The role of information heterogeneity in blockchain-based traceability systems: evidence from fresh fruits buyers in China

RESEARCH ARTICLE

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Abstract

Blockchain technology is now being piloted to agri-food traceability systems to restore consumers' confidence for food quality and safety. It is important for the industry to understand what information to be recorded and tracked in blockchain-based fresh produce traceability systems to meet consumers' preferences for information. Yet little research has focused specifically on consumers' preferences concerning information attributes traced by this new blockchain technology. This study conducts a best-worst scaling experiment with fresh fruit buyers in China to investigate consumers' preference and perceived value regarding sixteen information attributes about blockchain-based fresh fruit traceability systems. The results from the analysis of a random parameter logit model reveal that consumers consistently rank testing information as the first-most valuable attribute, followed by production inputs (pesticides and fertilizers), quality certification and grades information attributes, while supplier and logistics information are considered to be the least valuable traceability one. Furthermore, there exist significant heterogeneity in relative value placed on traceable information attributes. The findings identify four different consumer segments by using a latent class modelling approach: (1) sensitivity for authoritative information, (2) preferences for comprehensive information, (3) information preferences equally, and (4) preferences for production inputs information. Preference heterogeneity is mainly explained by risk attitude, risk perception, information concern, traceability cognition, gender and other factors. The findings from this study can provide stakeholders and policymakers with certain insights as well as strategies on information provision and disclosure for fresh produce blockchain-based traceability.

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1. Introduction

The traditional agri-food supply chain has been beset with an information asymmetry problem that prevents consumers from acquiring information about food quality and safety (Lin *et al.,* 2019). Asymmetric food information was likely to cause adverse selection or moral hazard on the market, leading to market failure or even food safety incidents (Caswell and Mojduszka, 1996; Mccluskey and Loureiro, 2003). Food labels then emerged as a solution to break information asymmetry between products and consumers (Gao and Schroeder, 2010). Traceability labels, like QR code, can transform the credence attribute into the search attribute (Opara, 2003). Consumers can scan the QR code with their mobile phones to have access to specific product attributes. Such information disclosure also helps strengthen food regulatory enforcement and create private market incentives. In China, the 'Pilot projects for the quality and safety supervision systems of urban agricultural products' was implemented in early 2004 to prevent quality and safety risks in agri-food production, processing and circulation. By the end of 2014, a total of five batches of pilot projects had been carried out in 58 cities to launch the 'Circulation traceability systems for meat and vegetables'. In the meantime, the pilot subjects were gradually expanded from meat and vegetables to fruits, Chinese traditional medicinal crops, alcohol, dairy products, aquatic products and others. However, this traditional food traceability systems based on a centralized system is confronted with such risks as data tampering, information faking, and information island among stakeholders (Bodkhe *et al.,* 2020; Lin *et al.,* 2019; Sander *et al.,* 2018). The authenticity of traceability information was consequently questioned by consumers (Liu *et al.,* 2019; Wu *et al.,* 2015; Zhang *et al.,* 2012). In short, existing traceability systems failed to ensure consistent information flow along the food chains (Badia-Melis *et al.,* 2015).

In recent years, to restore consumers' confidence in food safety and quality, blockchain technology is being applied to agri-food traceability systems to effect complete tracking and disclosure of food quality and safety information (Demestichas *et al.*, 2020; Fu *et al.*, 2020; Niknejad *et al.*, 2021). Blockchain is a decentralized ledger with an encryption algorithm, chronological storage and data sharing (Chen *et al.*, 2022; Sander *et al.*, 2018). The technology, when adopted, can store data on distributed blocks, connect them with chains; and generate a unique electronic label (such as a QR code) for a product. Users are thus able to obtain traceable information through standard digital port information scanning (Collart and Canales, 2022). If an incident related to food safety occurs, the system can quickly track back to the source of possible problems for solutions. Compared with traditional food traceability systems, the new systems provide safer, more transparent and accurate information (Iansti and Lakhani, 2017) only if the input information is accurate, which help to improve information authenticity and credibility in the food value chain (Feng *et al.*, 2020; Galvez *et al.*, 2018). Otherwise, quality problems can arise as in any other system (e.g. a garbage-in-and-garbage out principle). Trusted food traceability systems can thus be rebuilt by making use of these advantages. In agri-food traceability, most of blockchain-based applications were implemented as pilot projects (Kamath, 2018; Lin *et al.,* 2021; Thomasson, 2019). In 2021, a document issued by the Chinese Ministry of Agriculture and Rural Affairs encouraged leading enterprises to apply blockchain technology into the construction of product traceability systems[1]. Yet, there is scant evidence of whether the embedding of this new technology can booster consumers' confidence in food traceability.

Although blockchain is not the only technology used in food traceability, the reason why we focus on this technology is that it can effectively solve the problems in current traceability systems, like structure centralization, low data security and easy tampering, ensure the integrity and authenticity of the 'farm to table' information, and achieve more effective control on food safety. The role of the information technology is to provide effective traceability information, but what types of information is more effective needs to be further clarified (Hilten *et al.,* 2020). Verbeke (2005) argued that the information supply was effective only if it met the information needs of the target audience. Thus, whether the food information match consumer needs remains extremely critical for new blockchain-based traceability systems. Evidence shows that the information from food traceability systems could positively affect consumers' perception of food quality

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[1] The information can be found at: http://www.moa.gov.cn/nybgb/2021/202111/202112/t20211222_6385258.htm (in Chinese)

(Dickinson and Bailey, 2002). Traceability information powered by blockchain was important for consumers' decision-making, which contributed a lot to better product diagnosis and purchase decisions (Zhai *et al.,* 2022).

Several questions arise to be systematically explored under the background of blockchain-based traceability. First, blockchain-based traceability can be regarded as an enhanced version or a higher level of traceability. To consumers as the users of traceable information, how can they assess the information value based on blockchain traceability? Secondly, which attributes of the most preferred information can be traced by a blockchain-based traceability system? And is there any heterogeneity in information preferences among consumers? Knowledge gaps may exist in terms of consumers' preferences for information provision and the heterogeneity in consumer preferences, and the question how stakeholders can effectively improve their communication concerning product information needs to be further explored.

The theoretical research in blockchain has touched upon food traceability (Collart and Canales, 2022), and its practical applications (Casino *et al.*, 2021; Hilten *et al.*, 2020). In addition, a few scholars have analyzed consumers' purchase intention of blockchain traceable food (Lin *et al.*, 2021; Violino *et al.*, 2019). Some have studied consumers' preference for food traceability information (Liu *et al.*, 2018; Van Rijswijk and Frewer, 2012), yet there are inconclusive findings regarding information preferences. The measurement methods applied in these studies, such as scale and interview, were subjective and overlooked the proportion of the preference for each information attribute, and the heterogeneity in consumer characteristics and information sources. More importantly, little research has identified the amount of fresh produce information traced by blockchain technology from the perspective of consumers' preferences, especially for fresh fruit. This study, from an explorative perspective, addresses this gap to assess the fresh fruit information value on blockchain-based traceability.

With the improvement in living standards and the increased demand for nutrition and health, the consumption of fresh fruits has increased several-fold. In 2020, compared with that in 2013, the per capita consumption of fresh fruits and melons by urban residents has increased by 26%, reaching 60.1 kg, which is much higher than that of meat, eggs and milk[2]. However, the problem of fruit quality and safety has become more prominent. According to previous researches (Li *et al.*, 2022; Ma and Yuan, 2018; Wu *et al.*, 2017), the incidence of agricultural product safety was much higher than that of other types of food, and fruits and fruit products were one of the five food categories with the largest number of incidents. Therefore, the implementation of blockchain-based traceability in the fruit industry has gained more practical significance and would provide coherent insights for private market incentives, regulatory enforcement, and advanced supply chain adoption.

In a nutshell, by taking fresh fruits as a study object, this research intends to explore consumers' preference and perceived value for blockchain-based traceable information based on a best-worst scaling (BWS) experiment. Also, it tries to examine the heterogeneity influence on consumers' preference for information in decision-making. Finally, discussions are conducted regarding the way that fresh produce blockchain-based traceability systems effectively record and transmit information in aim to overcome information asymmetry and upscale information disclosure.

The study is structured as follows: the following section provides a literature review on blockchain and BWS method; section 3 explains the BWS experiment design and discusses the data and empirical methods applied; section 4 presents the empirical results and discussions; and conclusions are finally drawn, together with research implications, study limitations and future research directions.

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[2] Consumption data from China Statistical Yearbook (2021): http://www.stats.gov.cn/tjsj/ndsj/2021/indexch.htm (in Chinese)

2. Literature review

2.1 Research on the theory and application of blockchain in the agri-food traceability

Blockchain is defined as a decentralized ledger that contains transactions as data blocks, linking to their predecessors by a cryptographic pointer. The chain continues to the originator, the first block (Kouhizadeh *et al.*, 2021). Blockchain technology has security features, such as distributed consensus, data immutability, tamper-resistant, encrypted timestamp, verified, and transparent information (Creydt and Fischer, 2019). This technology enables transparent, secure, decentralized ledgers, smart contracts and reliable networks for sustainable supply chain management (Kouhizadeh *et al.*, 2021). Especially under the supply chain disruptions like the COVID-19 pandemic, blockchain-based traceability can effectively address consumers' quality and safety concerns and the transparency of fresh agricultural product supply chain (Collart and Canales, 2022). The blockchain traceable QR code label can be regarded as an extrinsic food quality attribute, which enables wider understanding of product quality and fosters a better information management along the food supply chains, thanks to improved information accessibility, availability and sharing (Stranieri *et al.*, 2021).

Some scholars have evaluated the application of blockchain into the traceability of specific agricultural products. Casino *et al.* (2021) proposed a blockchain-enabled food supply chain traceability model for the dairy sector. Results show that this model produced several benefits in improving trust, efficiency, quality and resilience. Meidayanti *et al.* (2019) designed a traceability system for beef supply chain based on blockchain technology, which included farmers, feedlots, processing plants and retailers. It was found that the blockchain could create a transparent and efficient supply chain through data sharing among stakeholders. Bumblauskas *et al.* (2020) revealed that a company in the Midwest of the United States introduced blockchain technology and the internet of things (IoT) technology to trace egg supply chain management. The traceable and transparent food supply chain can not only help consumers to obtain pre-purchase information, but also facilitate stakeholders to establish better relationship with their customers, and reduce the risk and the cost of food recalls, frauds and product losses. In addition, Van Hilten *et al.* (2020) proposed that the optimization of chain partner collaboration and the selection of capture data were two key factors in building up blockchain-based traceability for European organic food enterprises.

Walmart, IBM, and Tsinghua University launched a field project to carry out the traceability systems powered by blockchain technology in 2016, specifically involving two blockchain pilots: pork products in China and mangoes in Americas. The results showed that the technology not only reduced the time spent in tracing mangoes from South and Central America to North America, cutting it down from seven days to 2.2 seconds, but also promoted greater transparency across Walmart's food supply chain (Kamath, 2018). Visser and Hanich (2018) described that the World Wildlife Fund employed blockchain to trace tuna produced in the Pacific Islands, and recorded the whole-process information from catch to dining table. Carrefour also launched blockchain-traceable products. According to the preliminary report of the Carrefour initiative, consumers were willing to accept blockchain-traceable products and preferred to spend up to 90 seconds reading source information (Thomasson, 2019).

2.2 Research on blockchain-based traceability and consumer willingness

A few studies have analyzed consumers' purchase intentions for blockchain traceable products, their willingness to use the blockchain-based traceability systems and influencing factors. Dionysis *et al.* (2022) noted that attitude, perceived behavior control and environmental protection measures enhanced consumers' willingness to buy blockchain traceable coffee. Sander *et al.* (2018) believed that blockchain technology would have a greatly positive impact on purchase intentions. Lin *et al.* (2021) found that attitude, perceived behavior control, information system quality and trust significantly influenced the usage intention in adopting blockchain organic food traceability system. Garaus and Treiblmaier (2021) found that blockchain-based traceability positively affected consumers' trust and subsequently influenced the

choices made by consumers and retailers. Some scholars have also investigated consumer preferences and their willingness to pay for food with a blockchain-based traceability label, and found that consumers did have such a premium for food, like olive oil (Violino *et al.*, 2019), mutton (Williamson, 2019), and beef (Lin *et al.,* 2020; Shew *et al.*, 2022).

2.3 Research on the application of best-worst scaling experiment

The BWS experiment, also known as maximum difference scaling, originated from the discrete choice experiment (Finn and Louviere, 1992). BWS requires respondents to select the best and worst items from a series of options, based on their cognition. Thus, they have to make trade-offs while choosing best and worst options. The best and worst choices indicate the biggest difference in respondents' preference for options, thus the priority of their preference being evaluated at an individual level (Lusk and Briggeman, 2009). Compared with traditional ranking methods (like likert rating scale or paired comparison method, ranking method, and scoring method), BWS can effectively overcome deviation defects (for example, acquiescence deviation, social expectation deviation and extreme response deviation) when applied to the comparison of multiple objects and the improvement of the discrimination among different options (Louviere *et al.*, 2013; Widmar *et al.,* 2019).

Many scholars have applied BWS to study the preference for food labels and information attributes. Lagerkvist (2013) employed BWS to evaluate the importance of package label information in consumers' choosing beef. The results showed that the information about the traceability to a specific breeder and the country of origin played an important role, which served as quality cues for consumers. Jin *et al.* (2019) applied BWS to study the evaluation made by Chinese consumers on thirteen attributes of fresh milk, and concluded that, to those consumers, safety certification and shelf life were most concerned, while country of origin, purchasing location and package were ranked as the least preferred attributes. Liu *et al.* (2018) studied Chinese consumers' preference for traceable information on pork, vegetables and dairy products, suggesting that consumers had distinct information preferences. However, the study adopted the simplest counting analysis, which could not ensure the accuracy of each attribute preference, and neglected the impact of other factors on the preference.

To sum up, some scholars have conducted extensive studies on theory and pilot application of blockchain in agri-food traceability field. Existing literature has also analyzed consumers' purchase intentions and their willingness to pay for blockchain-traceable products, and usage intention for blockchain-based traceability systems. However, there is little research that explored how consumers weigh up or balance food information based on this new traceability system powered by blockchain, from the perspective of consumers' information needs. In complementing the studies and addressing these gaps, our article possibly contributes to the strand of literature on food blockchain-based traceability in multiple ways. First, this study quantifies consumers' perceptions and preference shares for blockchain-based traceability information in an attempt to offer insights on the role of information preferences. Secondly, existing traceability studies mostly focus on meat products, such as pork, beef, chicken and dairy, and pay less attention to fresh fruits, thus leading to research gap regarding traceability information in the fresh fruit industry. Our BWS experiment encompasses a list of fruit information attributes. It will enhance our understanding of consumer preferences for blockchain traceable fresh produce from a new and important aspect, as blockchain technology is expanding to agriculture products, including fresh fruit (such as peaches, oranges and apples), and it will solve problems that seem to be fairly demanding for traditional traceability methods. Thirdly, BWS allowed us to specify a larger number of attributes (in our study sixteen fruit information attributes were identified) to provide sufficient data for researchers and accurately estimate the importance of each attribute. This study examined the relative valuation of each attribute, and the results showed preference heterogeneity among consumers regarding blockchain-traceable information. Furthermore, this study's findings may offer useful implications for food value chain stakeholders who are interested in establishing blockchain-based traceability systems.

3. BWS experiment and empirical methods

3.1 Experiment design

The information attributes refer to the collection of information recorded in the production, processing, circulation and sales and they form the basis for the establishment of the traceability systems for fresh produce (Opara, 2003). The implementation of a blockchain-based traceability system is a realistic approach to improve fruit quality and safety measures. The study was structured based on the findings from relevant researches (Dekhili *et al.*, 2011; Jin *et al.*, 2017) and pilot studies, with and crop growth characteristics, biological traits and supply chains information taken into consideration. Our study identified sixteen information attributes on fresh fruits, like origin information, growth environment and growth process. Table 1 provides detailed information on the attributes being studied.

The choice set design is the key to the implementation of BWS. When designing a BWS experiment, we need to consider the number of choice sets and attributes simultaneously. Too many choice sets may tire respondents, while too many attributes in each choice set may be distracting (Scarpa *et al.*, 2011). Balanced incomplete block design (BIBD) is one of the experimental designs mostly implemented in BWS (Villanueva and Glenk, 2021). However, researchers have noted difficulties when generating BIBD with a restricted number of choice sets and attributes. For this reason, many studies relax the orthogonality criterion when generating BIBD experimental designs, i.e. near balanced incomplete block design (NBIBD) (Muunda *et al.*, 2021). Therefore, to allocate different information attributes to each choice set, we used Maxdiff macro in Sawtooth Software (Provo UT, USA) to generate a NBIBD design after 10,000 iterations. The final BWS experiment had sixty choice sets, with each set including four information attributes (as shown in Figure 1). The sixty choice sets were separated into five blocks, twelve for each, to reduce the cognitive burden on

Table 1. List of blockchain traceable fruit information and its description.

	Information attributes	Description
1	Origin information	Orchard location, address, variety, area
2	Growth environment	Soil type, temperature and humidity, water, topography
3	Growth process	Date and stage (seed selection, plowing and irrigation, sowing, cutting branching, deworming)
4	Fertilizer record	Date, product name, size, active ingredient, dosage per mu, total dosage
5	Chemical pesticides	Date, product name, size, composition, object to being prevented, dosage, safety interval
6	Green technology	Insect pheromone, insecticidal lamp, trap board, orchard grass cover, natural enemy trap belt
7	Harvesting information	Picking time, maturity, post-harvest pretreatment (cleaning and pre-cooling)
8	Agri-food quality grades	Grading standard, grading method (labor/computer), classification attributes, classification technology
9	Fruit quality information	Size, shape, coloring rate, defect, sweetness, acidity, firmness
10	Packaging information	Packing date, packing specifications, packing materials
11	Testing information	Testing agency, pesticides residue testing report, planting soil and water quality testing report
12	Quality certification	Whether to obtain green/organic/geographical certification
13	Logistics information	Transportation temperature, product flow trajectory, arrival time
14	Storage management	Storage unit, storage environment, storage method, preservation measures
15	Supplier information	Supplier/distributor profile, address, the person in charge, business license
16	Retail information	Dealer profile, address, the person in charge, product batch, sales date, and shelf life

the respondents from having to evaluate more questions during the survey. Each attribute was presented three times per block, and one information attribute was compared with another one 0.6 times. The mean of position frequencies was set at 0.75 to satisfy almost orthogonality. On the whole, the design met the criteria including frequency balance, position balance, connectivity among tasks proposed by Ola and Menapace (2020) for optimal experimental design, and almost orthogonality (Muunda *et al.*, 2021). And to avoid the order effect biases (Koemle and Yu, 2020), blocks and the choice sets within each block were randomized for each participant. The five blocks of the BWS experiment were included in five versions of the questionnaires.

3.2 Survey design

It should be noted that before presenting the BWS tasks in the survey, we drafted an *information statement* about the *blockchain-based fresh produce traceability systems*, which was adapted from Collart and Canales (2022) research, with details shown in Supplementary Figure S1. So far blockchain technology has not been widely used in the construction of agricultural product traceability systems, for it is still in the pre-development stage. Though face-to-face pilot investigation, it was found that respondents were unfamiliar with this relatively new traceability technology, and therefore, the provision of the information on the blockchain-based fresh produce traceability was necessary for respondents to answer the best-worst questions.

For each BWS choice set, respondents were asked to select two from four pieces of fruit information, that is, the most valuable (most important) and the least valuable (least important) to be recorded into the blockchain-based traceability systems. Apart from the information statement mentioned above, choice sets were preceded with the following words:

> 'You will now be asked to select the fruit information which you think is the most or least valuable/ important in blockchain-based traceability systems. Please answer the following questions as honestly as possible and we would like to know which fruit information you want to be traced by the blockchain technology from farm to your table.
>
> Take the blockchain-based fresh fruits traceability systems as an example, 12 choice tasks are provided below. Each choice task contains four traceability information attributes. From each set, please indicate the piece of information you think is the most valuable (most important) information to be traced by blockchain technology and the piece of information you think is the least valuable (least important) one for you as a consumer: Please tell us your preferences regarding blockchain traceable information for fresh fruits'.

Least valuable (one answer)	Information attributes	Most valuable (one answer)
☐	**Origin information** (Orchard location, address, variety, area)	☐
☐	**Logistics information** (Transportation, temperature, product flow trajectory, arrival time)	☐
☐	**Green technology information** (Insect pheromone, insecticidal lamp, trap board, orchard grass cover, natural enemy trap belt)	☐
☐	**Storage management information** (Storage unit, storage environment, storage method, preservation measures)	☐

Figure 1. An example of a BWS choice set.

Figure 1 shows an example of one of the BWS choice sets used in this study. In order to avoid fatigue and distraction, after the first six BWS questions were answered, a prompt would automatically pop up to encourage the continued response[3]. In addition, the questionnaire also investigated the respondents' food safety perception, risk perception, risk attitude, traceability cognition, and other factors. Conventional demographic questions were also included, such as gender, age, education and income.

3.3 Data collection

The dataset was obtained through an online questionnaire distributed and collected by the professional survey company Wenjunxing (www.wjx.cn), which is the largest online survey platform in China widely used in academic research (Chen and Wang, 2022). The online survey was adopted in the study for its low cost and high efficiency. 71.6% of Chinese population are frequent users of mobile internet (China Internet Network Information Center, 2021). Another reason for the adoption was the COVID-19 pandemic, as China had implemented strict prevention policies to restrict or prohibit mobility from 2020 onward, especially in areas reporting positive infection.

To ensure the validity of the online survey, a pilot one was carried out in Nanjing on April 9.[4] The study randomly surveyed respondents in three representative places including supermarkets, communities and shopping malls, mainly through filling out the online questionnaire. A total of 33 samples were obtained. In addition, we modified the diction in the questionnaire based on respondents' feedback. The rationality of fruit information attributes in this study was verified through the pilot investigation.

An online formal survey was utilized to collect data from Chinese residents from April 12 to May 20th, 2021. This survey was fielded in four Chinese cities (as shown in Figure 2): Nanjing, Beijing, Xi'an, and Fuzhou. The selection of survey regions was mainly based on the following considerations: first, these four cities are pilot sites for building *circulation traceability systems projects for meat and vegetables* in batches with the support of government policies. Nanjing in southern China was among the first batch to construct the traceability systems from 2010; Beijing in the north and Xi'an in the west were the third ones from 2012; and Fuzhou on the southern coast was selected into the fourth batch from 2013. The diversity in city profiles allowed more generalized conclusions on consumer preference for fruit information attributes. Secondly, there were geographic, economic, and social differences across those cities selected; they could reflect the possible heterogeneity among consumers for traceable fresh agricultural products. According to National Bureau of Statistics (2020)[5], the per capita disposable income of urban residents in Beijing, Nanjing, Fuzhou and Xi'an was $10,996, $7,614, $6,794 and $4,962, respectively. Difference in income represented the regions with different levels of economic development, which could contribute to the data representativeness and results produced. Furthermore, the research time was set from April to May in the consideration of the characteristics of fruit market and better opportunities to purchase fruits.

The survey platform was responsible for randomly distributing questionnaires into the databases of four cities. A total of 1,126 completed responses were collected. According to the sample screening rules (primary food shopper of the household, who had purchased fruit in the past month, and over 18 years old), after those with missing or wrong answers and obvious logical errors were removed, 1,058 valid samples were finally obtained, of which 284 in Nanjing (including pilot observations, because diction revisions after the pilot investigation as mentioned above did not have a significant impact on the model results of the research), 257 in Beijing, 261 in Xi'an and 256 samples in Fuzhou, respectively.

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[3] Prompt content: Congratulations! You've already answered half of the tasks. It's great! There are still six tasks left. Please continue to balance this information and make your choice. Only when all the tasks are completed can the questionnaire be valid. Thanks so much!

[4] Note that we chose Nanjing as the pilot survey place because there were no COVID-19 positive patients mobility in this city on April. Thus residents in this city can move freely.

[5] Data available online at: www.stats.gov.cn (in Chinese).
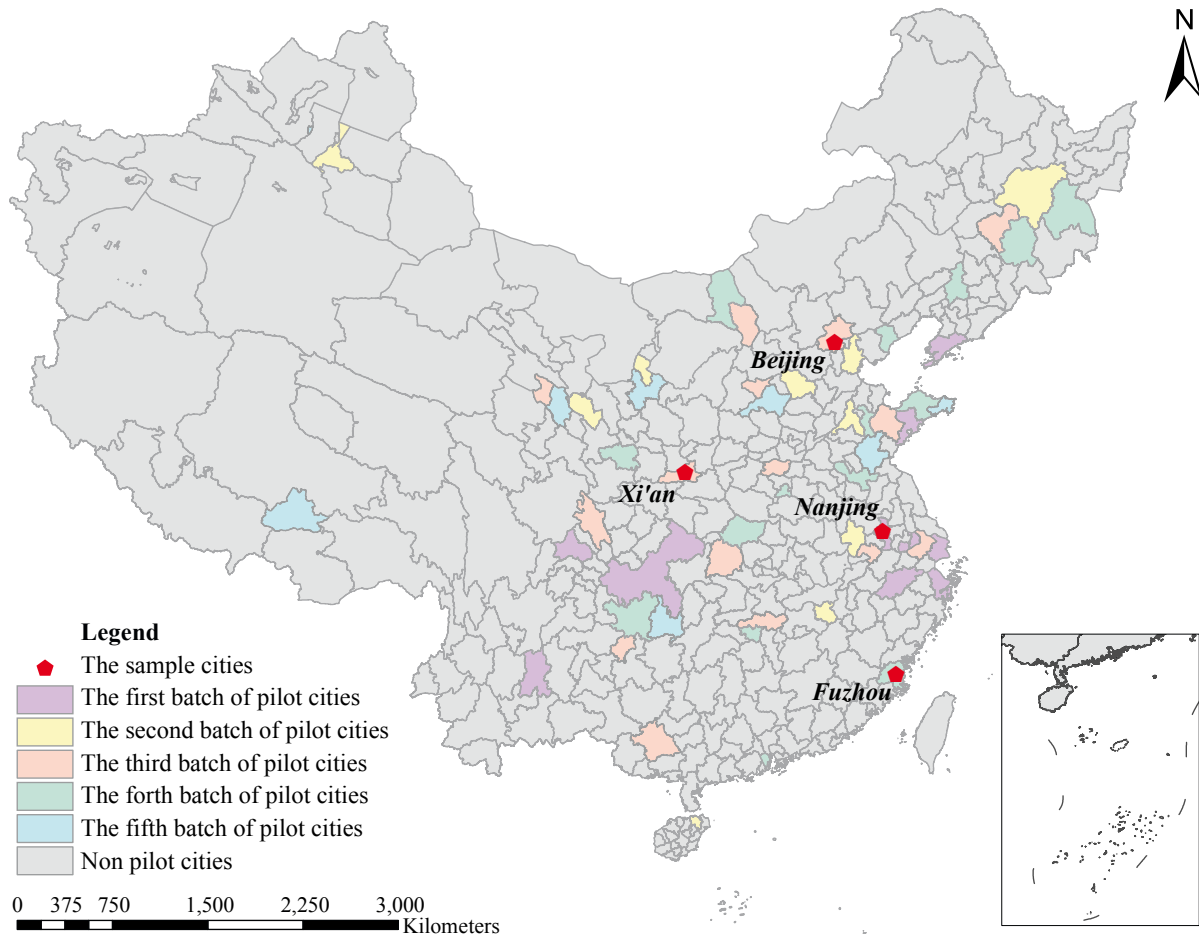
Figure 2. Four locations for formal survey: Nanjing, Beijing, Xi'an, and Fuzhou.

3.4 Method and model construction

■ *Count method*

The scoring method provides a basis for analyzing BWS data (Louviere *et al.*, 2015). The results of the scoring method can filter out a reference information attribute for the subsequent choice model, and can also be used to test the robustness of the model results (Ola and Menapace, 2020). This study calculated: (1) the number of times that each traceability information was selected as the most or the least valuable across all choice sets; and (2) the difference between the biggest and smallest scores between each attribute. In order to more intuitively explain the BWS data, we transformed the scores to a positive scale by using the square root of the ratio of the biggest to the smallest scores of each information attribute (as show in Table 3). In addition, we standardized the positive scales where the most valuable information (testing attribute) took the value of 100 by multiplying the weighting factor (31.95) obtained, with the formula below adopted (Loose and Lockshin, 2013). This means that all the least valuable information was interpreted as the ratio relative to the most valuable information.

$$Weighting\ factor\ for\ standardized\ ratio\ scale = \frac{100}{max(sqrt\frac{B}{W})} \tag{1}$$

To compare the relative importance of each information attribute and further simplify the interpretation, the square-root scale was weighted and standardized to add up to 100%, in which the weighting factor was 5.25 in our paper. The specific formula is shown below:

$$Weighting\ factor\ for\ relative\ importance = \frac{100}{\sum_{n=1}^{i}(sqrt\frac{B}{W})} \tag{2}$$

■ *Model estimation*

Based on the basic framework of random utility theory (Lancaster, 1966; McFadden, 1974), it was assumed that U_{nit} represented the total utility of respondent n ($n = 1, \ldots, 1058$) with the information i ($i = 1, \ldots, 16$) chosen from choice set t ($t = 1, \ldots, 12$) which was composed of the deterministic part V_{nit}, and unobservable random error term ε_{nit}. The expression could be written as follows:

$$U_{nit} = V_{nit} + \varepsilon_{nit} \tag{3}$$

Considering the utility maximization, respondent n would choose information i over information j when the utility from selecting i was greater than that from selecting j, namely, $U_{nit} > U_{njt}(\forall j \neq i)$.

However, in the BWS experiment, when responding to each best-worst question, respondents could be conceptualized as choosing the two items that maximized the difference between two items on an underlying scale of value. If each choice set had I information attribute (4 in our case), respondents would select a best and worst pair from $I(I-1)$ possible best-worst combinations (12 in this study) to maximize value difference. If a respondent n chose information i and j as best and worst combination, the latent unobserved level of value between i and j would be given in the following equation:

$$U_{ij} = \lambda_i - \lambda_j + \varepsilon_{ij} \tag{4}$$

Where ε_{ij} represents the random error term; λ_i is defined as the observable location of the information i on the scale of value. Therefore, the probability that respondent n chooses information i and j in choice set t is the probability that the difference i and j is greater than the distance between all other $I(I-1)-1$ possible combinations.

Assuming the homogeneity of preference, this parameter would remain constant among all consumers. We used the multinomial logit model or conditional logit model (MNL), which assumed that the error terms were *i.i.d.* type I extreme value (McFadden, 1974). The probability that the respondent n selects the information attribute i as best information attribute and j as worst information attribute among combinations of alternative $I(I-1)$ is specified through the formula below:

$$P_{nij} = \frac{e^{\lambda_i - \lambda_j}}{\sum_k^I \sum_m^I e^{\lambda_k - \lambda_m}} \tag{5}$$

The dependent variable takes the value 1 when consumers select a pair of traceability information in the choice set as best and worst and 0 for the remaining $I(I-1)-1$ possible combinations not chosen by consumers. The maximum likelihood estimation was used to estimate the parameter λ_i, which provided the value of information i relative to the information normalized to 0 to avoid the dummy variable trap (Lusk and Briggeman, 2009). Effect coding was adopted for data transformation: the information attribute had the value 1 when the attribute was described as the most valuable, and value -1 when described as the least valuable, and 0 otherwise.

Consumer preferences for blockchain traceable information attributes may be heterogeneous. The random parameters logit (RPL) model, also known as mixed logit model, is considered to be a highly flexible one, which relaxes the limitations of a traditional logit model. It is commonly used to account for heterogeneity in preferences among individuals. The coefficients of each attribute are not fixed and can be changed randomly according to a specified distribution (McFadden and Train, 2000). Therefore, following Lusk and Briggeman (2009), the importance parameter of information attribute i in the RPL is assumed to be different for each respondent n, as shown below:

$$\hat{\lambda}_{ni} = \bar{\lambda}_i + \sigma_i \mu_{ni} \tag{6}$$

Where $\bar{\lambda}_i$ and σ_i refer to the mean and standard deviation of λ_i, and μ_{ni} to a random error normally distributed with mean zero and unit standard deviation. Equation (6) was substituted into equation (5), and the parameters were estimated by maximizing a simulated log-likelihood function (Train, 2003). In the standard RPL model, it is assumed that parameters are independent; however, information attributes are expected to be interdependent. To consider this interdependency, the correlation structure of information parameters was assumed to follow a multivariate normal distribution (Bazzani *et al.,* 2018).

To identify possible drivers of preference heterogeneity, we further estimated the latent class (LC) model, where the preference heterogeneity was discrete (Boxall and Adamowicz, 2002). The distribution of preference parameters involved a discrete density function, which could estimate the homogeneous preference of each class and better reflected the characteristics of each potential class of respondents. If respondents belong to a specific potential class *q*, the conditional probability of choice can be expressed as:

$$P_{nij}|q = \frac{e^{\lambda_{iq}-\lambda_{jq}}}{\sum_k^I \sum_m^I e^{\lambda_{kq}-\lambda_{mq}}} \qquad (7)$$

Where λ_{iq} represents class-specific utility parameters, that is, the preference heterogeneity between different classes. Thus, the probability that the respondent *n* falls into a certain class is represented as follows:

$$P(q) = \frac{e^{\theta_q Z_k}}{\sum_{q=1}^Q e^{\theta_q Z_k}} \qquad (8)$$

Where Z_k represents a set of observable characteristics that enter the model as candidate drivers of class membership, and θ_q represents a series of eigenvectors that affect consumers categorization into a potential class (Ouma *et al.*, 2007).

Considering the mean of the parameter estimates of λ_i might be confounded with differences in scale, because the random error term could vary with respondents or alternatives, the estimated parameters in RPL and LC model might not be easily interpretable. Thus, we calculated shares of preference (SP) for each information attribute (Wolf and Tonsor, 2013). Each SP reflected the information's importance on a ratio scale, which described the prediction probability of each information being selected as the most valuable.

$$\text{shares of preference for information } i = S_i = \frac{e^{\hat{\lambda}_i}}{\sum_{k=1}^J e^{\hat{\lambda}_k}} \qquad (9)$$

If one information attribute *i* was twice as a big preference share as another attribute, it could be accurately believed that the attribute *i* was twice as important or preferred as the other. The SP for each of the sixteen information attributes could be summed to one. In addition, this study also calculated the individual-specific preference shares based on individual parameters of RPL model to further estimate the correlation of information attributes and the difference between regional preference shares. All the models were estimated by using Stata 16.0 software.

4. Descriptive statistics and empirical analysis

4.1 Respondents' socioeconomic and demographic characteristics

The characteristics of our survey respondents are presented in Table 2. Among those sampled, women accounted for 60%. Based on previous similar surveys, most of the primary food buyers in a family are women. The age of respondents averaged 31 years old, but the standard deviation was large, and the age distribution was relatively uniform, basically in line with the age structure distribution of urban residents across the country. Most of the respondents received a college or undergraduate education, reflecting a high level of education in our samples, which might be related to the fact that provincial capital cities had been selected for the survey. Households in our samples had about two children. Households with an annual income of more than $22,350 accounted for 51.2%. According to China statistical yearbook 2020, compared with overall urban residents in China, online survey samples are characterized with a high proportion of female

Table 2. Characteristics of survey pooled samples (n=1,058).

Variables	Variable descriptions	Mean/%	Std dev.
Gender	Female=1; Male=0	0.60	0.49
Age	Age (years)	30.92	7.96
Education	Senior high school or lower	7.2%	-
	College educated	82.8%	-
	Graduate educated or above	10.0%	-
Children	Number of those below 18	1.78	0.77
Family income	$7,450 and below	10.1%	-
	$7,450-22,350	38.7%	-
	$22,350 and above	51.2%	-
Purchase experience	Have purchased agricultural products with traceable labels before (yes=1; otherwise=0)	0.83	0.37
Scanning experience	Have scanned traceability QR label before (yes=1; otherwise=0)	0.49	0.50
Traceability cognition	Have heard of food traceability systems before (yes=1; otherwise=0)	0.85	0.36
Food safety perception	Consumer's perception toward food quality and safety (including excessive pesticide residues, illegal use of additives, overuse of antibiotics and food-borne disease outbreak) (1=not at all concerned and 5=extremely concerned in 5-point Likert scale)	4.10	0.64
Origin concern	Concerns about mislabeling of production origin on food products (1=not at all concerned and 5=extremely concerned in 5-point Likert scale)	3.61	1.00
Information concern	Concerns about product handling, and practices (planting, breeding, processing, transportation, retail) (1=not at all concerned and 5=extremely concerned in 5-point Likert scale)	3.58	0.97
Risk perception[1]	Consumer's risk perception toward fruit quality and safety (5-point Likert scale; the value 1 to 5 means the risk perception from weak to strong)	3.78	0.57
Risk attitude[2]	Consumer's risk attitude toward fruit quality and safety (5-point Likert scale; the value 1 to 5 means the risk preference from low to high)	2.45	0.68
Sample size	1,058		

[1] Variable sums up the results of four questions and takes mean value: (1) At present, incidents involving food safety, such as pesticide residues and illegal use of preservatives and industrial waxes, occur from time to time. I am more concerned about health risks after fresh products are purchased; (2) At present, fresh fruits containing chemical substances, resulting from industrial waste or polluted water, account for a large part of fresh fruits on the market; (3) At present, fresh fruits containing chemical substances harm consumers' health; and (4) Increasing phenomenon of forged origin identification (i.e. mislabeled production origin on fresh produce) raises the level of risk on fruit market: 1 = strongly disagree, 2 = somewhat disagree, 3 = neutral, 4 = somewhat agree, 5 = strongly agree.

[2] Variable sums up the results of four questions and takes mean value: (1) Although I often heard bad news regarding pesticide residues and the illegal use of preservatives and industrial waxes, this does not affect my purchasing of fresh fruits; (2) I do not care about production origin when buying fresh fruits; (3) When consuming fresh fruits, I never worry about pesticide residues, preservatives, or industrial waxes; and (4) I can accept the health risks caused by fresh fruits containing chemicals. 1 = strongly disagree, 2 = somewhat disagree, 3 = neutral, 4 = somewhat agree, 5 = strongly agree.

participants, young age, high education level and high income. Compared with the results of field research in the existing literature (Liu *et al.,* 2019; Tian *et al.*, 2022; Wu *et al.,* 2015), the samples were very similar in terms of basic structural characteristics.

From the consumption experience of the respondents, more than 80% had purchased traceable fresh agricultural products, and 85% had heard of food product traceability systems. Likewise, less than half of respondents had queried traceability QR code, showing that some gained knowledge about traceable foods. Yet, the low scanning rate indicates that traceability systems might not be good enough, and the traceability information recorded did not appeal much to consumers. Questions regarding consumers' perception about food quality and safety were measured on a five-point Likert scale ranging from 1 (not at all concerned) to 5 (extremely concerned). More than 90% (score >3) were cared about the quality and safety of fresh agricultural products. The higher proportion of concern about food quality might be related to the current improvement of people's income level, increased attention to a healthy diet and the frequent occurrence of food safety incidents, which may affect consumers' safety perception. In addition, more than half of the respondents pay more attention to identifying food origin. At the same time, consumers were also concerned for the information about product handling, and practices (planting, breeding, processing, transportation, and retail) involved in the supply chain.

Consumers' risk response can be divided into risk perception and risk attitude (Pennings *et al.*, 2002), both measured on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). For risk perception, the score from 1 to 5 meant the risk perception from weak to strong. Results show that about 87.2% (score >3) were concerned about fresh fruit quality and safety, including pesticide residues, illegal use of preservatives and industrial waxes, chemicals contained, and counterfeited origin sources. About 7.0% (score = 3) respondents showed neutral risk perception. Only 5.8% (score <3) were not concerned about fruit quality and safety risk. In terms of risk attitude, the score from 1 to 5 indicated the risk preference from low to high (or the risk-averse from high to low). The average score was 2.45, indicating that respondents were generally risk-averse. Among them, 74.3% (score <3) were risk-averse, 16.3% (score >3) were willing to accept a risk when consuming fresh fruits, indicating that these people had a stronger risk preference, and the remaining 9.5% (score = 3) were risk-neutral. In general, most of the respondents showed a high level of risk perception and were identified as being risk-averse.

Our study also reports summary statistics of sub-samples' characteristics in different survey regions, as detailed in Supplementary Table S1. *Kruskal-Wallis* test showed that there were statistical differences in age, education, income, children and risk perception in respondents samples across regions. The average age of respondents in Beijing was significantly older than that in Fuzhou. In terms of education level, respondents in Xi'an showed the highest proportion of education level in senior high school and below, accounting for 11.1%. The overall education level of the respondents in Beijing was higher than that of other three regions, the proportion of graduate education being 17.9%. Most households in Fuzhou'sample had about two children. In terms of annual income, households in Beijing were the highest, the income of $22,350 accounting for 67.3%, while the samples from Xi'an showed the lowest. On average, respondents in Fuzhou and Xi'an had higher risk perception of fruit than those in Beijing and Nanjing.

4.2 Counting scores

The results of the B-W scores, standardization ratio scale and relative importance are presented in Table 3. In general, the ranking of traceable information was highly consistent, whether based on the square root of the B-W scores, standardization ratio or standardized relative importance scores. We focused on the standardized relative importance scores. About 16.4% of the consumers believed that the testing information to be traced by blockchain technology was the most valuable, followed by chemical pesticides information (14.8%) and quality certification information (11.3%). These three information attributes together accounted for a plurality of weights, which implied that consumers were more concerned about risks brought about by the uncertainty in food safety, reflecting a greater health concern and risk perception. Thus, the information related to food safety should be recorded preferentially by the blockchain-based traceability systems. In addition, the fourth and fifth most valuable information attributes were fertilizer record and agri-food quality grades, with the rest concerning fruit quality information, green technology, retail information, and storage information. Only a small percentage of consumers believed that fruit harvesting information (3.7%) and

Table 3. Raw scores and weight importance of blockchain-based traceability information.

Information attributes	Best	Worst	Best – Worst scores	Sqrt(B/W)[1]	Standardized ratio scale[2] (%)	Relative importance[3] (%)	Rank
Testing information	1,989	203	1,786	3.13	100.0	16.4	1
Chemical pesticides	1,711	215	1,496	2.82	90.1	14.8	2
Quality certification	1,404	302	1,102	2.16	68.9	11.3	3
Fertilizer record	984	482	502	1.43	45.6	7.5	4
Agri-food quality grades	1,026	521	505	1.40	44.8	7.4	5
Fruit quality information	892	618	274	1.20	38.4	6.3	6
Green technology	886	653	233	1.16	37.2	6.1	7
Retail information	668	801	-133	0.91	29.2	4.8	8
Storage information	497	708	-211	0.84	26.8	4.4	9
Harvesting information	504	994	-490	0.71	22.7	3.7	10
Packaging information	453	1,064	-611	0.65	20.8	3.4	11
Growth process	396	1,210	-814	0.57	18.3	3.0	12
Origin information	374	1,158	-784	0.57	18.2	3.0	13
Growth environment	339	1,066	-727	0.56	18.0	3.0	14
Supplier information	293	1,369	-1,076	0.46	14.8	2.4	15
Logistics information	280	1,332	-1,052	0.46	14.6	2.4	16
Sample size	1,058						

[1] Sqrt(B/W) = square root of ratio of best and worst counts.

[2] Standardized ratio scale = sqrt(B/W) × multiply weighting factor (31.95).

[3] Relative importance = sqrt(B/W) × weighting factor (5.25).

packaging information (3.4%) had the most blockchain traceable value. For the information related to the place of origin, about 3% of the consumers surveyed considered that the growth process, the origin or the growth environment information was the most valuable or important in the blockchain-based traceability systems. Supplier information and logistics information were both considered as the least-valued attributes.

4.3 Model results

■ *Relative value of blockchain traceable information*

Results in Table 4 show the relative importance of the sixteen traceability information as estimated from the MNL and the RPL models. To avoid a multicollinearity problem, one explanatory information attribute had to be omitted in the maximum likelihood estimation, so the value of each information attribute was estimated relative to logistics information (the least valuable information according to B-W scores in Table 3). From the overall goodness of fit and the significance of parameters, the *P*-values of MNL and RPL model were significant at the statistical level of 1%, indicating that both models had good goodness of fit. Based on a lower Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), the RPL model displayed a better fit than the MNL. According to the RPL model, the estimate of derived standard deviations was highly significant at 1% significance level, apart from storage information, indicating the presence of heterogeneity in preferences for blockchain traced information among respondents.

This research further estimates the SP for the sixteen items of traceability information, based on the mean parameter estimates from RPL model by using equation (9) to better obtain the value ranking of different information attributes, which could facilitate the effective construction of a blockchain-based traceability system. The SP for information attributes are also reported in Table 4. On average, testing information with a ratio of 23.3% was the most valuable attribute to be traced by blockchain technology. The testing information

Table 4. Multinomial logit (MNL) model and random parameters logit (RPL) model estimation and shares of preference.[1]

Information attributes	MNL	RPL		
	Coefficient	Coefficient	Standard deviation	SP[2]
Origin information	0.171***	0.167***	0.584***	2.4%
	(0.038)	(0.044)	(0.057)	
Growth environment	0.217***	0.217***	0.754***	2.5%
	(0.038)	(0.046)	(0.053)	
Growth process	0.154***	0.142***	0.721***	2.4%
	(0.038)	(0.045)	(0.055)	
Fertilizer record	1.064***	1.187***	0.525***	6.7%
	(0.038)	(0.044)	(0.066)	
Chemical pesticides	1.808***	2.098***	0.769***	16.6%
	(0.041)	(0.051)	(0.061)	
Green technology	0.864***	0.965***	0.729***	5.4%
	(0.038)	(0.045)	(0.055)	
Harvesting information	0.384***	0.422***	0.337***	3.1%
	(0.038)	(0.041)	(0.065)	
Agri-food quality grades	1.036***	1.170***	0.553***	6.6%
	(0.038)	(0.044)	(0.058)	
Fruit quality information	0.911***	1.012***	0.715***	5.6%
	(0.038)	(0.045)	(0.056)	
Packaging information	0.283***	0.308***	0.404***	2.8%
	(0.038)	(0.041)	(0.066)	
Testing information	2.047***	2.436***	1.062***	23.3%
	(0.042)	(0.058)	(0.069)	
Quality certification	1.483***	1.656***	0.447***	10.7%
	(0.039)	(0.044)	(0.085)	
Storage information	0.558***	0.621***	0.076	3.8%
	(0.038)	(0.040)	(0.063)	
Supplier information	-0.029	-0.033	0.392***	2.0%
	(0.038)	(0.042)	(0.088)	
Retail information	0.610***	0.685***	0.564***	4.1%
	(0.037)	(0.043)	(0.072)	
Logistics information	0.000	0.000		2.0%
Log likelihood	-27,663.81	-27,001.17		
AIC	55,357.61	54,062.33		
BIC	55,506.62	54,360.35		
Observations	152,352	152,352		
Sample size	1,058			

[1] ***, ** and * represent 1%, 5% and 10% statistical significance levels, respectively. Standard errors between parentheses.

[2] SP = Shares of preference, estimated from the RPL model.

defined in this study included testing agencies, pesticides residue testing report, and soil and water quality tests. It can enable consumers to become aware of risk factors in food consumption and, therefore, reduce the perceived risk-bias (Zhou *et al.*, 2022). Previous studies also showed that safety was the most important food value (Bazzani *et al.,* 2018; Lusk and Briggeman, 2009). The higher importance of testing information may reflect that the information with strong credibility normally provided by a third-party authority was regarded as an important indicator for food safety among consumers.

The SP for chemical pesticides was ranked second-most valuable information, followed by quality certification information (green, organic or geographical certification). Consumers rated testing information and chemical pesticides information 2 times and 1.6 times as important as quality certification information, respectively. Most studies showed that consumers were willing to pay significant premium for certified agricultural products (Hu *et al.,* 2009; Liu *et al.,* 2017; Yu *et al.,* 2014); therefore, it is important for certification-related information to be traced by blockchain technology, because it could ensure that the products are truly organic or green, or have been produced in line with the methods and standards set out for organic/green agricultural products.

In terms of production inputs, chemical pesticides were perceived to be about 2.5 times and 3 times as valuable as fertilizer record and green technology information respectively. It indicates that the use of pesticides in fruit production, especially pesticide residues, was the focus of consumers' concerns; these results were similar to the research findings of Jin *et al.* (2017). In their work, Jin *et al.* (2017) ranked the traceable information of the apples in eight categories of information on a scale, and found that up to 90% of consumers had the willingness to learn about quality certification, and pesticide and fertilizer information. Liu *et al.* (2018) also found that Chinese consumers were most concerned about pesticides information for vegetables. Excessive pesticide residues would not only pollute groundwater and soil, but also directly endangered human health. Blockchain traceable technology can enhance the transparency in the application process of pesticides, thus regulating pesticide application behavior and preventing excessive use.

With an SP of 6.6%, agri-food information on quality grades was perceived to be about 1.2 times and 2 times as important as fruit quality information and harvesting information, respectively. It suggests that consumers preferred quality grades information to be traced by blockchain traceability relative to other fruit information The possible reason was that the information classified the quality differences of agricultural products, which helped to spread the information of product quality, thus reducing information asymmetry between buyers and sellers. At present, China has formulated relevant national and industrial standards for certain varieties of fruits (10 international plans, 9 national standards and 3 industrial standards for fruit grading) to ensure food quality (NPSPSI, 2022). Previous studies have also shown that information about product grades could meet consumers' preferences and improve consumers' welfare (Zhao and Yu, 2009). This indicates that placing grades information at the top of blockchain-based traceability systems could gratify broader demands in the purchase of fresh fruits. However, appearance quality and harvest date could be directly observed, and most consumers might consider it unnecessary to conduct traceability for such information.

In terms of circulation chain, retail and storage management were ranked as the medium-most important attributes, with SP accounting for 4.1 and 3.8%, respectively. And about 2.8% of consumers preferred packaging information (including packing date, specifications and materials) to be traced by blockchain technology. A possible reason of preferred package could be that packaging attribute could impact product prices (Loose and Szolnoki, 2012), and consumers' product expectations and purchase behaviors (da Rosa *et al.,* 2018). Once the package materials contaminated the food items, blockchain technology could accurately locate the accountable party and timely implement the recall. But the reason for the low shares may be that we did not clearly define whether the packaging material was biodegradable in advance, which might have caused consumers not to take it as the important information.

The remaining five information attributes were fairly close in importance, with their shares ranging between 2 and 2.5%. Supplier and logistics information were considered as the least valuable, similar to the findings from Liu *et al.* (2018) and Jin and Zhou (2014), who reported that transportation information was least preferred among consumers. The growth environment was predicted as the most valuable for about 2.5% of respondents, followed by the information on growth process and origin. It suggests that most consumers did not care about whether such information had been traced.

Note that the traceability value of origin was ranked relatively low in our study, which was consistent with other research findings (Bazzani *et al.,* 2018; Lusk and Briggeman, 2009); they found that the origin information was considered as the least important food value in the US and Norway study. However, these

findings contradicted the survey results in four European countries documented by Van Rijswijk and Frewer (2012), which reported region of origin was the most important characteristic about which consumers needed to be informed. Existing literature suggests that consumers were generally willing to pay a price premium for local food products or those with a designated origin (Costanigro *et al.,* 2011; Lim and Hu, 2016), and the country-of-origin conception could also affect consumers' evaluation of a product (Zhang *et al.,* 2021). What has been discussed above implies that there exists heterogeneity in origin preferences across countries or regions. Lusk *et al.* (2006) revealed that consumers' motivation for origin labels was that credible labeling of an origin was often associated with product quality and safety. Thus, one possible explanation is that origin is likely to serve as a proxy for food safety and even for other attributes (Lusk and Briggeman, 2009). However, the origin as a term in our article, different from the definition of the country of origin (Gao *et al.,* 2019; Yu *et al.,* 2016), mainly refers to orchard location, address, variety and area, which were not directly related to food safety. The attribute directly related to food safety formation (e.g. testing, chemical pesticides) in our study were ranked as the most valuable, and as such, it is possible that if an origin was a proxy for food safety, it would also be ranked high on the value list, when the attributes related to safety were not fully disentangled from origin.

■ *Correlation analysis*

In order to gain a deeper insight into potential relationships among the SPs for the sixteen information attributes, the study further evaluated the correlations between blockchain-traced information attributes by using individual-specific coefficients from the RPL estimation, and correlation estimates are exhibited in Supplementary Table S2. The correlations could help to further clarify the directionality of trade-offs amongst these information attributes. The results show that there was a negative correlation between chemical pesticides and origin information, indicating that consumers who viewed pesticide information as important were less likely to value origin as an important attribute. Testing information was negatively and significantly correlated with all other information attributes, indicating that consumers who cared most about testing information would trade it off with other information. In other words, such consumers tended to place a lower value on other information attributes. The quality certification was positively correlated with all other information attributes (excluding chemical pesticides and testing information), meaning that consumers who attached importance to certification information often believed that such information as harvesting, packaging and origin information were very worthy of being traced by blockchain technology. Further information is detailed in Supplementary Table S2.

■ *Preference shares of information in sub-sample*

Further evaluation was made on the preference shares based on RPL models at a sub-sample level in an attempt to understand how the residents from four cities would rank fruit information attributes. The *Kruskal-Wallis* test method was employed to test the differences among regions (Table 5). On the whole, although the SP of information attributes in the four cities were different, the preference ranking was slightly similar but not completely consistent. As shown in Table 5, testing, chemical pesticides and quality certification information were still ranked as more valuable information for traceability by the consumers surveyed. However, the preference ranking of the remaining information attributes surveyed in the four cities was somewhat inconsistent. For example, fertilizer record information was rated as the fourth-most valuable attribute in Fuzhou' than in Xi-an'. Compared with consumers in Nanjing, those in Beijing believed that the traceability of fruit quality information in blockchain-based traceability systems was more valuable than that of green technology information.

Table 5. Preference shares and importance rankings of blockchain-based traceability information.[1]

Information attributes	Shares of preference				K-W test[2]
	Nanjing	Beijing	Fuzhou	Xi-an	
Origin information	3.0%	1.9%	2.2%	2.3%	0.029**
Growth environment	3.3%	2.5%	2.1%	2.2%	0.0004***
Growth process	2.9%	2.0%	2.2%	2.0%	0.012**
Fertilizer record	7.6%	6.9%	6.2%	6.0%	0.018**
Chemical pesticides	14.2%	17.4%	19.2%	17.0%	0.160
Green technology	5.8%	5.0%	5.2%	5.0%	0.487
Harvesting information	3.7%	2.6%	2.8%	3.1%	0.018**
Agri-food quality grades	7.5%	6.4%	5.8%	6.2%	0.082*
Fruit quality information	5.8%	6.0%	4.8%	5.3%	0.305
Packaging information	3.6%	1.7%	2.8%	2.9%	0.0001***
Testing information	18.0%	27.7%	24.1%	23.6%	0.010**
Quality certification	11.3%	11.0%	11.0%	11.3%	0.129
Storage information	3.9%	3.2%	3.6%	4.4%	0.001***
Supplier information	2.3%	1.2%	2.2%	1.9%	0.0001***
Retail information	4.9%	2.8%	3.8%	4.8%	0.0002***
Logistics information	2.3%	1.6%	1.9%	2.1%	0.001***
Sample size	284	257	256	261	-

[1] ***, ** and * represent 1%, 5% and 10% statistical significance levels, respectively.

[2] K-W test = Kruskal-Wallis test.

The results from *Kruskal-Wallis* test also verified that the overall distributions of consumers' preferences for different information attributes were not completely equal. They demonstrated significant differences in preference shares of traceability information (except the information of chemical pesticides, green technology, fruit quality and certification) in different regions, indicating consumers' preferences for information attributes were somewhat regionally heterogeneous. It was also indicated that enterprises interested in implementing the traceability systems should not only record the most valuable information, but also should care for the inconsistency of local preferences for certain types of information. However, considering that the blockchain is still in the initial stage in the field of food traceability, and the complexity of the agricultural product supply chain, it really poses a great challenge for the traceability systems to take into account the differences of local preferences on the basis of unified standards. Therefore, at present, priority should be given to recording the product information that consumers most preferred, and smart contract procedures should be used to realize real-time transmission and information tracking. With the development of blockchain applications, differentiated traceability strategies can be implemented for target markets in the future.

■ *Consumer segmentation*

To further explore the source of heterogeneity indicated by the results of standard deviations of the RPL model estimates, the study analyzed the data by using the LC model to account for heterogeneity. Consistent Akaike Information Criterion (CAIC), Log-Likelihood (LL), AIC and BIC are generally used as the basis for LC model segmentation (Greene and Hensher, 2003). Although all indicators were improved with the increase in class quantity, the indicator values from classes 4 to 5 were much smaller than those in classes 3 to 4 (see Supplementary Table S3). In addition, with reference to the existing literature on LC modelling (Ola and Menapace, 2020), the optimal latent classes were finally determined in the study based on two criteria: the predicative ability of the model for choice behaviors and the interpretability of the coefficients. The former could be determined with the mean highest posterior probability of the class membership across all respondents (Pacifico and Yoo, 2013). Estimation results showed that mean posterior probability were highest in classes 4 and 5 (89.23% and 88.7%, respectively). The coefficients in class 4 were comparatively

easier to interpret than those in class 5. Therefore, four clusters were finally selected and each cluster relative to reference class 4 was thus analyzed.

Results in Supplementary Table S4 report the coefficients of the information attributes, class shares, covariates predicting class memberships, and the SP for the information in each class. Our study characterizes each class according to significant covariates affecting class membership and mainly reports the results based on the SP.

From the above latent classes, class 1, with a 21.8% class probability, indicates that the majority of the variables present statistically significant coefficients, excluding the supplier variable. This group rated testing information (30.8%) and quality certification (19.3%) as the most important attributes to be traced by blockchain technology. The remaining preference shares included chemical pesticides (12.6%), fruit quality information (8.9%), agri-food quality grades (8.6%), and green technology (6.0%), and the least valuable information attributes in this class were the logistics and supplier information (0.4% each). Overall, this cluster suggests that consumers' preference shares for the information (testing report, green, organic or geographical certification) issued by a third-party authority or laboratory were significantly higher compared to other clusters, meaning that consumers in the class paid more attention to the information related to third-party authoritative certification of agricultural products. Thus, the first cluster was characterized as the 'Sensitivity for authoritative information' class. In terms of socioeconomic characteristics, gender, age, purchase experience, scanning experience and city variables were the predictors of class membership, since the members were more likely to be male, older (50 years and above) and living in Beijing. And the consumers in this class, although they did not purchase traceable agricultural products, had scanned the QR code to query traceable information before, implying the consumers in the class were relatively concerned about the traceability information. Even though previous studies showed that consumers were willing to pay premium for traceable products (Bai *et al.,* 2013; Lee *et al.,* 2011; Yin *et al.,* 2018), such willingness was often affected by various factors, including price, knowledge, income, trust and risk perception (Liu *et al.,* 2019; Zhai *et al.,* 2022; Zhang *et al.,* 2012; Zhao *et al.,* 2010). On the other hand, it could also be the case that the information provision failed to meet consumer' needs for traceability information, and consumers might not trust the authenticity of the information (Liu *et al.,* 2019; Wu *et al.,* 2015; Zhang *et al.,* 2012). Thus, the scanning of the traceable code may be only a channel for consumers to obtain product information, but does not necessarily lead to purchase behavior.

Consumers in class 2 account for 26% of all the subjects surveyed. In this cluster, the parameters of origin and harvesting information were not significant, while other information attributes were at the 1% significance level. From the preference share of each attribute, the attribute most valued by the consumers was testing information, taking up 36.3% of preference shares. The second most valuable attribute was chemical pesticides (15.5%), followed by quality certification information (12.4%). In addition, the shares of retailer information and agri-food quality grades were very close (6.4% and 6.3%, respectively), followed by chemical fertilizer (4.4%), packaging (3.1%), storage (2.7%), fruit quality information (2.6%), green technology information (2.2%), supplier (1.9%) and logistics information (1.5%). However, the estimates for growth environment and growth process information were both statistically and significantly negative, indicating that subjects in this class believed that blockchain-based traceability for these two types of information was the least valuable. Compared with the first cluster, the information preferred by the consumers in this group was relatively comprehensive and diversified. Specifically, it shows consumers not only viewed the information related to authoritative certification (including testing and quality certification) as the most valuable attributes, but also selected chemical pesticides, retail and quality grades information as the most valuable ones as well, this class thus named 'Preferences for comprehensive information'. In terms of covariates, traceability cognition and gender were rated as significant predictors of class membership, indicating that the consumers in class 2 were likely to be male and lacking in traceability knowledge.

About 28.2% of respondents constituted class 3. The origin, growth environment, fertilizer record, growth process and green technology information variables were insignificant for the class. The remaining information attributes were all significantly positive, except the supplier information. In terms of preference shares, the

most valuable traceability attribute was fruit quality information, gaining 8.7% of preference shares; quality certification and chemical pesticides (7.6% each SP) were equally preferred as the second-most important information to be traced. Retail information was very close to receive 7.5% of the shares, followed by testing information (7.4%). It implies that, through the comparison of the preference shares scores, consumers in this class exhibited more concerns about retail information than the other three consumer segments. The least valuable information attributes in this class included the supplier information, growth process and green technology. On the whole, consumers' preference scores for each type of information were relatively similar, and a strong preference for any particular piece of information had not been detected, the highest being 8.7% and the lowest being 4.4%. Therefore, this class was named as 'Information preferences equally', which had preference shares almost equal to those for most information attributes. The relative shares of this cluster suggests that consumers not only concerned about the traceability information related to product quality, but also had a significant preference for the information from circulation (e.g. storage and packaging information) to the retail terminal.

As for the covariates in class 3, the coefficient of the information concern variable was significantly positive at 1% statistical level, indicating that the cluster was more likely to include consumers who were more concerned about the information of product handling and practice. With respect to risk perception, it can be observed that risk perception was statistically significant and negative, while risk attitude was significantly positive, implying that consumers in class 3 were more likely to be made up of those with a lower sensitivity to risk perception about fruit quality and safety. The positive risk attitude indicates that class 3 was more likely to include consumers who had a stronger risk preference as well. It is acknowledged that risk attitude reflects consumers' willingness to consume food under different risk situations (Jin *et al.*, 2017; Schroeder *et al.*, 2007). Those with stronger risk preference had higher tendency to accept the risk in fruit quality and safety than people with risk averse. In regards to the variables for food safety perception and traceability cognition, it was found that the class was more likely to include consumers who cared less about food safety and had a low-level of awareness regarding traceable agricultural products. In general, the relatively balanced preference shares scores for information attributes in class 3 might be explained by the consumers' characteristics as analyzed above. In addition, the above findings also demonstrated that, by comparing the absolute value of the coefficients, risk perception had a greater impact than risk attitude. The results lend support to the work of Petrolia (2016) and Lusk and Coble (2005), which reported that when examining consumers' choice behavior, there was a need to consider risk perception in addition to risk attitude.

The remaining 24% of the respondents was categorized into class 4. Chemical pesticides information was clearly rated as the most valuable blockchain-traceable information, accounting for 37.9% of shares, which was much higher than preference shares in other groups. Such information was 1.3 times and 4.1 times as important as testing information and fertilizer record information, respectively. Other attributes had following preference shares: 5.7% for green technology, 4.3% for quality certification information, and Less than 2% of these consumers selecting agri-food quality grades, storage management, growth process, fruit quality, retail, harvesting and growth environment information as an important attribute in blockchain-based traceability. The least preferred tracing information included origin information, logistics, packaging and supplier information. As a whole, consumers in class 4 attached more importance to the tracing of fruit production inputs, thus labelled into 'Preferences for production inputs information', which referred to a group that unquestionably cared about safety issues and was likely to be composed of women members. The information preferences of these consumers were similar to results reported by Matzembacher *et al.* (2018), which showed that the traceability of pests and inputs was considered as important elements to increase consumers' trust, while the traceability of inputs was the most relevant element in a traceability system.

5. Conclusions and policy implications

5.1 Conclusions

The application of blockchain technology into global food supply chain traceability can effectively prevent food fraud and ensure food safety (Creydt and Fischer, 2019). The establishment of a blockchain-based traceability systems will not only improve the efficiency and transparency within specific food chains traceability (Bomblauskas *et al.,* 2020), but also enhance consumers' trust for food safety when information accessibility, availability and authenticity is secured (Collart and Canales, 2022). The effectiveness of blockchain-based traceability systems depends largely on the values of information attributes. However, what is to be recorded, stored, and transmitted to end buyers has not been studied. Besides, little research has focused specifically on consumers' preferences concerning the information traced by this new digital blockchain technology. Information disclosure based on blockchain tracing might help restore and enhance consumers' confidence and trust in food safety. To this end, the present work investigates consumers' preferences and priority regarding the provision of sixteen information attributes about blockchain-based fresh fruit traceability systems through online survey data of 1,058 urban residents in China. It aims to identify shares in consumes' perceived value about blockchain-traceable information, and explore the heterogeneity in their choices.

The RPL model estimation results show that consumers consistently believed that the provision of testing information was the most valuable element in blockchain-based traceability systems. The high value placed on testing information reveals that consumers might, to a large extent, regard the testing information as an important indicator of food safety. Likewise, chemical pesticides was rated as the second-most valuable information. Consumers could judge the safety of specific food by retrieving information about chemical pesticides via traceable QR code. Quality certification information was rated by consumers as the third-most important attribute followed by fertilizer record information. Consumers also gave high value to the information related to other aspects of fruit quality, such as agri-food quality grades, external quality information (such as size, shape and color) and green technology information. Retail, storage management, harvesting information and packaging information were listed as the middle-most important ones. At the tail end of the rankings, our study findings indicate that consumers viewed the five information attributes that were fairly close in importance, with their shares less than 2.5% (including growth environment, growth process, origin and supplier, logistics information), as the least valuable information in blockchain-based traceability systems.

In addition, correlation estimates show that consumers who placed a high value on testing information tended to trade it off with other information. On the other hand, the separate sub-sample estimation for each city suggests that the preference shares of information in the four cities were different, and the ranking of other information attributes except for testing, chemical pesticides and quality certification in these places were somewhat inconsistent. On the whole, regardless of total sample or sub-sample estimation, consumers consistently ranked the attributes concerning product-related testing, quality certification, production inputs (pesticides and fertilizers) and grades information as the ones with the greatest value in blockchain-based traceability systems.

Furthermore, our study into preference heterogeneity provides additional insights into how different segments of consumers evaluated information attributes traced by blockchain technology. Four different consumer segments were identified through a LC modelling approach. In terms of the characteristics of these classes, it was observed that such variables as risk attitude, risk perception, information concern, traceability cognition, purchase experience, food safety perception, scanning experience, gender, and age all had an effect on membership probabilities.

Class 1 characterized as 'Sensitivity for authoritative information', accounts for the smallest part of the sample. This group perceived testing information and quality certification as the most valuable attributes, and considered logistics and supplier information as the least ones. The class members were more likely to be male, older than 50 years and experienced in scanning traceable QR code. While consumers in the second class characterized as 'Preferences for comprehensive information' were likely to be male and lacking in traceability knowledge. They not only regarded the authoritative information related to testing and quality certification as the most valuable attributes, but also selected pesticides inputs, retail and quality grades information as the most valuable ones, and placed the least value on growth environment and growth process information. The biggest third group (28.2%) characterized as 'Information preferences equally' deemed fruit quality information, quality certification and chemical pesticides as the most valuable traceability attributes; to them, all information was almost equally valued in terms of preference shares scores, namely, not revealing a strong preference for any particular piece of information. This group was found to be the consumers more concerned about the product information relevant to handling and practices; they had lower level of risk perception, food safety perception and traceability cognition, but showed a stronger risk preference. For the fourth class, labelled into 'Preferences for production inputs information', chemical pesticides was rated as the most-valued information attribute, followed by testing and fertilizer record information, and its members, more likely to be female, were less concerned about agri-food quality grades, storage, growth process, and fruit quality information.

5.2 Policy implications

It is important for the stakeholders in fresh food supply chain and the policy-makers to understand consumers' views on traceability information. The acquisition of such knowledge would help policy-makers to fully understand consumers' preferences and needs for product traceability information, and provide decision-making strategies for digital information collection to avoid information deviation. The study findings suggest several implications for policy and practice to realize a broader trajectory in fresh fruit traceability.

First, food product labels can provide consumers with rich and specific product information (Rupprecht *et al.,* 2020). However, information overloading may increase cognitive burden to consumers, causing impatience or even the loss of confidence (Salaün and Flores, 2001). In such cases, the most feasible thing is to provide accurate, effective and trustworthy information via blockchain-based traceability labelling. Our findings suggest that the blockchain-based fresh fruit traceability systems could prioritize the top seven categories of information for traceability management that were most valued by consumers, specifically, safety testing of product and environment, pesticides and fertilizer inputs, green or organic certification, quality grades, external quality attributes, and green technology practices. Blockchain technology can store the data on distributed blocks and connect them with chains, to ensure data security, integrity, tamper proof and transparency. Also, in order to ensure the authenticity of the input data, priority should be given to the collection of the above data in combination with IoT, big data and other enabled technologies, so that the needs from consumers for key information traceability can be better met.

Secondly, the study findings endorse that stakeholders should consider the consistency and heterogeneity in consumer' preferences for information attributes in different regions, and prioritize a list of traceable information based on local preferences. For example, consumers in four cities consistently rated these three types of information (testing, chemical pesticides and quality certification) as the most important ones in blockchain-based traceability, while the ranking of other attributes appeared to be somewhat inconsistent.

Thirdly, results from this study signal that consumer segmentation should be considered when traceable fresh produce is promoted. Enterprises should provide diversified blockchain-based traceability products (including different information attributes), locate target groups and implement differentiated marketing strategies to enhance market competitiveness. For instance, for male consumers in class 2 lacking the knowledge in traceability, producers can prioritize the promotion of traceable agricultural products bearing testing, certification, pesticide application, retail and quality grades information, with the traceable content briefed in the form of labels.

6. Limitation and way forward

The findings from this research can facilitate the understanding of the consumers' information preferences and provide the theoretical support necessary for the development of blockchain-based traceability to match such preferences. Yet this study is subject to several limitations, which might be avenues for future research. Previous studies showed that consumers had different concerns regarding fresh food and processed food products traceability (Van Rijswijk and Frewer, 2012). Our research mainly focused on fresh fruits, and the information on consumers' traceability preferences may vary with different categories of agricultural products. Future research using the BWS method can be extended to more fresh food or processed agricultural products, such as vegetables, rice and fruit juice, to help establish blockchain-based traceability systems for multiple products, which should be based on consumers' information needs.

In addition, this study mainly examined the preferences for information attributes in blockchain-based traceability systems, but did not discuss consumers' willingness to pay more for the access to the most valued information, and the reading of the information available to them. And future research can also explore the possibility of increased purchase with traceable information. The discussions into these issues might be conducive to better and effective information communication which is based on blockchain-traceable systems, and can ultimately influence the acceptance of technology-traced fresh produce among consumers.

Blockchain-based traceability can effectively improve the resilience of the fresh produce supply chain, as well as the transparency and authenticity of food information. But participants may also be confronted with possible disadvantages, such as the high cost of software development and maintenance, data privacy, input quality (Collart and Canales, 2022), and other challenges including understanding inadequacy, stakeholder cooperation and raw data manipulation (Duan *et al.,* 2020). One limitation of this study lies in the fact that we did not state such disadvantages faced by blockchain-based traceability in the information statement before experiment. Future research may examine the impact of different intervention frames of blockchain-based traceability information, including positive, negative and balanced intervention, on consumers' information preferences and their willingness to pay.

Another limitation that needs to be acknowledged is the definitions used for the information attributes, as these may be different from those used in other studies, for example, those used for origin and packaging. Results regarding these two attributes turn out to be surprising, given current market trends. For example, biodegradable packaging is quite popular now, but it was not rated as important to respondents in our study, a situation which may be caused by attribute definition. Therefore, the research conclusion may not be applicable when the importance of a certain attribute is solely compared. It should be noted that we mainly discussed consumers' preferences for product information attributes in the context of blockchain-based traceability systems, and tried to reveal which type of information would gain the most traceable value from perspective of consumer demand. Thus, we did not consider the attributes of blockchain itself in experiment. In the future, studies on consumers' preferences and their willingness to pay for blockchain traceability or other traceability methods, the attributes of blockchain can be added to the choice experiments, like decentralization and tamper-resistance.

Upscaling traceability for agricultural products based on blockchain technology is a longer-term and complex task. It requires stakeholders in fresh produce supply chain, including farmers, producers, distributors, suppliers and retailers, to guarantee that raw data information collected genuinely originate from corresponding products so as to redress market failures caused by information asymmetry. Meanwhile, information monitoring and supervision from a third party (such as government institutions and consumers) might help deliver authentic and accurate information to prevent food fraud or faked information. Further, it is also necessary to improve information communication with consumers, publicize the advantages of blockchain-based traceability and improve consumers' value sensitivity to blockchain technology.

Conflict of interest

The authors have no conflict of interest with this paper.

Acknowledgements

Supplementary material

Supplementary material can be found online at https://doi.org/10.22434/IFAMR2022.0080.

Figure S1. Information statement about blockchain-based fresh produce traceability systems.
Table S1. Comparison of characteristics amongst survey sub-samples.
Table S2. Person correlations between blockchain-traced information attributes using individual-specific estimates from the RPL model.
Table S3. Information criteria scores.
Table S4. Latent class model estimates and shares of preference of traceable information.

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