agreed with the benefits identified from the interview. The most notable benefits were origin checking (81%) and increasing product trustworthiness (80%). Then the participants saw benefits of product satisfaction (68%), production improvement (61%), and sale enhancement (45%), respectively.

Participants also indicated other benefits. For instance, seven participants suggested that the application could create stories, noteworthiness, or other sentimentality about the product. The participants also mentioned the benefits of encouraging competition between producers, supporting a specific location or producer, and the usefulness for specific users or other usages.

E. PERCEIVED CHALLENGES OF THE SYSTEM IN GENERAL
Figure 9 shows the challenges in the adoption of the system in general. The most concerning issue was inaccurate or incomplete information (71%). Participants were also concerned about disclosure of trade secrets (52%), difficulty in information filling (49%), and problems between people in the supply chain (28%), respectively. Problems with the Revenue Department were the least concerned issue (15%). A small number of participants were also concerned that the application might increase the cost or price and that there could be problems related to infrastructure such as the readiness of equipment.

F. INFLUENCE OF BLOCKCHAIN
We specifically asked participants how blockchain affects the decision to use the system. The responses showed that 67 percent of participants, including 80 percent of professional producers, saw a positive influence of blockchain in application adoption, as illustrated in Figure 10. Table 4 shows comments about how blockchain affects their decision to use the system from 202 participants. Note that we also found one case with contradicting answers: the participant indicated a negative influence of blockchain but commented that blockchain increases confidence in the information.

The most notable benefits were related to information, which was indicated by 67 participants. The blockchain had a positive influence on the adoption as it could help in origin checking. The information was deemed transparent, verifiable, traceable, authentic, accurate, and/or credible. The system could help prevent fraud, counterfeiting, as well as information alteration. While 48 participants just repeated their answers without further explanation, 44 participants...
TABLE 4. Content analysis result of the question “How the use of the blockchain to keep a copy of the data at all involved parties and prevent secret editing affects your decision to use the system?” The Krippendorff’s alpha is 0.87.

| Code description                      | Count |
|---------------------------------------|-------|
| Benefits related to a product or quality | 3     |
| Benefits related to information        | 67    |
| Benefits for producers                 | 2     |
| Benefits for customers                 | 8     |
| Emotional benefits                     | 44    |
| Challenges related to privacy          | 6     |
| Challenges related to information      | 27    |
| Challenges related to producers        | 2     |
| Emotional or educational challenges    | 9     |
| Unclear answer or answer with no explanation | 48    |

indicated other emotional benefits. They felt an increase in credibility, trust, confidence, honesty, sincerity, and safety. Other benefits included benefits related to product or quality (e.g., help improving or controlling product quality), benefits for producers (e.g., help in sales, marketing, exporting, or adding value to the product), and benefits for customers (e.g., help them understand the product, help in choosing or making purchasing decisions).

The most notable challenges in the adoption were also related to the information, as indicated by 27 participants. The participants had doubts about the person filling out the information or whether the information was correct, complete, and/or accurate. Some participants emphasized that the system would be useful only when the information is complete, correct, and/or reliable. As the information was permanently stored, some also raised concerns when they wanted to edit or update the information. Other challenges included challenges related to privacy (e.g., disclosure of trade secret or personal information), challenges related to producers (e.g., variety in practice and standards, slander from competitors, or other problems between people in the supply chain), and emotional or educational challenges (e.g., not trust, not confident, not understood, not knowledgeable, or unable to see the benefits of blockchain and/or traceability enough to provide an opinion).

G. INFLUENCE OF INFORMATION DISCLOSURE

We also investigated how our proposal to provide optional disclosure affects the decision to use the system. Figure 11 illustrates the willingness to adopt our application, with and without optional information disclosure. Interestingly, the option to select disclosed information only slightly decreased the willingness to adopt the application (3.86 on average or 2% decreasing). 71 percent of participants, including all professional producers, gave the same score regardless of the disclosure option. Two participants dramatically decreased their willingness to adopt the application with the disclosure option (i.e., from 4 or 5 to 1). Unfortunately, only one reason “the trade secret” was given without any other explanation.

Table 5 shows comments about the adopting our application with optional information disclosure from 221 participants. 86 participants saw that optional disclosure had a positive or good influence or was acceptable. Notable benefits of the option were (1) respect for privacy or trade secrets and (2) increasing trustworthiness and confidence. One participant explained that by allowing producers to choose what to disclose, producers could show the strengths that they want consumers to know, which could ease the purchasing decision. 43 participants thought that optional disclosure had little or no influence on adoption, while the opinion of 37 participants was more dependent on the disclosed information. For example, several participants commented that they had more trust in products that disclose more information. Nevertheless, the disclosure option could have a negative influence, as given by 24 participants. This option could make users unsure about filled-in information, especially in terms of completeness. Some participants saw no use of the application if many producers chose not to disclose the essential information.

TABLE 5. Content analysis result of the question “If the system allows relevant parties to choose to disclose the information by themselves, will you use it or not?” Krippendorff’s alpha is 0.91.

| Code description                                      | Count |
|-------------------------------------------------------|-------|
| Participants were not sure about the answer            | 2     |
| Optional disclosure had no or little influence         | 43    |
| Optional disclosure had positive or good influence or was acceptable | 86 |
| The positive or negative influence depended on disclosed information | 37 |
| The positive or negative influence depended on other factors | 2 |
| Optional disclosure had negative or bad influence      | 24    |
| The answer was unclear whether optional disclosure had a positive or negative influence | 23 |
Table 6 shows other comments, particularly suggestions, from 113 participants. 29 participants provided suggestions related to commerce, such as functions to sell or promote products, and functions to view, search, or recommend products. This code also included general functionalities found in e-commerce platforms, such as feedback, review, and rating. 23 participants provided suggestions on the process or product, such as waste management or a more detailed roasting level. 18 participants mentioned the need for information verification and other information-related functionalities. For instance, one participant suggested storing fact and figure data on-chain and storing other opinion-based information in a typical database, since storing unreliable opinions permanently might not be fair for the producers. 16 participants suggested other functionalities or improvements in user interface design.

Participants also commented about the adoption. For example, a few participants did not understand or see the benefits of blockchain and/or traceability applications. There were positive, negative, and other comments. In particular, a few participants suggested using the system to trace other products.

H. OTHER COMMENTS AND SUGGESTIONS

Table 6 shows other comments, particularly suggestions, from 113 participants. 29 participants provided suggestions related to commerce, such as functions to sell or promote products, and functions to view, search, or recommend products. This code also included general functionalities found in e-commerce platforms, such as feedback, review, and rating. 23 participants provided suggestions on the process or product, such as waste management or a more detailed roasting level. 18 participants mentioned the need for information verification and other information-related functionalities. For instance, one participant suggested storing fact and figure data on-chain and storing other opinion-based information in a typical database, since storing unreliable opinions permanently might not be fair for the producers. 16 participants suggested other functionalities or improvements in user interface design.

Participants also commented about the adoption. For example, a few participants did not understand or see the benefits of blockchain and/or traceability applications. There were positive, negative, and other comments. In particular, a few participants suggested using the system to trace other products.

VII. DISCUSSION

From our interview and survey studies, we could observe that participants kept mentioning some benefits and challenges of our system, and it was sometimes difficult to discern which feature contributed to those points. For instance, we found the benefit of origin checking in questions about the overall system, information disclosure, and blockchain. In general, compared to a typical traceability system, we deemed blockchain could notably improve confidence and trustworthiness, while options to select information to be disclosed could notably protect privacy and trade secrets without negative effects if implemented correctly.

Table 7 lists the benefits, challenges, and suggestions derived from our studies. We include remarks that discuss whether our findings are similar to or varied from other works. Note that we mainly point to our previous work [42] since the review covered various blockchain-based systems that were applied to agri-food supply chains.

In general, our findings support existing knowledge, with some variations related to sales enhancement, problems with the revenue department, suggestions related to commerce, suggestions related to information or verification, and suggestions related to business and motivation. The order of importance of the challenges also differs from the related works summarized in Table 1.

We summarize our findings when developing a blockchain-based coffee traceability system into implications for easing the adoption and design implications.

A. IMPLICATIONS FOR EASING THE ADOPTION

While the customer participants could see the benefits of our system, the source of their concern stemmed from the producers. In the interview, the producer participants could see extra work and problems with unclear immediate benefits. However, we observed that farmer participants were willing to adopt our system more than the producers in the middle of the supply chain. Both the farmer participants and customer participants mentioned direct purchasing, while the roaster participants were afraid of losing customers. This conflict could lead to difficulty in the adoption. However, the results from the survey hinted that professional producers were willing to adopt the application, especially if we could address their concerns about the trustworthiness and completeness of the information, disclosure of sensitive information, and difficulty or extra work in information filling. We discuss suggestions to address these concerns in the following points.

1) PROVIDE TRUSTWORTHINESS AND COMPLETENESS OF INFORMATION BY CROSS-CHECKING WITH THIRD PARTIES OR OTHER USERS

The main challenge of the system adoption was ensuring the trustworthiness and completeness of the information, which was not directly related to blockchain in the view of practitioners and our research team. Still, it was mentioned repeatedly in our interviews and survey, apparently when we asked about the blockchain. While blockchain technology ensures the integrity of information, the trustworthiness and completeness of the information entered remain an unsolved research question, as discussed in many reviews (e.g., [11], [61]). A human can enter wrong data intentionally or unintentionally. Unlike bitcoin, blockchain-based traceability systems are too complex to design bullet-proof smart contracts to prevent bad data from entering the system. Bager et al. [40], for example, suggested using IoT to mitigate this issue. However, additional sensors could further increase the cost, and the data could still be manipulated.

Fortunately, the participants seem to be satisfied with trustworthiness verification. Identity verification, review, and rating exist in many applications nowadays. Customers could consider these factors to justify information from unknown sellers on online shopping sites, which have trustworthiness issues similar to our case. Our participants also mentioned...
### TABLE 7. Benefits, challenges, and suggestions from user interviews and survey. The interview column reports the ID of the participant who mentioned the topic. The asterisks (*) indicate that the participants mentioned the topic when we specifically asked about concerns regarding blockchain. The survey column reports the number of participants who agreed with the topic (for benefits and challenges) or mentioned the topic (for suggestions).

| Topic                                                  | Interviewee | Survey | Remarks                                                                 |
|--------------------------------------------------------|-------------|--------|-------------------------------------------------------------------------|
| **Benefits**                                           |             |        |                                                                         |
| Origin checking                                        | P1, C2, C4, C5 | 283    | Traceability allowed users to check the origin and follow agri-food products in a supply chain [42]. |
| Product authenticity and trustworthiness               | C1, C3, C5* | 281    | Traceability enhanced food authenticity, and relationship between stakeholders was better through enhanced customers' trust [42]. |
| Product satisfaction                                   | C1, C4, C5  | 239    | While the positive influence on purchasing decisions benefited intermediaries [42], our findings leaned toward benefits for customers. |
| Production improvement                                  | P3, C3, C4  | 214    | Information and Communications Technology (ICT) and blockchain technology provided information availability for effective decision-making and production improvement [38]. |
| Sale enhancement                                        | P3, P4, C3, C4, C5 | 157    | Sale enhancement was mentioned briefly as intermediaries' benefit [42], but mentioned moderately in this research. Many participants also mentioned the emotional benefits of blockchain, such as creating a compelling story of the product, which could indirectly relate to purchasing interests. |
| **Challenges**                                         |             |        |                                                                         |
| Inaccurate or incomplete information                    | C1*, C3*, C4*, C5*, P4* | 248    | Traceability relied on data collection, which was difficult to ensure the quality [42]. |
| Disclosure of trade secrets                             | P2, P5, C2, C4 | 182    | Privacy, including trade secrets of business, was seen as one of the major drawbacks of blockchain [42]. |
| Difficulty or extra work in information filling         | C2*, C4, P2*, P3*, P4*, P5 | 172    | Time to learn and enter information could be seen as increasing in business cost [42]. |
| Problems between people in the supply chain             | P2, C3*     | 97     | This issue was a known challenge in relationship between stakeholders [42]. |
| Problems with the Revenue Department                    | P2          | 52     | We have yet to find this concern in other work.                          |
| **Suggestions**                                        |             |        |                                                                         |
| Suggestions related to commerce                         | P1, P2, P3, C1, C3 | 29     | E-commerce of agricultural products Xiong et al. [59] or a review system Wang et al. [60] are other application areas of blockchain. However, few of our participants suggested that opinion information, such as ratings and reviews, should not be stored on a blockchain. |
| Suggestions related to process or product                | P1, P2, C1, C2, C4, C5 | 23     | Suggestions about additional processing steps or product information are typical. |
| Suggestions related to information or verification       | P2, P4*, C1*, C5 | 18     | Several solutions had been proposed such as the use of IoT Bager et al. [40] or verification from third parties (discussed in traceability [42]). Our participants proposed using traditional solutions, such as rating and review, to cross-check the information. |
| Suggestions related to business and motivation           | P2, P4, P5, C4 | NA     | Improving users' familiarity with blockchain and the role of governments were suggestions to address cost and risk [42]. However, correlations between our participants' experience and willingness to adopt the system hinted that improving users' familiarity with traceability may be more useful than improving users' familiarity with blockchain. |

Verification from third parties, similar to what was discussed in [42]. Implementing trustworthiness verification or integrating the traditional system for trustworthiness verification should strengthen the benefit of blockchain systems.

2) **PROTECT SENSITIVE INFORMATION BY ALIGNING USERS’ INTERESTS OR ALLOWING CONTROL OF INFORMATION DISCLOSURE**

One concern of the producers for adopting our system was the disclosure of sensitive information, but the customers recognized this concern. We found that the customer participants were generally interested in public information, as a part of package or advertisement messages. For instance, they were only interested in the final price of the product and the planting city or province. The cost of raw materials or farmer names were considered good to know, but not necessary. The suggestion to record the cost for transparency by Bager et al. [40] might not work in Thailand and other countries where producers share the same concerns. Thus, designing a traceability system should always involve all…
stakeholders, including customers, to align their interests, which may differ in each country.

Alternatively, allowing information providers to control information disclosure could be an interesting option. Many customers in the survey indicated their understanding of the trade secrets and did not decrease their willingness to adopt the system if some information remained undisclosed. Although professional producers did not show increased interest in the adoption, the disclosure option could be a way to ease the adoption for roasters who were more concerned about this issue. However, whether it is feasible to implement this feature is a subject of future research.

3) EDUCATE AND GIVE PRODUCERS THE MOTIVATION FOR DIFFICULTY AND EXTRA WORK

Compared to Europe or America, a traceability system is still less well-known in Thailand, nor do we have a regulation to encourage or force stakeholders’ participation. As we observed many suggestions about commerce, producers may be interested in our system if they know that traceability can statistically increase sales or that traceability is a requirement in exporting products to the countries with this regulation.

B. DESIGN IMPLICATIONS

Thai coffee traceability systems should consider flexibility and ease-of-understand of the design. The responses from the interview and the survey suggest three main implications for design.

1) PROVIDE FLEXIBILITY BY ALLOWING MIXING BEANS FROM MULTIPLE SOURCES IN EACH STEP, PARTIAL USAGE OF BEANS, AND MULTIPLE USER ROLES

The Thai coffee supply chain is complex with varying standards and practices. During the interview, our producer participants seemed reluctant to adopt the system if they found that the system could not capture their current practices. It is understandable since changing the process or using this system in parallel with the existing one could incur the extra cost or extra work. The features to mix beans from multiple sources in each step, partial usage of beans, and multiple user roles, described in Section IV, made the system flexible enough to capture such varying standards and practices.

2) USE TIMELINE-BASED DESIGN WHEN THE CHAIN IS SIMPLE OR CAN BE SIMPLIFIED

Ease-of-understand is an important consideration for traceability information visualization, especially for customers who are typically not familiar with the supply chain process. In this research, we came up with various design alternatives that present the same set of data and found that the timeline-based design was preferred. This preference could be because time is an important factor in coffee quality. Though it might not be evaluated against other designs, the timeline-based design had been implemented by many systems (e.g., eggs [62] and olive oil [63]). However, this design required careful consideration when the supply chain became more complex. In our case, we summarized and grouped items, but it may not be feasible in some other cases.

The map-based design was also a good alternative with better scalability if the implementation could hide or group the pinned locations and paths in relation to the zoom level of the map. To our surprise, many participants also viewed text-based design positively. Hence, it could be a good, budgeted, and easy-to-implement alternative for traceability systems in general.

3) HIGHLIGHT TRUSTWORTHINESS OR COMPLETENESS OF INFORMATION

Accuracy and completeness of information were the major concerns of users. Our designs included certificate icons with pop-up certificate detail, which could be seen as one method of trustworthiness verification. However, since we did not highlight it in the video demonstration, many participants might not notice this feature and raise concerns about the verification. Thus, it is important to make verification of trustworthiness or completeness of information apparent to users to ease their concerns.

C. LIMITATIONS OF OUR STUDY

Our study has three main limitations. The first limitation is the number of participants and their background. Most of our participants were customers. Also, conducting online interviews meant we excluded users who were not familiar with the technology. Designing for people with low digital literacy is another challenge that should be addressed in the future. Though we believe there should not be significant changes to the benefits, challenges, and suggestions, different user groups could lead to a redesigned information flow and user interface.

The second limitation is the lack of interaction between participants and the prototype. We report all findings, including what participants might miss or misunderstand due to this limitation, as they could highlight important features or poor designs from a user perspective. For instance, we suggested apparent data verification because most participants missed our certificate icons from the video demonstration.

The last limitation is the implementation. We implemented our first design as a web-based mobile-friendly prototype with Hyperledger Fabric as a blockchain layer. However, findings from the interviews suggested major modifications, and we decided to use an interactive prototype to quickly iterate the design to reflect users’ suggestions and better understand stakeholders before going to actual implementation. For instance, our implementation only supported input from three types of users (farmers, millers, and roasters), and each user had one role, which is a false assumption in the Thai coffee supply chain. In the future, we need to implement the design and convince more stakeholders to participate in the blockchain.
VIII. CONCLUSION

We developed a blockchain-based traceability system for coffee in Thailand. The system could record essential steps in coffee production. The information flow and visualization were informed by user comments. Our design provided flexibility by allowing mixing beans from multiple sources in each step, partial usage of beans, and multiple user roles. We compared text-based, timeline-based, and map-based designs of traceability information visualization and found that users most preferred the timeline-based design. However, the design requires careful consideration when the supply chain becomes more complex. User comments also hinted that the user interface should clearly show that the information is trustworthy and complete.

We used the system prototype as a tool to investigate benefits, challenges, and suggestions for the adoption of blockchain-based traceability systems from users’ perspectives using mixed-method research. We interviewed 10 participants and conducted a survey in which we received responses from 350 participants. The participants agreed that our system could be useful, notably, for product origin verification, product authenticity and trustworthiness, and product satisfaction. They tended to adopt our system, and the blockchain had a positive influence on the adoption. However, some concerns might hinder the adoption. Our participants were particularly concerned about disclosure of trade secrets, inaccurate or incomplete information, and the difficulty or extra work in information filling. We also discuss implications that should address some challenges and ease the adoption. Practitioners should consider (1) supporting cross-checking trustworthiness and completeness of information with third parties or other users, (2) aligning users’ interests or allowing control of information disclosure to protect sensitive business information, and (3) educating and motivating producers to overcome difficulty and extra work concerns. Although some features are yet to be implemented and will be our future work, we believe details about our designs and findings from user studies are useful for future research in agri-food blockchain-based traceability systems, especially in developing countries where traceability systems are not well-known similar to Thailand.

APPENDIX A

INTERVIEW QUESTIONS

Below is the list of questions for interviews. The interviews were originally in Thai.

Part I: Participant information
- Age
- Gender
- Highest education
- How long do you use mobile applications per day?
- Please tell us about your experiences related to coffee (e.g., planting, processing, or drinking habit)
- Do you know traceability?
- Do you know blockchain?

Part II: Coffee traceability system
- Please see the demonstration video, do you think the system reflects the process being performed? Are there any parts that are similar/contradict the process being done?
- (An interviewee showed and briefly explained each design) What is your opinion on presenting information with text, timeline, and maps? Which one do you prefer? Why?

Part III: Adoption
- If the system works, will you use it or not? Why?
- If the system works, what will be the impact or benefit?
- To provide transparent and reliable information, the blockchain system keeps a copy of the data at all involved parties. Furthermore, the information that has been imported into the system cannot be edited in secret. Do you have any comments or concerns about using the system?
- For producers:
  - To use the system, you may need to record information or install an automatic device for recording data. Do you have any concerns about this?
  - To use the system, you may be required to disclose information about the production, as presented in the video. Could you disclose the information? Is there any information that is not easy to disclose?
- For consumers:
  - What information would you like to know when making a purchase decision? Do you want to know anything other than what is stored in the system, as presented in the video?
  - Do you think a traceability system can add value to the product or not? How?

Part IV: General system suggestions
- Do you have other suggestions about the system?
- Do you have any additional comments or questions?

APPENDIX B

SURVEY QUESTIONS

Below is the list of questions for our survey. The survey was originally in Thai.

Part I: Participant information
- Age (20 - 29, 30 - 39, 40 - 49, 50 and above)
- Gender (Male, Female, Non-specified)
- Highest education (School or Vocational Certificate or less, Diploma or High vocational certificate or equivalent, Bachelor, Master, Ph.D.)
- Occupation (Farmer, Government service/state enterprise, Company employee, Merchant/freelance, Student, Other)
- How long do you use mobile applications per day? (0 - 1 hour, 1 - 3 hours, 3 - 5 hours, 5 and above)
- Please tell us about your experiences related to coffee (No experience, Less than 1 year, 1 - 5 years, 6 - 10 years, More than 10 years)
Part II: Coffee traceability system

Do you know traceability? (Unknown, Never use, Sometimes use, Frequently use)
• Do you know blockchain? (Unknown, Never use, Sometimes use, Frequently use)

Part III: Adoption

If the system works, what will be the benefit? (Help in origin checking, Help in production improvement, Sale enhancement, Product satisfaction, Increase product trustworthiness, Others - please specify)

If the system works, will you use it or not? (1 - definitely not use, 5 - definitely use)
• If the system allows relevant parties to choose to disclose the information by themselves, will you use it or not? For example, a roaster can choose to disclose only the source of the coffee beans but not the farmer’s name. A taster can choose to reveal only their pseudonym but not their real name. (1 - definitely not use, 5 - definitely use)

How does allowing relevant parties to choose to disclose the information by themselves affect your decision to use the system? (Open-ended)

Does the use of the blockchain to keep a copy of the data at all involved parties and prevent secret editing affect your decision to use the system? (Unsure, Negative, Natural, Positive)

How does the use of the blockchain to keep a copy of the data at all involved parties and prevent secret editing affect your decision to use the system? (Open-ended)

Do you have any additional comments or questions? (Open-ended)

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