Integrative Analysis of QR Codes for Food Supply Chain Integrity

Pengfei Li



Propositions

1. The value of a QR code on food packaging emerges only when all actors along the supply chain recognize its meaning. (this thesis)
2. The likelihood of consumers scanning QR codes increases when the information they convey is perceived as useful. (this thesis)
3. Spam emails are a barrier to academic collaboration.
4. Preventive approaches centered on early warning play a critical role in the effective management of food fraud.
5. Academic papers are a form of communication that is not intended for the general public.
6. The main challenge for Ph.D. candidates is to balance genuine curiosity with society's expectation for research outcomes.

Propositions belonging to the thesis, entitled

Integrative Analysis of QR Codes for Food Supply Chain Integrity

Pengfei Li

Wageningen, 26 November 2025

Integrative Analysis of QR Codes for Food Supply Chain Integrity

Pengfei Li

Thesis committee

Promotor

Prof. Dr K.A. Hettinga

Professor in Food Quality and Design

Wageningen University & Research

Co-promotor

Dr S.W. Erasmus

Assistant Professor in Food Quality and Design

Wageningen University & Research

Other members

Prof. Dr I.E. de Hooge, Wageningen University & Research

Dr C. Coral, Humboldt-Universität zu Berlin, Germany

Dr F. Minnens, Flanders Research Institute for Agriculture, Fisheries and Food (ILVO), Merelbeke, Belgium

Dr Y. Bouzembrak, Wageningen University & Research

This research was conducted under the auspices of the Graduate School VLAG (Biobased, Biomolecular, Chemical, Food, and Nutrition Sciences)

Integrative Analysis of QR Codes for Food Supply Chain Integrity

Pengfei Li

Thesis

submitted in fulfilment of the requirements for the degree of doctor

at Wageningen University

by the authority of the Rector Magnificus,

Prof. Dr C Kroeze

in the presence of the

Thesis Committee appointed by the Academic Board

to be defended in public

on Friday 22 May 2026

at 3:30 p.m. in the Omnia Auditorium.

Pengfei Li

Integrative Analysis of QR Codes for Food Supply Chain Integrity

280 pages.

PhD thesis, Wageningen University, Wageningen, the Netherlands (2026)

With references, with summary in English

DOI: https://doi.org/10.18174/681673

Table of contents

Chapter 1 1

General Introduction

Chapter 2 21

Applications of food packaging QR codes in information transmission toward food supply chain integrity

Chapter 3 57

Drivers, barriers, and strategies of identification technology implementation for wine authentication

Chapter 4 95

Factors influencing consumers' behavioral intention to use authentication QR codes on food packages

Chapter 5 149

A meta-analysis of consumers' willingness to pay for the special food attributes

Chapter 6 219

Food counterfeiting detection based on the spatial-temporal analysis of consumers scanning QR codes - A feasibility analysis

Chapter 7 245

General Discussion

Summary 265

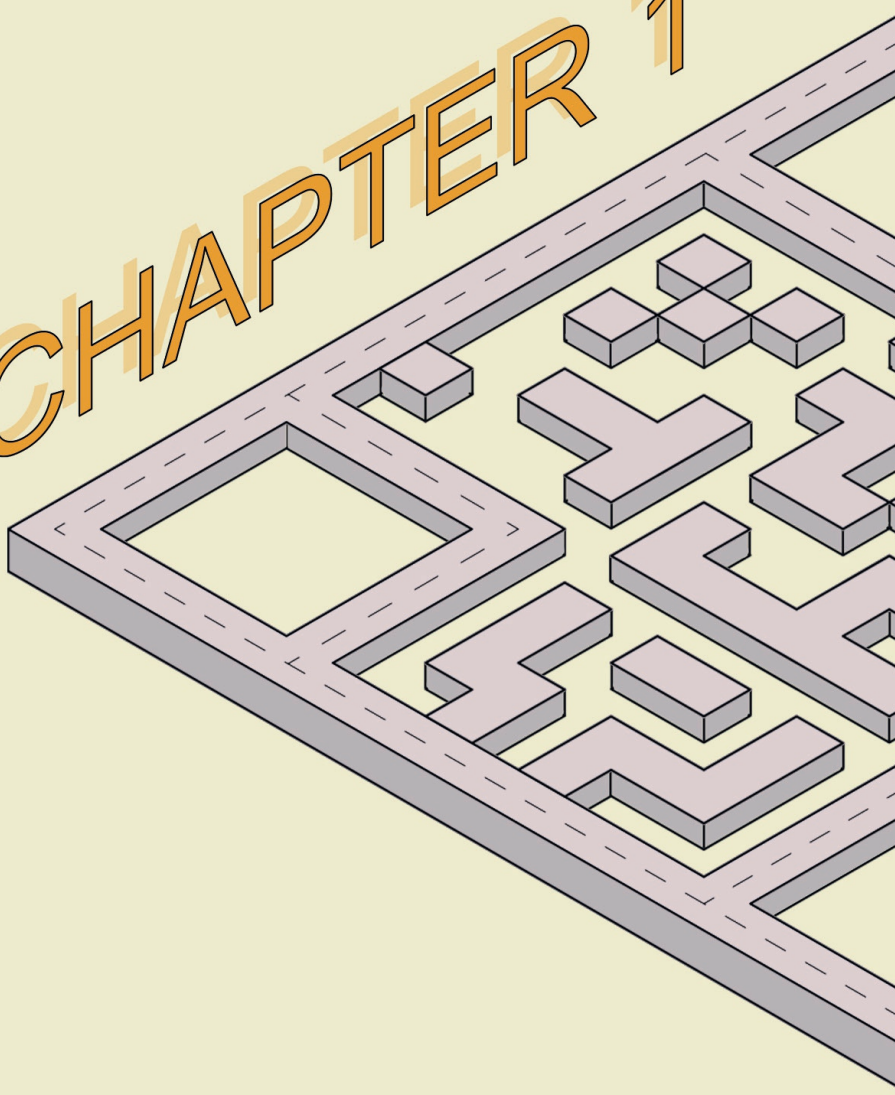
Acknowledgements 269

About the author 271

List of publications 272

Overview of completed training activities 273

CHAPTER 1



Chapter 1

General Introduction

1.1 Introduction

1.1.1 Food supply chain integrity

The food supply chain includes a series of activities, such as production, processing, transportation, and distribution, leading to the movement of food from farms to consumers' tables (Ahumada & Villalobos, 2009). The food supply chain is like a collaborative network of actors to meet consumer demands for food. Compared with other supply chains, the food supply chain is more complex and difficult to manage (Ali & Suleiman, 2018). This complexity is mainly driven by globalization, which has increased transportation distances, extended supply chain structures, and involved a greater number of participants, posing significant challenges to the transparency and integrity of the system (Ali et al., 2017). Food supply chain integrity refers to the consistency and reliability of safety, quality, transparency, authenticity, and traceability throughout all stages of the food supply chain (Davidson et al., 2017). Food supply chain integrity involves the honest and accurate information transmission of all elements related to the attributes of food products, safeguarding food authenticity (Roy & Srivastava, 2022).

1.1.2 Food authenticity

Food authenticity refers to the character of food which is produced according to specific procedures and meets precise criteria throughout the production and supply chain (Sobolev et al., 2017). Originality, one of the main properties of food authenticity, refers to a genuine version of a product (Chousou & Mattas, 2021). Food authenticity has always attracted public attention and ensuring the authenticity and safety of foods is an important requirement for food businesses, regulators, and consumers. Difficulties in guaranteeing food authenticity have consequently led to the emergence of food fraud as a major concern.

1.1.3 Food fraud

Food fraud is generally defined as illegal deception for economic gain using food (Spink et al., 2019b). Food fraud is linked to quality and safety and is a looming problem for all supply chain actors, such as manufacturers, suppliers, and consumers. It not only affects the manufacturers' and suppliers' reputation and profit, but it can also be harmful for the consumers' health (Niu et al., 2021). The number of reported cases of food fraud rises continuously, which leads to a loss of $52 billion per year to legal producers around the world (van Ruth et al., 2017). It is necessary and urgent to develop advanced technology to ensure food authenticity, so as to ensure the profits of all participants in the food supply chain.

Food fraud can be divided into various kinds, which are outlined below (Robson et al., 2021; Spink et al., 2019a; Visciano & Schirone, 2021).

- Adulteration. The food is added with one or some substances in a premeditated and intentional manner to cover up some defects in nutrition, weight, color, etc.
- Substitution. The high-value ingredient or part of the food is replaced by that of lower value to increase its perceived value or reduce the cost of its production.
- Simulation. It consists of forming, ex novo, a food that may appear to be the original.
- Counterfeiting. The faking of a higher quality product with one of lesser quality to obtain an illicit economic benefit.
- Theft. Dishonestly obtaining food, drink, or feed products to profit from their use or sale.
- Product overrun. The product did not pass the standards, either with factory defects or was slightly damaged, or there is a product made in excess of production agreements.
- Packaging recycling. The original product is replaced with a lower-quality product. This type of fraud is common in beverages, e.g., wine.
- Diversion. The sale or distribution of legitimate products outside of the intended markets.
- Waste diversion. This involves the illegal diverting of food or drink meant for disposal back into the supply chain. In this case, the label of the product can be counterfeited, changing the expiration date of the food.
- Document fraud. Making, using, or possessing dishonest documents with the objective of selling or marketing a fraudulent or substandard food.

Since information manipulation is a common feature of food fraud, the accuracy and transparency of food labeling have become essential to prevent such deceptive activities.

1.1.4 Food label

A food ‘label’ refers to the presentation of written, printed, or graphic information on the packaging, container, or wrapper that encases a food product. In general, labels play a crucial role in mitigating information asymmetry between producers and consumers, as producers typically possess far more detailed knowledge about their products than consumers do (Nelson, 1970). By providing essential information on labels, producers can help bridge this knowledge gap, thereby promoting more informed consumer choices (Asioli et al., 2017). Due to the consumers' increasing awareness of the importance of food labels, a proliferation of information on food labels arises from food

producers, regulators, and third-party certifiers, to facilitate healthy food choices and product differentiation and marketing (Tonkin et al., 2015).

Labels serve as a crucial informational tool for consumers (Weinrich & Spiller, 2016). A well-designed food label can positively influence national dietary habits, as it plays a crucial role in guiding the food choices of millions of people (Temple & Fraser, 2014). Between 45% and 80% of US adults report reading food labels to search for information (Ollberding et al., 2011). A study conducted in China found that about 60% of consumers regularly examine food labels when making purchasing decisions (Yue et al., 2020).

Given the importance of food labels to consumers' decision-making on food selection, there are multiple regulatory frameworks for food labels. In America, the Food and Drug Administration (FDA) released guidance for food labeling to outline the fundamental requirements. The publication of Regulation (EU) No. 1169/2011 on providing food information to consumers has established a harmonized framework for food labeling across Europe, promoting transparency and enhancing consumer confidence while safeguarding public health. In accordance with this regulation, the European Union mandates that food label information must be accurate, clearly visible, easily understandable, non-misleading, and permanent (EU Food Labeling Rules, 2024).

1.1.5 Food information

Since food information is presented on the food label, the label functions as a carrier for conveying this information and aligning it with the corresponding claims. A food claim refers to any explicit or implicit statement that suggests or implies that a food product possesses certain characteristics (Berry et al., 2017). The information on labels varies and may include words, trademarks, product and brand names, symbols, notices, and so on (Fliess et al., 2007).

1.1.5.1 Mandatory and voluntary information

The elements of food information on the label can be classified into two categories: mandatory and voluntary (Zainol et al., 2015).

Mandatory information on food labels is governed by a complex hierarchy of international legislation, regulations, and guidelines. While the specific requirements for label contents may vary across countries (Mackey & Metz, 2009), they generally include essential information, such as the name of the food products, ingredients, allergen information, date marking, origin, nutrition declaration, instructions for use, net quantity, and so on (EU Food Labeling Rules, 2024). The inherent nature of mandatory information means that it must be shown clearly on the labels attached to the food

packages. The aim of mandatory information on food labels is to establish a level playing field for the functioning of a unified market while safeguarding consumers' right to make informed decisions about the products they purchase (Penca, 2020).

Voluntary information on the food label is also called 'business information' (Stuart, 2010). It focuses on strategically positioning products within competitive markets, enhancing overall product consumption, reinforcing brand loyalty, and attracting consumers to purchase. The voluntary information on food labels is generally related to a variety of specific food attributes, including specific health claims, nutritional benefits, organic certifications, sustainability practices, ingredient sourcing, and so on (Golan et al., 2001). Firms have some control over the voluntary information displayed on the food labels. Specifically, they have the discretion to determine both the inclusion of such information and the specific details presented (Roe et al., 2014). The adoption rate of voluntary food labels has been steadily increasing over time, reflecting a growing recognition of their value (Jones et al., 2024). This trend suggests that consumers become more inclined to seek out voluntary food product information that supports informed decision-making.

The mandatory and voluntary information are complementary. Mandatory information ensures that consumers are well-informed about the basic characteristics of the food product, while voluntary information provides an opportunity for consumers to differentiate the products based on special characteristics of the food. Both mandatory and voluntary information on food labels allows for a more comprehensive and transparent way for consumers to make choices.

1.1.5.2 Text and digital information

The display of food information on the label can be classified into two categories: text and digital information.

Text information on food labels refers to the printed content displayed on the packaging of food products (Sørensen et al., 2012). The text information serves as the primary method of conveying essential food details to consumers. As all packaged food products in the market are required to include food labels with textual content, the text information represents the most widely accessible and direct source of information available to consumers. Consequently, the text information on food labels directly influences the consumer's food selection.

Digital information can be displayed through user devices (e.g., laptops, smartphones) instead of requiring physical changes on food packages (Fuchs et al., 2022). An increasing number of food companies are utilizing digital tools, such as QR codes and NFC-enabled labels, to convey digital information to consumers (Tanner et al., 2019).

These technologies serve as a means to redirect consumers to digital platforms or web pages where detailed product information can be accessed, making them particularly transformative for food labeling design. They enable marketers to provide additional information to consumers within a compact space on the packaging (Ozkaya et al., 2015).

Generally, labels convey information primarily through text, which can limit the amount and depth of information that can be included due to space constraints. One potential solution to address these constraints and enhance labeling strategies is the digitalization of information (Li et al., 2024). The digital information always complements the text information on the food label (Mascarello et al., 2024). By integrating digital elements, such as QR codes or augmented reality features, labels can provide consumers with access to a broader range of information, allowing for a more comprehensive and interactive understanding of the product and its attributes. QR codes have become a crucial tool in the wine industry, e.g., for complying with EU labeling regulations, allowing wineries to convey more detailed ingredient and nutritional information to consumers in a compliant, efficient, and flexible manner (European Parliament and the Council, 2021).

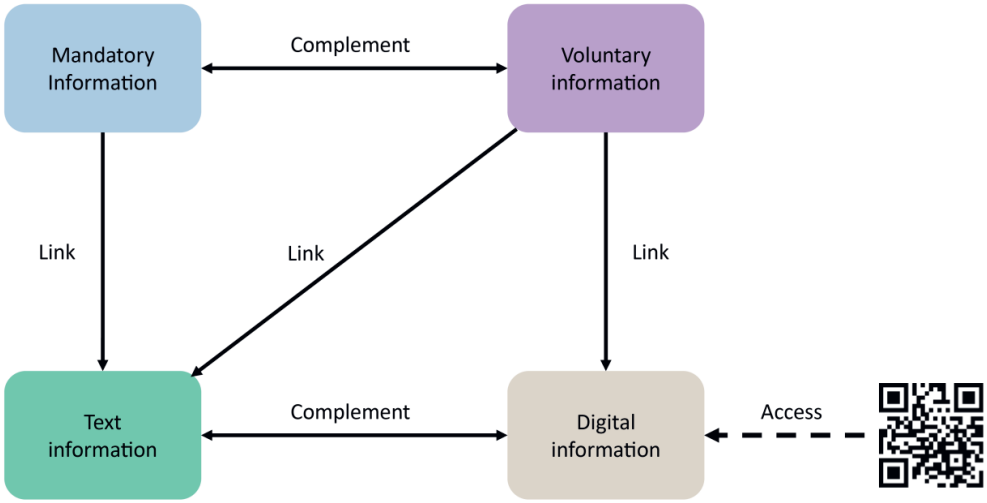


Fig. 1.1. The relationship among different types of food information on food labels. Solid arrows labeled 'Link' indicate that information expressed in one form can be transformed or represented in another form. Double-headed arrows labeled 'Complement' represent that the two types of information are complementary in terms of their content. The dashed arrow labeled 'Access' shows that digital information can be obtained through external digital tools, such as QR codes.

1.1.5.3 Relationship among information types

In general, overall mandatory information is required by regulation to be presented as text on food labels, enabling consumers to easily access this information. In contrast, there are no specific requirements regarding whether voluntary information must be provided in text or digital form. Consumers can access digital information through identification technologies, such as QR codes (Nguyen & Alang, 2024). The relationship among different types of food information on food labels is shown in **Fig. 1.1**.

1.6 Identification devices

Consumers often encounter information asymmetry and are limited in their ability to assess a food product and its quality based solely on their knowledge and perceptions (Frau & Keszey, 2024). In this context, digital identification devices enable consumers to access the various types of food information, thereby helping to mitigate the information asymmetry that is prevalent in food markets (Yoo et al., 2015). The digital identification technologies, such as QR codes, are gaining attention for their ability to efficiently and accurately verify and convey information (Park et al., 2024). A QR code is a common identification device in the packaging of batch and single items (Tu et al., 2021). Such identification devices have become popular instead of traditional systems, which include alphanumerical identification and require manual identification. The new devices are faster and less expensive, which makes food supply chain actors curious (Šenk et al., 2013).

A QR code is a two-dimensional barcode that smartphones can capture. After capturing the QR code, the encoded information can be a text, URL, phone number, date or video, while occupying only approximately one-tenth of the space required by traditional barcodes (Chang et al., 2021). QR codes serve as a communication tool, enabling consumers to scan codes on food packaging and access information through mobile applications or websites (Gatteschi et al., 2020). Some food manufacturers use techniques to generate QR codes for each production batch of food, and sometimes even for (expensive) single products. The QR codes are then printed on labels and applied to products. Once equipped with a QR code, each food is made ‘smart’, to tell users more about the type, origin, originality, and its own history while moving through the supply chain.

The popularity of QR codes on food packaging has been increasing at a really high pace with the growth of smartphone users (Li et al., 2017; Shin et al., 2012). More food companies and consumers pay attention to QR codes on food packaging. Supporting this shift, in a previous study, 61.6% of Italian respondents showed a favorable

reception of QR codes as a tool for accessing food information (Mascarello et al., 2024). A report by Mobileron, a mobile-centric security platform, indicates that 84% of individuals surveyed in the United States had scanned a QR code at least once in 2020, with 32% of respondents reporting that they had scanned a QR code on the packaging of different types of products within the prior six months (Businesswire, 2020). Similarly, in Vietnam, in accordance with Decision 645/QD-TTg, the national e-commerce development program for 2020-2021 aims to support all types of businesses in adopting digital technologies, such as QR codes and barcodes, for product authentication (Industry and Trade Newspaper, 2023).

1.7 QR code for food authentication

Food fraud, a growing challenge in the food supply chain, has driven the development of fraud authentication methods to ensure product integrity. The technologies used for food authentication can be categorized into analytical and automation authentication technologies. Analytical technologies have been widely applied to food fraud detection, including isotope analysis, chemometrics, near infrared spectroscopy, DNA barcoding, and so on (Badia-Melisa et al., 2015). However, as Davidson et al. (2017) pointed out, all analytical methods for food fraud detection can be used to get results, but it will take much time. Fraud detection technology is highly valuable; however, by the time fraudulent activity is identified, the breach has often already occurred. Therefore, developing preventive or real-time detection approaches is crucial to identify food fraud before or as it happens, minimizing its threat on the food supply chain.

QR code-based authentication has been developed to enable consumers to complete self-authentication. The QR code has been regarded as a feasible technology for detecting food fraud. Popovic et al. (2021) created a mobile app about wines that interacts with consumers, who can scan a QR code to identify a product instantly. An update on the status and location of that bottle is provided, which can be used to identify whether there is a potential counterfeit issue with that particular bottle. Bala Krishna and Dugar (2016) proposed a product authentication method by using QR code to combat counterfeiting. If the counterfeiting practitioner tries to copy the QR information of an existing product, or if the same QR code is scanned again, then the product authentication system using the QR code displays the following message: ‘QR code was scanned earlier’ or ‘The product is not genuine’. This idea has been applied in the fraud detection of champagne to provide protection against outright counterfeiting, and to make sure prices are not undercut in grey or parallel markets (Jesse, 2019).

1.8 Challenges in QR code promotion

QR code technology is increasingly being adopted within the manufacturing sector to enhance the food supply chain transparency and integrity (Peng et al., 2018). However, there are still some general challenges in implementing QR codes in the food supply chain, causing that it does not live up to its potential. Previous studies were collected to extract the challenges in QR code implementation as shown in **Table 1.1**).

Table 1.1. The challenges in QR code implementation.

Challenge	References	Elaboration
Insufficient visibility	Rai et al., 2024	QR codes are not easily seen, scanned, noticed, or accessed by consumers, possibly caused by the small size, insufficient contrast, or improper position.
Cannot be updated	Anir et al. (2008); Fan et al. (2019);	QR codes can only be connected to specified websites. Once the website showing the information is restructured, a new QR code needs to be created.
Environmental sensitivity	Fan et al. (2019); Sheikha (2021)	QR codes are highly susceptible to environmental factors, including dirt, scratches, and physical damage. If the code is broken in any way, it may become unreadable and fail to function properly.
Short reading range	Tanner (2024)	The small QR codes may not be scanned efficiently from a long distance. Generally, for every 10 cm of distance from the code, the length and width of the code should be increased by an additional 1 cm.
Time-consuming	Qian et al. (2012)	Scanning QR codes can be time-consuming, as each code requires individual scanning and a clear line of sight for accurate reading.
Vulnerability to replication	Köhler & Pizzol (2020)	QR codes are usually printed on paper and can be easily copied without getting any permission.
Internet connection	Aktaş (2017)	Only if consumers have an internet connection, they can access the online content linked to the QR code.

1.9 Multidisciplinary research approach

Several methods, including interviews, questionnaire surveys, and willingness-to-pay surveys, have been developed and employed to provide insights into the adoption of QR codes in many industries.

Interviews, as a common method in qualitative research, involve collecting valuable information, insights, experiences, and perspectives on a specific issue from experts with a broad background, which are often difficult to obtain through observation alone (Rossetto, 2014). The interview process is characterized by active, supportive listening,

with interviewers employing techniques such as paraphrasing and probing to encourage interviewees to provide more in-depth responses (Baxter & Babbie, 2003). Htun et al. (2023) conducted interviews with consumers in Europe to explore their attitudes toward QR codes and their expectations regarding food. Okazaki et al. (2013) examined the participants' positive and negative perspectives on the use of QR codes in cross-media integration. Söğüt and Atasever Belli (2024) investigated the perspectives of language learners on the integration of QR codes into writing and speaking practices.

A questionnaire survey is a valuable research approach on collecting participants' quantitative opinions and feedback on a specific topic. It allows for the systematic collection of data in a standardized way, ensuring that the data are internally consistent and coherent for analysis (Roopa & Rani, 2012). Many studies developed questionnaires to examine the factors influencing users' intentions to use QR codes in mobile commerce and payment (Eren, 2022; Ho & Yang, 2017; Soormo et al., 2024; Widayat & Masudin, 2023). In the food field, Yang et al. (2022) investigated the factors that influence consumers' intentions to scan QR codes while purchasing eggs by assigning a questionnaire. Previous studies also explored how the factors influencing consumers' intention to use the QR codes for transferring various types of information, including antibiotic use (Bradford et al., 2022), sustainability (Bashir, 2022), and traceability (Kim & Woo, 2016).

Willingness-to-pay (WTP) can be defined as the maximum amount a consumer is willing to pay for a given quantity of goods or services. This method is commonly used in economics and market research to estimate the highest monetary value, showing consumers' preference for the product. In the food field, many studies explored the consumers' willingness to pay for food with special attributes, which is shown through a QR code (Petrontino et al., 2024; Tran et al., 2022; Ting et al., 2021; Yin et al., 2017).

1.10 Knowledge gap

QR codes on food packaging, which serve as a digital tool for product authentication, have attracted increasing attention in the food industry in recent years. However, the widespread and effective implementation of this technology relies not only on the active deployment by food producers but also on the engagement and usage by consumers. This implementation is influenced by various factors, and therefore, gaining a deep understanding of the perceptions, attitudes, and behavioral intentions of both the technology providers and users is essential for identifying the key factors influencing the implementation of the QR code technology. Such insights can facilitate the broader diffusion and practical application of digital technologies in the food sector.

Although some studies have examined the use of QR codes in the food industry, the overall application of QR codes for food authenticity information transmission remains unclear. Furthermore, food companies, as the key decision-makers in implementing QR codes for authenticity on food packaging, may encounter factors influencing the adoption of this technology. Understanding these factors is crucial for optimizing the use of authentication QR codes. However, there is a lack of research addressing these factors from the perspective of supply chain entities. In addition, a high level of consumers' intention to use can enhance food companies' motivation to implement authentication QR code. Previous studies on consumers' intentions to use QR codes indicate that influencing factors vary depending on the type of food information transmitted. As a result, it is essential to investigate the factors that affect consumers' intentions to use authentication QR codes. Additionally, while numerous studies have assessed consumers' willingness to pay for food with specific attributes, as communicated by QR codes, there is limited research that explores how different information transmission methods, including QR codes, impact consumers' willingness to pay. Last but not least, the current authentication mechanism is well-established, and developing a novel QR code-based authentication mechanism has the potential to significantly enhance the functionality of authentication systems by providing a more secure, efficient, and user-friendly way to verify identity.

1.11 Research aims and thesis outline

This PhD thesis aims to gain an in-depth understanding of the perceptions, attitudes, and behavioral intentions of both the technology providers and users toward the adoption of QR codes, to inform strategies that enhance the food supply chain integrity.

An overview of the thesis is shown in **Fig. 1.2.**

Chapter 2 provides a comprehensive review of the current applications of QR codes on food packaging in information transmission. An overview of the QR code configuration was presented, and the technical principles of information transmission are explained in comparison to other digital technologies. The limitations and potential development directions for enhancing QR code functionality were discussed.

In **Chapter 3**, experts in the Italian and Indian wine supply chains were interviewed to explore their viewpoints on the drivers, barriers, and strategies for the implementation of identification devices.

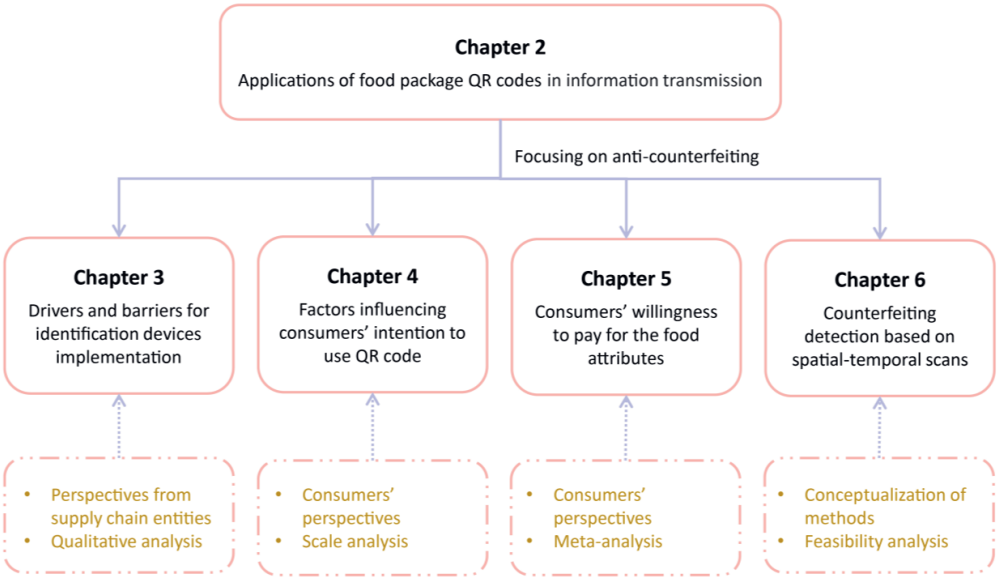


Fig. 1.2. Schematic overview of this PhD thesis.

In **Chapter 4**, a multi-item scale of consumers' behavioral intention to use authentication QR codes was designed to explore how the relevant factors influence the consumers' behavioral intention. The Structural Equation Model (SEM) and Artificial Neural Network (ANN) were used to verify the proposed hypotheses based on the Chinese and British consumers' responses.

Chapter 5 focused on the investigation of consumers' willingness to pay for the special food attributes conveyed by food labels. The premium of quality and safety information linked to food authenticity was evaluated. The premium caused by special information conveyed by QR code was compared to that of other information transmission carriers.

Chapter 6 proposed a promising approach to counterfeiting detection based on the spatial-temporal analysis of consumers scanning QR codes on food packaging. The normal spatial-temporal patterns were explained, and how the different types of food counterfeiting influenced the normal patterns was explored, while some possible models were proposed to detect the anomaly in patterns.

Chapter 7 offered a comprehensive discussion based on the findings from Chapters 2-6, reflecting on both the strengths and limitations of the studies. Additionally, it presented recommendations for future research and the key conclusions.

References

Aktaş, C. (2017). *The Evolution and Emergence of QR Codes*. Cambridge Scholars Publishing.

Ali, M. H., & Suleiman, N. (2018). Eleven shades of food integrity: A halal supply chain perspective. *Trends in Food Science & Technology*, *71*, 216-224. https://doi.org/10.1016/j.tifs.2017.11.016

Ali, M. H., Zhan, Y., Alam, S. S., Tse, Y. K., & Tan, K. H. (2017). Food supply chain integrity: the need to go beyond certification. *Industrial management & data systems*, *117*(8), 1589-1611. https://doi.org/10.1108/IMDS-09-2016-0357

Anir, N. A., Nizam, N. M. H., & Azmi, M. (2008). The users perceptions and opportunities in Malaysia in introducing RFID system for Halal food tracking. *WSEAS Transactions on Information Science and Applications Archive, 5*(5), 843-852. https://doi.org/10.5555/1467020.1467047

Asioli, D., Aschemann-Witzel, J., Caputo, V., Vecchio, R., Annunziata, A., Næs, T., & Varela, P. (2017). Making sense of the “clean label” trends: A review of consumer food choice behavior and discussion of industry implications. *Food Research International*, *99*, 58-71. https://doi.org/10.1016/j.foodres.2017.07.022

Ahumada, O., & Villalobos, J. R. (2009). Application of planning models in the agri-food supply chain: A review. *European journal of Operational research*, *196*(1), 1-20. https://doi.org/10.1016/j.ejor.2008.02.014

Badia-Melisa, R., Mishrab, P., Ruiz-Garcíaa, L. (2015). Food traceability: New trends and recent advances. A review. *Food Control, 57*, 393-401. https://doi.org/10.1016/j.foodcont.2015.05.005

Bala Krishna, M., & Dugar, A. (2016). Product authentication using QR codes: a mobile application to combat counterfeiting. *Wireless Personal Communications*, *90*, 381-398. https://doi.org/10.1007/s11277-016-3374-x

Bashir, H. (2022). Leveraging technology to communicate sustainability-related product information: Evidence from the field. *Journal of Cleaner Production*, *362*, 132508. https://doi.org/10.1016/j.jclepro.2022.132508

Baxter L. A., Babbie E. (2003). *The basics of communication research*. Boston, MA: Wadsworth.

Berry, C., Burton, S., & Howlett, E. (2017). It’s only natural: the mediating impact of consumers’ attribute inferences on the relationships between product claims, perceived product healthfulness, and purchase intentions. *Journal of the Academy of Marketing Science*, *45*(5), 698-719. https://doi.org/10.1007/s11747-016-0511-8

Bradford, H., McKernan, C., Elliott, C., & Dean, M. (2022). Consumer purchase intention towards a quick response (QR) code for antibiotic information: an exploratory study. *npj Science of Food*, *6*(1), 23. https://doi.org/10.1038/s41538-022-00136-4

Businesswire. (2020), MobileIron research reveals QR codes pose significant security risks to enterprises and end users, Retrieved from *https://www.businesswire.com/news/home/20200915005151/en/MobileIron-Research-Reveals-QR-Codes-Pose-Significant-Security-Risks-to-Enterprises-and-End-Users.* Accessed May 5, 2023.

Chang, V., Chen, W., Xu, Q. A., & Xiong, C. (2021). Towards the customers' intention to use QR codes in mobile payments. *Journal of Global Information Management*, *29*(6), 1-21. https://doi.org/10.4018/JGIM.20211101.oa37

Chousou, C., & Mattas, K. (2021). Assessing consumer attitudes and perceptions towards food authenticity. *British Food Journal*, *123*(5), 1947-1961. https://doi.org/10.1108/BFJ-03-2019-0177

Davidson, R.K., Antunes, W., Madslien, E.H., Belenguer, J., Gerevini, M., Torroba Perez, T., Prugger, R. (2017). From food defence to food supply chain integrity. *British Food Journal, 119*, 52-66. https://doi.org/10.1108/BFJ-04-2016-0138

Eren, B. A. (2022). QR code m-payment from a customer experience perspective. *Journal of Financial Services Marketing, 29*(1), 106-121. https://doi.org/10.1057/s41264-022-00186-5

EU Food labeling rules. (2024). Food labelling rules. Retrieved from *https://europa.eu/youreurope/business/product-requirements/food-labelling/general-rules/index_en.htm*. Accessed July 1, 2025.

European Parliament and of the Council. (2021). European Parliament and of the Council Regulation (EU) No. 2021/2117 of the European Parliament and of the Council amending regulations (EU) No. 1308/2013 Establishing a common Organization of the Markets in agricultural products, (EU) No. 1151/2012 on quality Schemes for agricultural Products and foodstuffs, (EU) No. 251/2014 on the definition, description, presentation, labelling and the protection of geographical indications of aromatized wine products and (EU) No. 228/2013 laying down specific measures for agriculture in the outermost regions of the union (2021). Retrieved from *https://eur-lex.europa.eu/eli/reg/2021/2117/oj*, Accessed January 26, 2024

Fan, B., Qian, J., Wu, X., Du, X., Li, W., Ji, Z., & Xin, X. (2019). Improving continuous traceability of food stuff by using barcode-RFID bidirectional transformation equipment: Two field experiments. *Food Control, 98*, 449-456. https://doi.org/10.1016/j.foodcont.2018.12.002

Fliess, B., Lee, H. J., Dubreuil, O. L., & Agatiello, O. R. (2007). CSR and trade: informing consumers about social and environmental conditions of globalised production: Part I.

Frau, M., & Keszey, T. (2024). Seeding innovation: the role of internal and external digital data in agri-food product innovation. *British Food Journal*, *126*(13), 286-302. https://doi.org/10.1108/BFJ-08-2023-0687

Fuchs, K. L., Lian, J., Michels, L., Mayer, S., Toniato, E., & Tiefenbeck, V. (2022). Effects of digital food labels on healthy food choices in online grocery shopping. *Nutrients*, *14*(10), 2044. https://doi.org/10.3390/nu14102044

Gatteschi, V., Lamberti, F., & Demartini, C. (2019). Blockchain technology use cases. In *Advanced applications of Blockchain technology* (pp. 91-114). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-13-8775-3_4

Golan, E., Kuchler, F., Mitchell, L., Greene, C., & Jessup, A. (2001). Economics of food labeling. *Journal of Consumer Policy*, *24*(2), 117-184. https://doi.org/10.1023/A:1012272504846

Ho, C. T. B., & Yang, J. M. D. (2017). Factors affecting users' mobile technology usage intentions: an example of QR code scanning for mobile commerce. *International Journal of Mobile Communications*, *15*(2), 185-209. https://doi.org/10.1504/IJMC.2017.082539

Htun, N.N., Wiśniewska, A., Nocella, G., Santa Cruz, E., Peracaula-Moner, A., Vehmas, K., Hakola, L., Liczmańska-Kopcewicz, K., Bridgett, L. & Verbert, K. (2023). Smart tag packaging technologies: A qualitative investigation of consumers' needs and expectations. *Packaging Technology and Science*, *36*(7), 595-613. https://doi.org/10.1002/pts.2731

Industry and Trade Newspaper. (2023). Traceability by QRCode: Transparency of product quality, protecting consumers' interests. Available from *https://www.vietnam.vn/en/truy-xuat-nguon-goc-bang-qrcode-minh-bach-chat-luong-san-pham-bao-ve-quyen-loi-nguoi-tieu-dung/*. Accessed June 10, 2025

Jesse, C. (2019). QR code champagne tracking technology helps to safeguard against fraud. Retrieved from *https://www.qrcodepress.com/qr-code-champagne-tracking-technology-helps-to-safeguard-against-fraud/8536714/*. Accessed October 27, 2025

Jones, A., Maganja, D., Shahid, M., Neal, B., & Pettigrew, S. (2024). Voluntary versus mandatory food labels, Australia. *Bulletin of the World Health Organization*, *102*(10), 691. https://doi.org/10.2471/BLT.24.291629

Kim, Y. G., & Woo, E. (2016). Consumer acceptance of a quick response (QR) code for the food traceability system: Application of an extended technology acceptance model (TAM). *Food Research International*, *85*, 266-272. https://doi.org/10.1016/j.foodres.2016.05.002

Köhler, S., & Pizzol, M. (2020). Technology assessment of blockchain-based technologies in the food supply chain. *Journal of Cleaner Production*, *269*, 122193. https://doi.org/10.1016/j.jclepro.2020.122193

Li, P., Yang, J., Jiménez-Carvelo, A. M., & Erasmus, S. W. (2024). Applications of food packaging quick response codes in information transmission toward food supply chain integrity. *Trends in Food Science & Technology*, *146*, 104384. https://doi.org/10.1016/j.tifs.2024.104384

Li, Z., Liu, G., Liu, L., Lai, X., & Xu, G. (2017). IoT-based tracking and tracing platform for prepackaged food supply chain. *Industrial Management & Data Systems*, *117*(9), 1906-1916. https://doi.org/10.1108/IMDS-11-2016-0489

Mackey, M. A., & Metz, M. (2009). Ease of reading of mandatory information on Canadian food product labels. *International Journal of Consumer Studies*, *33*(4), 369-381. https://doi.org/10.1111/j.1470-6431.2009.00787.x

Mascarello, G., Pinto, A., Crovato, S., Tiozzo Pezzoli, B., Pietropaoli, M., Bertola, M., Mutinelli, F. & Formato, G. (2024). Consumers' Perceptions and Behaviors Regarding Honey Purchases and Expectations on Traceability and Sustainability in Italy. *Sustainability*, *16*(20), 8846. https://doi.org/10.3390/su16208846

Nelson, P. (1970). Information and consumer behavior. *Journal of Political Economy*, *78*(2), 311-329.

Nguyen, M. T., & Alang, T. (2024). When do shoppers prefer using QR codes? Empirical evidence from Vietnam. *Future Business Journal*, *10*(1), 105. https://doi.org/10.1186/s43093-024-00391-9

Niu, L., Chen, M., Chen, X., Wu, L., & Tsai, F. S. (2021). Enterprise food fraud in China: Key factors identification from social co-governance perspective. *Frontiers in Public Health*, *9*, 752112. https://doi.org/10.3389/fpubh.2021.752112

Ollberding, N. J., Wolf, R. L., & Contento, I. (2011). Food label use and its relation to dietary intake among US adults. *Journal of the American Dietetic Association*, *111*(5), S47-S51. https://doi.org/10.1016/j.jada.2011.03.009

Ozkaya, E., Ozkaya, H. E., Roxas, J., Bryant, F., & Whitson, D. (2015). Factors affecting consumer usage of QR codes. *Journal of Direct, Data and Digital Marketing Practice*, *16*, 209-224. https://doi.org/10.1057/dddmp.2015.18

Park, J. W., Cho, Y. H., Park, M. K., & Kim, Y. D. (2024). Consumer Usability Test of Mobile Food Safety Inquiry Platform Based on Image Recognition. *Sustainability*, *16*(21), 9538. https://doi.org/10.3390/su16219538

Penca, J. (2020). Mainstreaming sustainable consumption of seafood through enhanced mandatory food labeling. *Frontiers in Marine Science*, *7*, 598682. https://doi.org/10.3389/fmars.2020.598682

Peng, Y., Zhang, L., Song, Z., Yan, J., Li, X., & Li, Z. (2018). A QR code based tracing method for fresh pork quality in cold chain. *Journal of Food Process Engineering*, *41*(4), e12685. https://doi.org/10.1111/jfpe.12685

Petrontino, A., Frem, M., Fucilli, V., Tria, E., Campobasso, A. A., & Bozzo, F. (2024). Consumers' purchase propensity for pasta tracked with blockchain technology and labelled with sustainable credence attributes. *Frontiers in Sustainable Food Systems*, *8*, 1367362. https://doi.org/10.3389/fsufs.2024.1367362

Popović, T., Krčo, S., Maraš, V., Hakola, L., Radonjić, S., van Kranenburg, R., & Šandi, S. (2021). A novel solution for counterfeit prevention in the wine industry based on IoT, smart tags, and crowd-sourced information. *Internet of Things*, *14*, 100375. https://doi.org/10.1016/j.iot.2021.100375

Qian, J., Yang, X., Wu, X., Zhao, L., Fan, B., & Xing, B. (2012). A traceability system incorporating 2D barcode and RFID technology for wheat flour mills. *Computers and Electronics in Agriculture, 89*, 76-85. https://doi.org/10.1016/j.compag.2012.08.004

Regulation (EU) nº. 1169/2011. (2011). Regulation (EU) nº. 1169/2011 of the European Parliament and of the Council of 25 October 2011 on the provision of food information to consumers, amending Regulations (EC) No 1924/2006 and (EC) No 1925/2006 of the European Parliament and of the Council, and repealing Commission Directive 87/250/EEC, Council Directive 90/496/EEC, Commission Directive 1999/10/EC, Directive 2000/13/EC of the European Parliament and of the Council, Commission Directives 2002/67/EC and 2008/5/EC and Commission Regulation (EC) No 608/2004.

Rai, K., Chaudhuri, R., Chatterjee, S., Vrontis, D., & Galati, A. (2024). Digital innovation and automation of business processes using quick response code: advancing the means-end chain theory. *Business Process Management Journal*. https://doi.org/10.1108/BPMJ-05-2024-0339

Robson, K., Dean, M., Haughey, S., & Elliott, C. (2021). A comprehensive review of food fraud terminologies and food fraud mitigation guides. *Food Control*, *120*, 107516. https://doi.org/10.1016/j.foodcont.2020.107516

Roe, B. E., Teisl, M. F., & Deans, C. R. (2014). The economics of voluntary versus mandatory labels. *Annual Review of Resource Economics, 6*(1), 407-427. https://doi.org/10.1146/annurev-resource-100913-012439

Roopa, S., & Rani, M. S. (2012). Questionnaire designing for a survey. *Journal of Indian Orthodontic Society*, *46*, 273-277. https://doi.org/10.5005/jp-journals-10021-1104

Rossetto, K. R. (2014). Qualitative research interviews: Assessing the therapeutic value and challenges. *Journal of Social and Personal Relationships*, *31*(4), 482-489. https://doi.org/10.1177/0265407514522892

Roy, V., & Srivastava, S. K. (2022). The safety-quality dominant view of food chain integrity: Implications for consumer-centric food chain governance. *International Journal of Management Reviews*, *24*(1), 3-24. https://doi.org/10.1111/ijmr.12258

Šenk, I., Ostojić, G., Tarjan, L., Stankovski, S., & Lazarević, M. (2013). Food product traceability by using automated identification technologies. In IFIP advances in information and communication technology (pp. 155-163). https://doi.org/10.1007/978-3-642-37291-9_17

Shin, D. H., Jung, J., & Chang, B. H. (2012). The psychology behind QR codes: User experience perspective. *Computers in Human Behavior*, *28*(4), 1417-1426. https://doi.org/10.1016/j.chb.2012.03.004

Sobolev, A. P., Circi, S., Capitani, D., Ingallina, C., & Mannina, L. (2017). Molecular fingerprinting of food authenticity. *Current Opinion in Food Science*, *16*, 59-66. Molecular fingerprinting of food authenticity

Sögüt, S., & Belli, S. A. (2024). QR Code Enriched Writing and Speaking Practices: Insights from EFL Learners at Tertiary Level. *Iranian Journal of Language Teaching Research*, *12*(2), 1-18. https://doi.org/10.30466/ijltr.2024.54921.2595

Soormo, R. B., Al-Rahmi, W. M., Dahri, N. A., Alblehai, F., Alshimai, A., Aldaijy, A., & Salameh, A. A. (2024). Evaluating the influence of UTAUT factors on the adoption of QR codes in MSMEs: An application of SEM and ANN Methodologies. *IEEE Access, 12*, 191304-191322. https://doi.org/10.1109/ACCESS.2024.3510375

Sørensen, H. S., Clement, J., & Gabrielsen, G. (2012). Food labels-an exploratory study into label information and what consumers see and understand. *The International Review of Retail, Distribution and Consumer Research*, *22*(1), 101-114. https://doi.org/10.1080/09593969.2011.634072

Spink, J., Bedard, B., Keogh, J., Moyer, D. C., Scimeca, J., & Vasan, A. (2019a). International survey of food fraud and related terminology: Preliminary results and discussion. *Journal of Food Science*, *84*(10), 2705-2718. https://doi.org/10.1111/1750-3841.14705

Spink, J., Hegarty, P. V., Fortin, N. D., Elliott, C. T., & Moyer, D. C. (2019b). The application of public policy theory to the emerging food fraud risk: Next steps. *Trends in Food Science & Technology*, *85*, 116-128. https://doi.org/10.1016/j.tifs.2019.01.002

Stuart, S. A. (2010). The relationship between mandatory and other food label information. *British Food Journal*, *112*(1), 21-31. https://doi.org/10.1108/00070701011011173

Tanner, K. QR-Code Usability Guidelines. Retrieved from https://www.nngroup.com/articles/qr-code-guidelines/. Accessed June 19, 2025

Tanner, S. A., McCarthy, M. B., & O'Reilly, S. J. (2019). Digital labelling in the retail environment: a domain-specific innovativeness perspective. *International Journal of Retail & Distribution Management*, *47*(12), 1336-1352. https://doi.org/10.1108/IJRDM-08-2018-0175

Temple, N. J., & Fraser, J. (2014). Food labels: a critical assessment. *Nutrition*, *30*(3), 257-260. https://doi.org/10.1016/j.nut.2013.06.012

Ting, C. T., Huang, Y. S., Lin, C. T., & Hsieh, Y. (2021). Measuring consumer' willingness to pay for food safety certification labels of packaged rice. *AIMS Agriculture and Food*, *6*(4), 1000-1010. https://doi.org/10.3934/agrfood.2021060

Tonkin, E., Wilson, A. M., Coveney, J., Webb, T., & Meyer, S. B. (2015). Trust in and through labelling-a systematic review and critique. *British Food Journal*, *117*(1), 318-338. https://doi.org/10.1108/BFJ-07-2014-0244

Tran, D., Broeckhoven, I., Hung, Y., Diem My, N. H., De Steur, H., & Verbeke, W. (2022). Willingness to pay for food labelling schemes in Vietnam: A choice experiment on water spinach. *Foods*, *11*(5), 722. https://doi.org/10.3390/foods11050722

Tu, Y. J., Zhou, W., & Piramuthu, S. (2021). Critical risk considerations in auto-ID security: Barcode vs. RFID. *Decision Support Systems*, *142*, 113471. https://doi.org/10.1016/j.dss.2020.113471

van Ruth, S. M. (2017). Large-scale research projects on food fraud in China and Europe have been launched. Retrieved from *https://www.wur.nl/nl/Onderzoek-Resultaten/Onderzoeksinstituten/food-safety-research/Expertisegebieden/Voedselfraude-en-productsamenstelling/Groot-EU-Chinees-onderzoeksproject-over-voedselfraude-van-start.htm.* Accessed May 27, 2021

Visciano, P., & Schirone, M. (2021). Food frauds: Global incidents and misleading situations. *Trends in Food Science & Technology*, *114*, 424-442. https://doi.org/10.1016/j.tifs.2021.06.010

Weinrich, R., & Spiller, A. (2016). Developing food labelling strategies: Multi-level labelling. *Journal of Cleaner Production*, *137*, 1138-1148. https://doi.org/10.1016/j.jclepro.2016.07.156

Widayat, W., & Masudin, I. (2023). QR-code-based payment. Does the consumer intend to adopt a retail buying transaction?. *Banks and Bank Systems*, *18*(3), 1-13. https://doi.org/10.21511/bbs.18(3).2023.01

Yang, S. H., Phan, H. T. T., Hsieh, C. M., & Li, T. N. (2022). What intentions and interesting information can attract consumers to scan QR code while buying eggs?. *Foods*, *11*(9), 1259. https://doi.org/10.3390/foods11091259

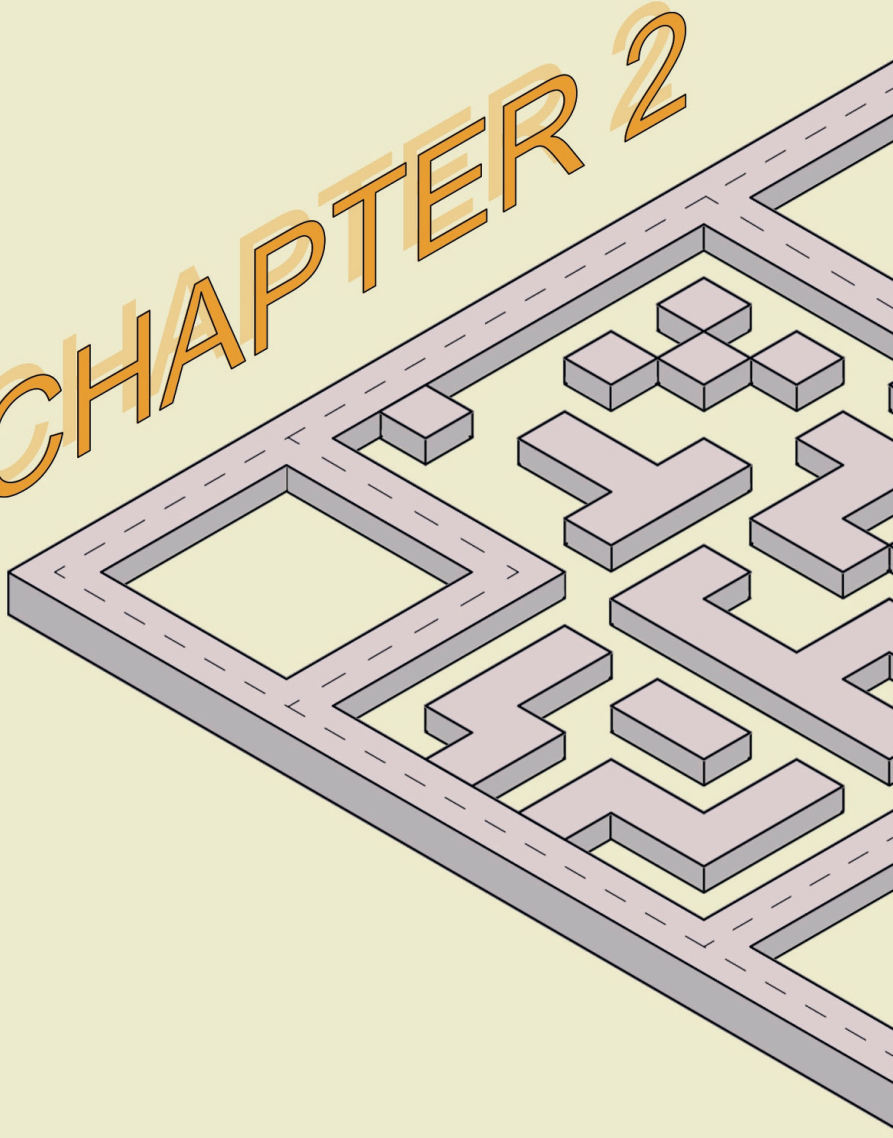
Yin, S., Li, Y., Xu, Y., Chen, M., & Wang, Y. (2017). Consumer preference and willingness to pay for the traceability information attribute of infant milk formula: Evidence from a choice experiment in China. *British Food Journal*, *119*(6), 1276-1288. https://doi.org/10.1108/BFJ-11-2016-0555

Yoo, C. W., Parameswaran, S., & Kishore, R. (2015). Knowing about your food from the farm to the table: Using information systems that reduce information asymmetry and health risks in retail contexts. *Information & Management*, *52*(6), 692-709. https://doi.org/10.1016/j.im.2015.06.003

Yue, D.A.I., Qiang, L.I., Wen, L.I.U., Hongrui, Z.H.A.N.G., Jia, H.A.O., Ye, D.O.N.G., Peng, L.I.U., Min, D.U.A.N. & Xiaoran, F.A.N. (2020, June). Research on consumers' cognition and demand for food label information. In *IOP Conference Series: Earth and Environmental Science* (Vol. 512, No. 1, p. 012071). IOP Publishing.

Zainol, Z. A., Nordin, R., & Akpoviri, F. I. (2015). Mandatory labelling of genetically modified (GM) foods. *International Environmental Agreements: Politics, Law and Economics*, *15*(2), 199-216. https://doi.org/10.1007/s10784-013-9230-5

CHAPTER 2



Chapter 2

Applications of food packaging QR codes in information transmission toward food supply chain integrity

This chapter has been published as:

Li, P., Yang, J., Jiménez-Carvelo, A. M., & Erasmus, S. W. (2024). Applications of food packaging quick response codes in information transmission toward food supply chain integrity. *Trends in Food Science & Technology*, *146*, 104384. https://doi.org/10.1016/j.tifs.2024.104384

Abstract

Manufacturers and consumers are increasingly aware that asymmetric information can lead to potential risks in food safety and supply chain integrity. The traditional paper labels, due to their limited size, are no longer able to realize the transmission of a large amount of information. Quick Response (QR) code, as one of the most versatile and commercially successful digital technologies, provides a feasible approach to connecting physical food with its relevant digital information, and its potential in information transmission has been gradually discovered in recent years and attracted great attention. In this review, a brief overview of the QR code configuration and technical principle of information transmission is provided, along with comparisons to other digital technologies. Moreover, it provides on useful overview of the current applications of QR codes developed and practiced in information transmission. On this basis, the limitations and development direction for improving its properties are discussed. Food packaging QR codes are suitable for information transmission due to their large data storage and quick information access. QR codes have good performance in traceability, quality evaluation, anti-counterfeiting, and marketing. Given its limitations, the flexible combination with other complementary technologies, improving the consumers' sense of gratification after use, and forcing and encouraging companies to implement are the possible development directions of maximizing QR code utilization in the future within the food supply chain.

Keywords

Authentication; Food label; Food traceability; Quick Response code; Information transmission

2.1 Introduction

Food packaging is defined as an inactive barrier enclosing food to prevent the products from tampering or physical, chemical, and biological contaminants (Islamipour et al., 2022). In addition to the function of food protection, the communication function of food packaging is also one of its essential features (Petersen & Brockhaus, 2017). The label, which is always set on the surface, is one of the key elements of food packaging, as the basic purpose of food labels is to convey the corresponding information, which assists the consumers in making food choices, assessing its value, and understanding its proper use (Bez Batti et al., 2022). The Food and Agriculture Organization of the United Nations (FAO) promotes the clear and trustworthy food label to convey information about the product's identity and contents, and on how to handle, prepare and consume it safely. Countries have the specific legislation on the mandatory information that needs to be displayed on food labels, mainly including the product's name, ingredients, contents, production date, special storage conditions, and manufacturers (FAO, 2016). Besides the mandatory information, an increasing amount of business information is provided on the label and can increase overall product consumption and reinforce brand loyalty (Stuart, 2010). However, the traditional paper label, limited by its size, cannot meet the needs of information transmission. The food label with the expanded communication capacity is regarded as a feasible way to break the traditional presentation of information.

Barcode technology is a simple method to present information. A one-dimensional (1D) barcode appears on the label of almost all packaged food because it can be regarded as the 'ticket' for food to enter the market. Given the limited data storage of 1D barcode, Two-dimensional (2D) code was created. Compared with 1D barcodes storing information just from one dimension, 2D barcodes can store information in horizontal and vertical directions, which enables 2D barcodes to include more characters. One of the most often used two-dimensional codes is the Quick Response (QR) code. The QR code was invented by a Japanese firm in 1994 initially for tracing parts in vehicle manufacturing and began to be applied to the food industry after the integrity of food safety systems were threatened by Bovine Spongiform Encephalopathy or Mad Cow Disease (Soon, 2008). At the beginning of the 21st century, the QR code started to replace the traditional hand-written and printed labels in the food industry and has been widely used in the food sector. Global Standards 1 (GS1), an international standards organization, launched a global initiative to migrate from traditional to next-generation barcodes including QR codes, and support the ambition to have all retailers able to read them at their points of sale by the end of 2027 (GS1, 2023). In fact, in Italy, the QR code has been the second main digital technology used in the agriculture and food industry (Statista, 2022a). Furthermore, for instance, the Brazilian dairy company

Languiru used QR codes on all cartons of milk, leading to a 6% growth in sales (Dairy Reporter, 2018).

The popularity of QR codes on food packaging has been improving at a high pace with the growth of smartphone users (Shin et al., 2012). More consumers pay attention to QR codes on food packaging. The threat of the spread of the COVID-19 pandemic to food safety led to increased public attention to food information, as well as their interest in QR codes which serve as a tool for information transmission. This is because QR codes can be linked to the network resource, which capacity can accommodate all information necessary for consumers, including nutrition (Fagerstrøm et al., 2022), food safety (Bradford et al., 2022), biotechnology in food production (McFadden & Lusk, 2018), allergen information (Radu et al., 2018), and Halal certification (Tan et al., 2022). The practical information helps consumers in decision-making of selecting food.

Due to the increasing interest in QR codes, their usage in information transmission has been developed, which is of great significance for ensuring food integrity. In this review, the concept and technology principle of QR codes are elaborated, and its advantages and applicability in food information transmission are highlighted through the comparison with other common digital technologies. The current applications of QR codes on food packaging are comprehensively summarized for traceability, quality evaluation, anti-counterfeiting and marketing purposes, which have been developed significantly in recent years and have highlighted the potential of QR codes in data transmission. Furthermore, the various challenges and limitations on promoting QR codes are discussed. On top of that, the application prospects and development directions of QR code in food information transmission are foreseen, which is expected to be useful for the promotion and further research of QR codes on food packaging.

2.2 The QR code

2.2.1 Configurations and usage

The QR code is a two-dimensional square matrix symbol, and its cells consist of several small black and white squares arranged in a grid pattern. QR codes consist of finder patterns, alignment patterns, timing patterns, and the encoding region (Lin et al., 2013), and its structure is shown in **Fig. 2.1**. Three finder patterns at the upper-left, upper-right, and left-bottom corners are used for position detection and enable QR codes to be detected in all directions (360°). Alignment patterns are used for correcting the distortion of QR codes, especially for correcting nonlinear distortion. Timing patterns, consisting of alternate black and white modules between any two of the position detection patterns, are identified for the central coordinate of each cell in QR

codes. The encoding region contains modules that represent data, error correction codewords, and information on the version and format (Lin et al., 2013).

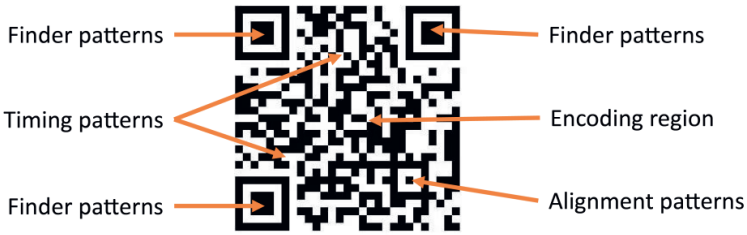


Fig. 2.1. The structure of a QR code.

QR codes have 40 versions in total. Different versions of QR codes have different sizes, different numbers of modules, and error correction levels (Pan et al., 2022). The minimum size of modules is 21×21 and the maximum is 177×177. In addition, QR codes are still accessible, although a maximum of 7%, 15%, 25%, or 30% of the code image is missing, damaged, or contains incorrect information (Bala Krishna & Dugar, 2016).

QR codes can be widely used in any size and for different materials of food packages, including cartons, metal containers, cardboard, paper, glass, and plastics, and for batched food, such as cartons, corrugated, and cardboard boxes.

2.2.2 Technical principle

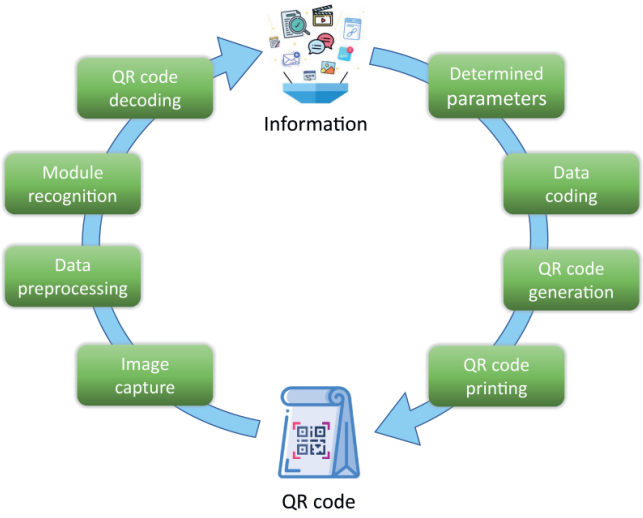


Fig. 2.2. The framework of QR code technology applied in food packaging (icons used from flaticon.com).

The framework of a QR code technology in food packaging mainly includes two parts, coding and decoding (**Fig. 2.2**). The content of QR codes is decided by the information the food companies desire to transfer and can be URL, text, phone number, coupons and messages (Dou & Li, 2008). The linked contents are analyzed to confirm the relevant parameters of QR codes, such as version, format, error correction level and character type. The contents of QR codes are separated into many groups and converted into a string of bits, which are diverted into black and white modules (black module to 1, white module to 0). All the modules must be arranged in the correct order. By adding the error correction codes, version, and format information, a QR code is generated by the encoder. Based on food packaging materials, the code printing technology is determined, such as inkjet printing, to print QR codes in the reserved space of food packaging. QR codes can be covered by a protective film to prevent damage. After that, QR codes have been attached to the food packaging, and the conversion of information to QR codes on food packaging has been completed.

The information linked with QR codes can be accessible to people who use devices to scan it. After opening the camera of scanners or smartphones and realizing automatic focusing, QR codes on the food packaging are captured and converted into a signal of reflected light, which is converted into a corresponding electronic signal through photoelectric conversion. QR code images are generally influenced by the external environment, such as lighting, shooting angle, and distance, to cause obvious distortion and noises resulting in decoding failure or wrong decoding (Xue et al., 2022). To improve the readability of QR codes, pre-processing operation on the image is essential, including grayscale conversion, binarization, and median filtering (Huo et al., 2021). The tilt correction, code segmentation, and module recognition are used to parse the version and format information, and the information on the color and position of each module group is collected to be diverted to a string of bits. A string of bits of each module group is diverted and combined in the correct order to present the information stored in QR codes. After decoding, the detailed content link to QR codes is accessible to the persons who scanned it.

2.2.3 Comparison with other digital technologies

The digital technologies of 1D barcode, Radio Frequency Identification (RFID), and QR code have been widely applied to food labels. They are both used for data delivery, but they also differ in various aspects.

1D barcode is one of the machine-readable optical labels and a pattern formed by many vertical and parallel lines of different widths. 1D barcodes have been developed as a mature tool for encoding simple food information and have been widely used in business food packaging. The standardized 1D barcodes, including the Universal

Product Code (UPC) barcodes and the European Article Number (EAN) barcodes, are regarded as a globally unique food identification to improve the accuracy and reliability of food product management between trading partners across the whole food supply chains (Dey et al., 2021). 1D barcodes can be easily integrated with various software systems, such as inventory management, enterprise resource planning (ERP), and point-of-sale (POS) systems, to implement automatic identification and transaction, causing the process of data collection and information transmission in the supply chain has been simplified (PayPal, 2023).

1D barcode and QR code have many similarities in attributes, but QR code has advantages in two main aspects, including storage capacity and readability. To be specific, a QR code can store up to 4296 characters of alphanumeric data in comparison to only 85 characters in a 1D barcode, because of the two-dimensional structure of the QR code (Hernando & Macías, 2023). The function of error correction in QR codes is also not available in the 1D barcodes.

QR codes and RFID are different in many attributes. RFID uses radio frequency signals and spatial coupling (electromagnetic coupling and electromagnetic transmission) transmission characteristics to achieve automatic identification and remotely communicate data between a tag and a reader. RFID technology can simultaneously read multiple tags by non-contact reading and be writable. The reading distance of RFID (up to 100 meters) is longer than that of the QR code (50 centimeters) (Chung, 2016). The memory capacity of RFID is about 32,000 alphanumeric characters, several times more than that of a QR code (Lou et al., 2011). It seems that RFID is superior to QR code in function, however, the high cost of RFID is the major disadvantage which cannot be ignored. The price of the RFID tag is approximately $0.66, meanwhile, QR codes are just printed by an inkjet printer, which means that the average cost for each QR code is around $0.0003 (Li et al., 2017). This disadvantage influences the usage of RFID in food packaging, as the RFID tag would greatly increase the final price of a single food product. Manufacturers are reluctant to increase the cost of food because of the expensive labels or packaging because they know that most consumers refuse to pay for it. Seino et al. (2004) proposed a similar system for fish traceability by using QR codes after discarding the use of RFID due to the costs of this technology and the weakness of reading if applied to the surface of products containing much water.

1D barcode, RFID and QR code cannot be replaced completely by each other, because of their important differences reflected in advantages and disadvantages in some respects. There are always differences in food packaging and product values, and these identification technologies will continue to be used in appropriate working

conditions. Factors, such as low-cost printing, ease of reading, and larger storage capacity, make QR codes a promising and feasible technology in food packaging.

2.3 Applications in food information transmission

2.3.1 Traceability

Food traceability refers to the ability to track the ongoing position of food products and trace their history. It builds a kind of food information chain to provide the information on processing, transportation, and sales of the food, which can increase the level of information transparency of food (Mishra, Mistry, Choudhary, Kudu, & Mishra, 2020). Unique identification is the requirement to achieve traceability (Karlsen et al., 2011). QR codes, as a unique identity for each food product, have been used for tracing the food in the whole food supply chain.

A food traceability system framework consists of all the possible stages in the supply chain, including production, processing, distribution, and logistics. **Fig. 2.3** illustrates an overview of the food information in the supply chain from farms to consumers, including production and processing information and distribution and logistics information. In the traceability system of a specific food, it may not include all the participants and traceability information mentioned in **Fig. 2.3**, but it involves some possible combinations of them. The intelligent food traceability system that integrates Blockchain, the Fifth Generation Mobile Communication Systems (5G), Cloud Computing, and Identification technology can achieve food recognition, monitoring, and tracing. Blockchain, employing a distributed database, can ensure the transparency, integrity, and security of information through data encryption and decentralized transmission (Kamble et al., 2020). The specific data on food are collected by each participant at each stage of the supply chain and uploaded to the structured database to ensure the uniformity of data to access or send (Costa et al., 2013), mainly including name, time, place, and operator. Cloud computing by which remote servers hosted on the Internet store and process data acts as large data centers to connect multiple computational, software, and storage resources and to provide configurable services and real-time data for food supply chain entities (Arvindhan, 2022; Saini & Raj, 2022). Cloud computing can provide the service of high storage and computation for the food traceability system (Kala & Nalesh, 2022). Additionally, 5G can provide low-latency, high energy-efficient, high-speed, and reliable mobile communication to meet food traceability system demands for device networking and high internet speed (Mehannaoui et al., 2023). 5G makes information transmission effective and simple, so the traceability information is easily accessible for consumers (Tang et al., 2021). QR code, as one of the identification technologies, is assigned automatically on the packaging of every food product and matched with a unique ID

code of this product in the databases. The consumers scan QR codes to access the traceability system, which can automatically find the data of this food product through its unique ID code which corresponds to a QR code. Once the data on the food products is retrieved, the critical traceability information about the products can be shown to consumers.

Food traceability has been the main application of QR codes in food industries (Yang, et al., 2022). A survey in Canada shows that the most main usage of scanned food QR codes among consumers is to obtain specific information about the product (Statista, 2022b). QR code application in food traceability (i.e., traceability system development) has attracted considerable research efforts. **Table 2.1** lists papers on the applications of QR codes in food traceability.

2.3.2 Quality evaluation

Though gas sensors for food spoilage monitoring have been previously developed and validated (Huang et al., 2014; Morsy et al., 2016), the disadvantages of these traditional methods are obvious, mainly including high costs, time-consuming processes, and lower portability, which causes the methods are only implemented in the laboratory (Chen et al., 2017). QR codes made by some special chemicals can be used as a volatility-sensitive sensor to convey the quality information of packaged food through color changes, demonstrating their applicability and convenience in evaluating the quality of item-level packaged food for consumers. QR codes can be used in quality monitoring of food that produces volatile substances when sealed packaging is intact.

Fig. 2.4 describes the procedure of using a QR code quality sensor to evaluate the freshness of food. The chemicals in QR codes attached to the inner lining of the package are responsive chemically to the food alkaline and/or acidic volatile substances inside the packaging, which are associated with food deterioration, such as ammonia, to present distinct color changes by intermolecular interactions (Pena-Pereira et al., 2023). The color of QR codes changes over time, and its image can be captured by the camera of a smartphone and processed by the built-in software to extract the color parameters, including the red, green, and blue (RGB) values after calibrating the color of the image to reduce the influence of illumination condition on the perception of the color (Escobedo et al., 2023). The RGB data of QR codes is processed by some methods, like Principal Component Analysis (PCA) (Chen et al., 2017; Conrado et al., 2021) and empirical formula (Zhang et al., 2022), to compare with the standard chart for accurate quantitative estimation of food quality, which is an explicit signal to consumers.

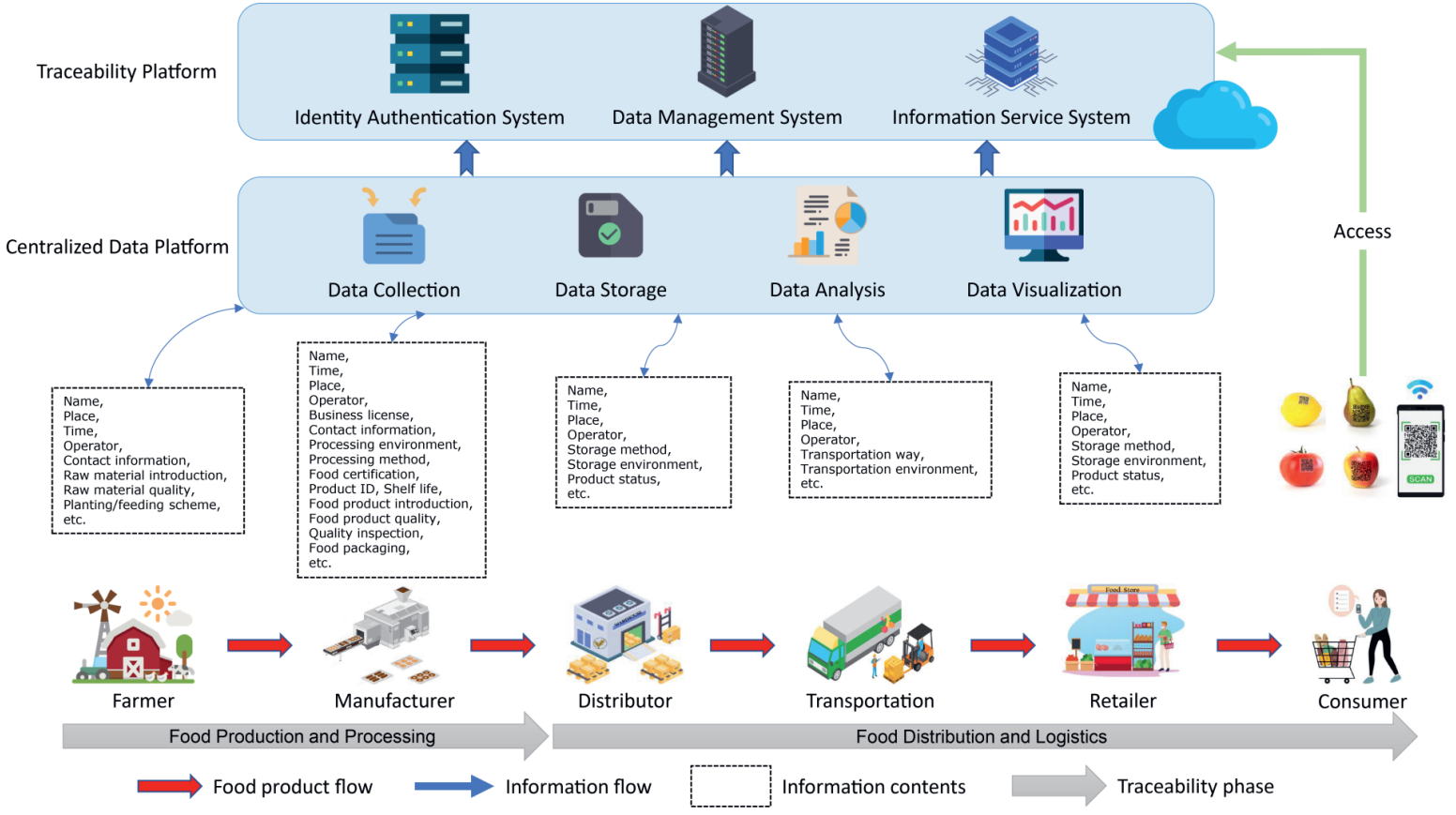


Fig. 2.3. The product flow and information flow in food traceability systems (icons used from biorender.com and flaticon.com).

Table 2.1. Lists of papers on QR code application in food traceability.

Food category	Product	Research theme	References
Aquatic products	General aquatic products	QR code application in traceability	Zhang et al. (2014)
		Traceability system development	Xiao et al. (2017)
	Fish	QR code application in traceability	Seino et al. (2004)
		Traceability modeling	Zhang et al. (2019)
		Traceability system development	Gao et al. (2019); Lin et al. (2020)
	Tuna	QR code application in traceability	Rogerson & Parry (2020)
Dairy products	Cheese	Traceability system development	Varavallo et al. (2022)
	Dairy products	Traceability system development	Li et al. (2016)
	Fruit yogurt	QR code readability analysis	Tarjan et al. (2014)
	Milk	Traceability system development	Latif et al. (2021)
		QR code application in traceability	Khanna et al. (2022)
Horticultural products	Apple	QR code identification equipment design	Qian et al. (2017)
		Traceability system development	Xie et al. (2022)
	Buckwheat	Traceability system development	Wang et al. (2021)
	Grain general	QR code identification equipment design	Liang et al. (2019)
		Traceability code generation	Deng & Feng (2021)
	Olive	QR code application in traceability	Liu et al. (2018)
		Web application development	Bayano-Tejero et al. (2019)
	Rice	Traceability system development	Sutopo et al. (2021)
	Vegetables general	QR code application in traceability	Qiao et al. (2013)
		Traceability modeling	Dong et al. (2020)
		Traceability system development	Hu et al. (2013); Yang et al., (2016); Yang et al. (2018)
	Water spinach	Consumers' perceptions of QR codes	Tran et al. (2022)
	Wheat	QR code application in traceability	Qian et al. (2012)

Table 2.1. Continued.

Food category	Product	Research theme	References
Horticultural products	Wheat	Traceability evaluation	Qian et al. (2017)
Meat products	Beef	Consumers' perceptions of QR codes	Magalhaes et al. (2021); Shew et al. (2022); Spence et al. (2018);
		Traceable resource unit transformation	Fan et al. (2019)
		Traceability system development	Liang et al. (2015)
	Pork	Management system development	Chen et al. (2016)
		Traceability system development	Bai et al. (2017); Chen et al. (2020); Peng et al. (2018)
Other products	Egg	Traceability system development	Bumblauskas et al. (2020)
	Food general	Consumers' perceptions of QR codes	Lin et al. (2022)
	Olive oil	Traceability system development	Violino et al. (2020)

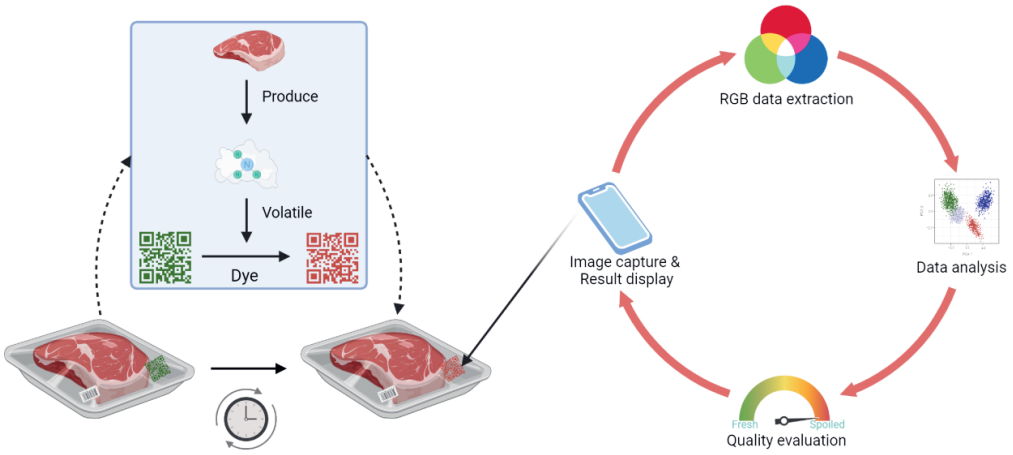


Fig. 2.4. Schematic of QR code application as a food quality sensor. Fresh food in sealed packaging (meat, for example) produces volatile substances with time, which react with chemical substances formed as QR codes. The color of the QR code varies with the increase in volatile substances concentration inside the sealed packaging (from green to red, for example). After consumers use smartphones to scan QR codes, the built-in software can extract the RGB values and then compare them with standard data in the database to evaluate the concentration of volatile substances in the packaging and food quality (icons used from biorender.com and flaticon.com).

A pH sensitive QR code was fabricated by Xu et al. (2021), and the influence of different ink ratios on its color difference was explored in the study. Chen et al. (2017) proposed a low-cost QR code without the expensive sensor hardware to accurately monitor the aging status of that packaged chicken under different temperature conditions. A central database cataloging the spoilage rate and profile of chicken draws the colorimetric standard charts to quantify color changes as a quantitative quality measure. Escobedo et al. (2023) created a built-in multi-sensing QR code whose three finder patterns are made from different reagents and materials for the monitoring of H_2S, CO_2, and NH_3. It has great potential in different types of ambient air analysis applications. Conrado et al. (2021) proposed a paper-based optoelectronic nose QR code to identify and evaluate the olive oil odor. The colorimetric result of QR codes can not only identify olive oil among other oil samples but also identify early oil oxidation under different temperatures. Zhang et al. (2022) designed a QR code with a reversible response to acid-base vapors. The impossibility of imitating this process enables QR codes not only to monitor food quality but also to prevent counterfeiting.

The QR code-enabled colorimetric sensor not only maintains the initial functionalities as a data carrier but also integrates the function of sensing in the meanwhile, and its

advantages mainly include: (1) High portability. The QR code-enabled colorimetric sensors are small, easy to use, quickly responsive, and capable of continuous monitoring. The modified QR code and mobile phone with a camera are used for readout for direct consumer use at the sale points. (2) Low cost. Smartphones with application programs are used as devices for data collection and analysis, with minimal infrastructure overhead. The low-cost optical sensing dyes do not result in a higher premium for modified QR code labels, making them acceptable to consumers. (3) High flexibility. QR code-enabled colorimetric sensors are made of flexible materials and thus, can be compressed, bent, and shaped to be better integrated with food packaging. (4) High accuracy. As a portable device to capture QR codes, the smartphone has been identified to have the same accuracy in reading color information as a benchtop spectrometer (Shen et al., 2012). The QR code-enabled sensor has been tested to have good performance in sensitivity under different illumination and environmental conditions. (5) Multifunctional. With the customized application, data processing, automatic readout, and information storage can be achieved, and real-time results of quality evaluation can be plotted on the phone screen where a warning message is displayed once the packaged food is identified as spoiled.

At present, QR code-enabled colorimetric sensors are still in the research stage and have not yet been widely used commercially. Future research needs to focus on identifying the characteristic volatile substances in different foods and their corresponding sensing dyes, optimizing the fabrication process of QR code-enabled sensors to improve their sensitivity and manufacturability, and further exploring the characteristics of QR code-enable sensors, including their validity period and target concentration range of volatile gas.

2.3.3 Anti-counterfeiting

Counterfeiting is a common type of food fraud, and the offenders deceive the consumers deliberately by fully replicating authentic food and its packaging (van Ruth et al., 2017). The authenticity of food and food labeling is becoming a significant concern for manufacturers, regulatory authorities, and consumers. The anti-counterfeiting system based on QR codes and authentication codes has been widely used in the market as shown in **Fig. 2.5a**. The unique authentication code for each batch of food product is linked to a QR code on food packaging and disclosed by producers online after the batch of food is available to consumers on supermarket shelves. Consumers can compare the authentication code acquired by scanning the food QR code with that disclosed online to authenticate the source of food (Chen et al., 2020). Although the cross-checking mechanism of QR codes and authentication codes can be used for counterfeiting detection, QR code and its links are often of public

access and visible to everybody, and copying QR codes on the packaging of authentic food and pasting it on the package of the counterfeit food products are not difficult for the offenders (Wang et al., 2018).

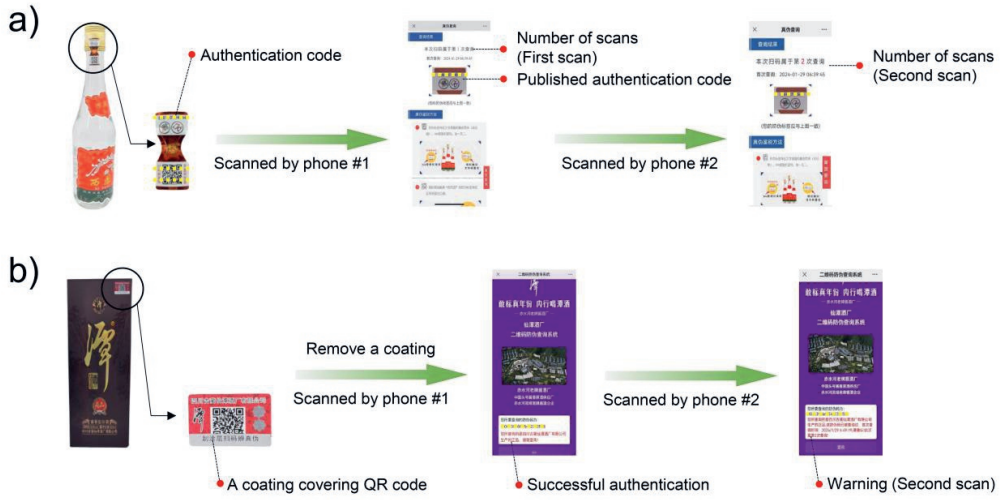


Fig. 2.5. QR codes and their linked authentication system interfaces. a) The bottle cap of the alcohol is labeled with a unique QR code and authentication code and can only be opened if the label is damaged. When a consumer accesses the authentication system linked with the QR code for the first time, the number of scans is shown as the first scan, and the authentication code and its corresponding pattern are published for the consumer to compare with those on the label. If the authentication code and its corresponding online and on the label are the same, the bottle of the alcohol is identified as authentic. When the QR code is scanned by another phone later, consumers can still access the online authentication code and pattern, but it is displayed as a second scan. b) A unique QR code on the packaging box of the alcohol is partially covered by the coat where the numerical authentication code is fully covered. After removing the coat, consumers can scan the QR code to complete the authentication of the bottle of alcohol. The first authentication will be considered successful, but if another phone is used to scan the QR code for authentication again, the system will warn consumers of the risk of counterfeiting and inform them of the number of authentications. The QR codes and authentication codes in the figure are masked by yellow dashed lines on purpose because the brand owner's consent to publicly disclose the verification codes is not obtained.

Analyzing the spatial-temporal information of consumers scanning QR codes are considered another feasible method to detect counterfeiting food with illegally copied QR codes (Jiménez-Carvelo et al., 2023). The information of consumers scanning QR

codes, including ID, scanning time, scanning location, scanner's smartphone model, number of scans, last scanning time, etc., is recorded in the database of the scanning system (Lin et al., 2022). Authentic food, its packaging, and QR codes are regarded with the same spatial-temporal information when there is no counterfeiting. The anomalies in scanning times or the location of the QR code may be a signal to warn the company that the corresponding food may be counterfeit. Krishna and Dugar (2016) proposed an anti-counterfeiting method based on the idea that QR codes are one-time scanning event. The unique QR codes can be scanned only once to provide a one-off authentication message to the customer. The QR code is covered with a plastic seal, which is removed by a customer after purchasing the product. The original packaging of the authentic product has been damaged, and therefore the product should no longer circulate in the market, meaning that the unique QR code should not be exposed to other customers. When a QR code on the product is scanned by a customer for the first time, this product is identified as 'genuine' after being verified through the database for product authentication. This QR code is judged to be copied from the authentic product package while it is scanned again, and the product with this QR code is identified as counterfeit. This authentication method has been applied commercially (**Fig. 2.5b**). Billet, a company specializing in printing labels for Champagne bottles, prints a QR code on the inside of the capsule, which is the protective wrapping or coating at the top of the bottle (Peak, 2019). Only the client who purchases the Champagne, can access the unique QR code after the capsules are destroyed when opening the bottle. The application of the capsule can ensure that the inside QR code is usually scanned at most once if there is no counterfeit food. This type of inner QR code which only provides a one-off authentication message to consumers is also used in infant formula packaging (Food Navigator Europe, 2020). The one-off authentication approach works well in combating counterfeiting food with fully fake packaging and QR codes, but it cannot be used in food with higher transferability which needs to be verified for authenticity many times, like expensive wine. Popović et al. (2021) proposed an approach in which the authenticity of wines is judged based on their status marked by consumers scanning the unique QR code. Once a bottle of wine with a unique QR code was already labeled as opened and empty by a consumer, it will set an alert if this QR code is scanned by others. A European firm with the pseudonym Demeter developed an app for wine authentication based on spatial information from scans (Rogerson & Parry, 2020). If the wine QR code is scanned in a location where it should not be (because it does not match the last known location or is not in that general area), the app would recognize it as fake and alert the consumers through a color-coded response.

2.3.4 Marketing

QR codes have developed as one of the most ubiquitous forms of digital promoting marketing in retail and have been widely adopted by food manufacturers. To be specific, the manufacturers can use four different approaches to achieve an increase in sales, including strengthening brand image, providing entertaining services, sharing cooking methods, and giving rewards. A summarized list of approaches to QR codes with existing applications is given in **Table 2.2**.

Corporate image influences consumers' evaluation and decision-making processes, which enhances the competitive advantages of companies and boosts product sales to some extent (Srivastava & Sharma, 2013). If the food QR code campaign is implemented properly, the consumers' recognition of companies can be enhanced, and corporate images can be reinforced as well (Blogherald, 2011). In general, companies always try to shape and publicize their positive images in public welfare undertakings and advocate for consumers to contribute to that. The Coca-Cola company designed a cup with QR codes linked to the website of the World Wildlife Fund (WWF) where consumers can donate to its cause to save the polar bear (Blogherald, 2011). With every $1 donated by consumers, the Coca-Cola company pledged to match that donation up to $1 million. Goodday Milk is shedding light on the plight of Bornean orangutans in Malaysia by a video linked by a QR code in its UHT banana milk packaging (Marketing-interactive, 2020). The company pledged to double their donations to WWF Malaysia’s orangutan conservation efforts, only if many consumers shared images of the product on social media. The Heinz company placed a QR code on the back of their eco-friendly plant-based ketchup bottle (PlantBottle™), which is linked to a smartphone application providing some environmentally responsible activities for consumers (Businesswire, 2012). After consumers share the actions of these activities on social media, Heinz Ketchup will help plant a tree with The Nature Conservancy as a response.

The various entertainment services linked with QR codes provide a moment of fun for consumers while they have food, resulting in an increase in usage intention and loyalty to products (Rotsios et al., 2022). QR codes on Coca-Cola packaging can take consumers to a branded Web Augmented Reality page, where they can try on the new and interesting face filters to share with friends (Mobile Marketing, 2020a). It has developed as an effective way of the campaign to promote the brand. QR codes were printed on KitKat wrappers and linked to the various forms of YouTube videos to fill consumers' break even better (QR Code Press, 2016). As a perfect fit between YouTube and the confectionery brand, QR codes can ensure that food brands continue to keep in line with the way modern consumers enjoy their breaks. The cup sleeve of

Tim Hortons coffee is designed with a QR code, which directs consumers to the Gulf News website to read the headline news (Dieline, 2012). The way of enjoying coffee while reading the latest news corresponds to the public consumption habit and is thus popular among consumers.

Table 2.2. Lists of approaches to applications of QR codes in marketing promotion.

Approaches	Food company	Category	Content linked with QR codes	References
Strengthening brand image	Coca-Cola	Beverage	Proposal of saving the polar bears' habitat and the WWF donation page	Blogherald (2011)
	Goodday Milk	Banana milk	A video of the plight of Bornean orangutans	Marketing-interactive (2020)
	Heinz	Catsup	A mobile application proposing some environmentally responsible activities	Businesswire (2012)
Providing entertaining services	Coca-Cola	Beverage	WebAR page with interesting face filters	Mobile Marketing (2020a)
	KitKat	Chocolate bar	Interesting YouTube videos	QR Code Press (2016)
	Tim Hortons	Coffee	Headline of the hour from Gulf News' Twitter account	Dieline (2012)
Sharing cooking methods	Big Bazaar, Reliance Fresh, D-Mart	General food	Textual recipes	Shinde et al. (2021)
	Chef's Basket	Pasta	A video of recipes	Scanova (2021)
	Itoham	Processed/ precooked food	Animated recipes	Dou & Li (2008)
Giving rewards	Emmi	Milk	Discount codes and raffle entries	Mobile Marketing (2020b)
	/	Olive oil	A digital token	Violino et al. (2019)

'/' Indicates no information offered in the paper.

Sharing instructional videos of cooking is another way to boost business. Food companies, especially those selling meat products, always link a textual recipe (Shindeet al., 2021), a video (Scanova, 2021), or even an animation (Dou & Li, 2008) to QR codes on food packages to display the product's numerous cooking methods.

These videos will present the cooking process in detail, which can enhance consumers' confidence in cooking and then arouse consumers' interest in this food to make quick purchase decisions.

Some economic motivational measures, such as discount codes, raffle entries (Mobile Marketing, 2020b), and digital vouchers (Violino et al., 2019), are taken by food companies through QR codes to stimulate consumers' desire to purchase the products. In this way, consumers' attention, and interest in QR codes on food packaging increases to some extent, and the sale volume of food products grows as well.

2.4 Limitations and challenges

Although a large amount of research has been conducted on QR codes in food information transmission, there are still some challenges that hinder its widespread usage.

2.4.1 Consumer engagement

The low willingness of consumers to scan QR codes is mainly because most consumers are not aware of the QR code's usefulness (Liu et al.,2018), although it brings many obvious benefits in ensuring food quality and improving transparency. At present, the traditional drivers, such as taste, brand, and price are still dominant in the food choice of consumers and the information linked with QR codes is not considered by some consumers when they select food. Although almost all QR codes have prompt words, such as 'Scan QR code for more information' and 'Scan me', they will still be ignored by many consumers because of their absence of understanding of or familiarity with QR codes (Yang et al., 2022).

2.4.2 High technical costs

The creation, printing, and pasting of QR codes are considered to be low-cost and easy to operate, only a computer/code generator, QR code printer, and tags are needed. However, for food traceability, the high cost of building and running a food tracking system or purchasing the right to use the commercial traceability platform may be the main factor affecting the attitude of food companies towards QR codes used in food traceability. The big food firms prefer to use QR code on their food products because they can afford the high costs of operation and maintenance of websites and databases. Although some technology companies or food organizations develop blockchain-based platforms and provide food traceability services to some food companies on the small to medium scale or selling low-value-added products, because of the huge investment in new equipment and updating the old equipment, these technology

companies always charge high service fees, which leads to adverse economics of QR code deployment.

2.4.3 High marginal cost

When consumers scan QR codes to inspect products and price options thoroughly, they must pay more time costs in the store. This is because consumers using a smart device must complete some complex actions, such as inputting manually a long traceability code on the platform linked to QR codes, to obtain more food information (Chung, 2016). If consumers have limited time to shop, their willingness to scan may be low to some extent. 'Do not have much time to scan during shopping' has been proven as one of the primary reasons for consumers' limited scanning (Yang et al., 2022).

Internet connection and available scanning devices are the premises that consumers enable to acquire real-time information by scanning QR codes. Free internet access can encourage consumers to use mobile devices in stores (Reyes-Menendez et al., 2018). In addition, providing the scanning device can significantly improve the likelihood that consumers will scan QR codes because most of them are reluctant to use their own devices to scan QR codes. Thus, free internet access and available scanning devices are feasible ways to reduce the marginal cost of information search for consumers so that the percentage of people who access QR codes will increase (Li & Messer, 2019).

2.4.4 Information overload

After scanning QR codes, consumers face more detailed and complex product information and need to spend much time on information retrieval, which undoubtedly complicates consumers' decision-making about food. The consumers' purpose of scanning QR codes on food packaging is often heterogeneous, and a key challenge is to ensure that most consumers can find the correct information in a short time after scanning. Based on the information-processing-parsimony hypothesis (Holbrook, 1978), consumers are always unlikely to read information that they are not interested in. If consumers eventually fail to find the information they need or encounter difficult page navigation on their first few scans, this is a bad experience for them, which probably causes that they are reluctant to keep scanning QR codes in the future. Thus, how to avoid information overload and how to ensure the users' efficiency in information search should attract the attention of food manufacturers.

2.4.5 Technical barriers

Decoding of QR codes becomes challenging when QR codes are pasted on the curved surfaces of food or the packaging, since the corresponding significant deformations occur, causing pattern distortion and irregular module spacing. The ball diameter of food products, the reading distance between cameras and QR codes, the interaction between reading distance and QR code size, and the interaction between ball diameter and QR code size are the primary factors affecting the readability of QR codes fixed to curved surfaces (Qianet al., 2021). In addition, the traditional QR code printing methods, including inkjet coding and laser coding, lead to QR codes being susceptible to color fading and easy wear and erasure (Wanget al., 2023). Once a QR code cannot be captured and recognized, it will lose readability. Another technical barrier is that QR codes need to be read in turn, which cannot meet the industrial requirements of reading multiple QR codes simultaneously (Ahamed et al., 2023). Consequently, in large-scale production and warehouse storage conditions, such as high-speed production lines or large warehousing and logistics systems, it is inefficient to identify food products by scanning QR codes.

2.5 Future perspectives

To promote the popularity of QR codes, its usage in combination with other complementary technologies can be considered as promising. QR codes and RFID can be used in the traceability of different levels of food packaging according to the advantages of these two technologies in many aspects (Qian et al., 2012). To be specific, at the production and transportation stages, an RFID is attached to the large package of a batch of food and transmits the information of this batch on the production, status, and location. RFID is advantageous in non-contact, multiple, and high-speed reading, meeting the industrial demand for a large amount of information collection on multiple batches of food. All the small-package single food products in a batch can share the same information transmitted by an RFID, and the cost of an RFID does not lead to a significant premium for a high-priced batch of food. At the distribution and retail stages, a batch of food is unpacked into many small-package single food products. These single food products are assigned low-cost QR codes on their packaging, making it feasible for consumers to trace the food by using smartphones (Fan et al., 2019). In short, RFID technology is adopted to transfer information on the movement of food products along the supply chain, while QR codes on the packaging of single food products serve the consumers. The combination of two technologies not only improves the information transmission efficiency throughout the whole food supply chain but also avoids the high food premium caused by the technology application. The identification association for a one-to-many relationship is established through

RFID and QR codes to realize the data connection and information transmission to build the food traceability system based on the integration of the two technologies.

The possibility that consumers adopt QR codes in the food purchase decision is dependent on the sense of gratification they have (Higgins, Wolf, & Wolf, 2014). How to provide useful information or pleasant service is crucial to satisfying information needs and improving consumers' experience of scanning. Firstly, a good fit should be formed between the paper label and QR code, causing consumers to have greater scan intention. The information linked with QR codes should be different from that of the paper label because consumers prefer to read the label directly rather than acquire the information on a little phone (Tanner et al., 2019). Secondly, if the food companies hope consumers can effectively search and use the information after scanning QR codes, they need to continuously optimize their websites and landing pages for mobile browsing and information offering discriminately. The information should be classified, segmented, and searched by the navigator. The website linked with QR codes should be comfortable and fun for consumers by optimizing computer factors (e.g., dropdown menus, buttons, radio, and checkboxes, etc.) and human factors (background color, visual images, information density, etc.) (Hausman, & Siekpe, 2009).

From a legislative point of view, customized legislation aiming at the food integrity needs in different countries can promote the further application of QR codes. Since genetically modified food has always been controversial in America (Zhang et al.,2023), the United States Department of Agriculture (USDA) has issued regulations allowing food manufacturers to use QR codes, as a supplementary tool for genetically modified labeling, to disclose more genetically modified ingredients in food, which protects consumers' right to know what they eat (Packaging Dive, 2023). In Regulation (EU) 2021/2117 (The European Parliament and of the Council, 2021), it is recommended that the full nutrition declaration and the list of ingredients of wine can be made available by electronic means, including QR codes, to ensure that consumers access specific, clear, transparent, and digitally accessible information. All halal-certified products in the Malaysian market shall be marked or labeled with a halal logo and a QR code to meet consumers' needs for halal food sources and processing information (The Department of Islamic Development Malaysia, 2021). Food companies should not only accept the recommendation about QR code implementation but also actively value the role of QR codes in efficient information transmission. It is worth noting that, with the changes in consumer purchasing decisions, the increasing popularity of QR codes, and the growing demand for food authenticity, QR codes are considered more popular among consumers, especially the younger (Atkin & Thach, 2012; Rotsios et al., 2022). Many large companies, such as Carrefour (Sunny et al., 2020) and Walmart (NFCW, 2019), are also promoting the use of QR codes on food packaging.

2.6 Conclusions

QR code is a promising technology that has good potential in information transmission. The paper introduces the structure, specification, and practicability of QR codes, and elaborates how QR codes store and transfer information. The advantages of food packaging QR codes are shown by comparing them with other digital technologies. QR codes on food packaging have many practical applications which are as follows: a) information providing of food traceability for consumers; b) accurate evaluation of food quality in sealed packaging; c) counterfeiting prevention; d) marketing promoting. The implementations of QR codes in food packaging are increasing at a great rate, but real applications of QR codes are still limited because of various obstacles, including low demands of consumers, high technical costs, marginal cost, and information overload.

The application of food packaging QR codes has gone beyond the limitations of traditional approaches on information transmission, resulting in a large and diverse amount of information transmitted digitally. The application of food packaging QR codes described in this work could account for their potentials in food transmission, which are expected to enhance the supply chain integrity. The future studies are warranted to focus on how to further improve the practical utilization of QR codes to increase their market prospects.

References

Ahamed, N. N., Vignesh, R. & Alam, T. (2023). Tracking and tracing the halal food supply chain management using blockchain, RFID, and QR code. *Multimedia Tools and Applications.* https://doi.org/10.1007/s11042-023-17474-4

Arvindhan, M. (2022). Effective motivational factors and comprehensive study of information security and policy challenges. In P. Johri, A. Anand, J. Vain, J. Singh, & M. Quasim (Eds.), *System Assurances* (pp. 531-545). Academic Press.

Atkin, T., & Thach, L. (2012). Millennial wine consumers: Risk perception and information search. *Wine Economics and Policy*, *1*(1), 54-62. https://doi.org/10.1016/j.wep.2012.08.002

Bai, H., Zhou, G., Hu, Y., Sun, A., Xu, X., Liu, X., & Lu, C. (2017). Traceability technologies for farm animals and their products in China. *Food Control*, *79*, 35-43. https://doi.org/10.1016/j.foodcont.2017.02.040

Bala Krishna, M., & Dugar, A. (2016). Product authentication using QR codes: a mobile application to combat counterfeiting. *Wireless Personal Communications*, *90*(1), 381-398. https://doi.org/10.1007/s11277-016-3374-x

Bayano-Tejero, S., Sola-Guirado, R. R., Gil-Ribes, J. A., & Blanco-Roldán, G. L. (2019). Machine to machine connections for integral management of the olive production. *Computers and Electronics in Agriculture*, *166*, 104980. https://doi.org/10.1016/j.compag.2019.104980

Bez Batti, E. A., Nascimento, A. B. D., Geraldo, A. P. G., Fernandes, A. C., Bernardo, G. L., Proenca, R. P. D. C., & Uggioni, P. L. (2022). Use of the term whole grain on the label of processed and ultra-processed foods based on cereals and pseudocereals in Brazil. *Frontiers in Nutrition*, *9*, 875913. https://doi.org/10.3389/fnut.2022.875913

Bradford, H., McKernan, C., Elliott, C., & Dean, M. (2022). Consumer purchase intention towards a quick response (QR) code for antibiotic information: an exploratory study. *npj Science of Food*, *6*(1), 23. https://doi.org/10.1038/s41538-022-00136-4

Blogherald. (2011). Coca-Cola launches first nationwide QR Code program. Retrieved *from https://www.blogherald.com/news/coca-cola-launches-first-nationwide-qr-code-program/*. Accessed June 13, 2022

Bumblauskas, D., Mann, A., Dugan, B., & Rittmer, J. (2020). A blockchain use case in food distribution: Do you know where your food has been?. *International Journal of Information Management*, *52*, 102008. https://doi.org/10.1016/j.ijinfomgt.2019.09.004

Businesswire. (2012). Heinz Ketchup inspires more environmentally responsible living this summer with PlantBottle™ packaging promotion. Retrieved from *https://www.businesswire.com/news/home/20120717006392/en/Heinz%C2%AE-Ketchup-Inspires-More-Environmentally-Responsible-Living-This-Summer-with-PlantBottle%E2%84%A2-Packaging-Promotion*. Accessed June 4, 2022

Chen, C. L., Deng, Y. Y., Li, C. T., Zhu, S., Chiu, Y. J., & Chen, P. Z. (2020). An IoT-based traceable drug anti-counterfeiting management system. *IEEE Access, 8*, 224532-224548. https://doi.org/10.1109/ACCESS.2020.3036832

Chen, P. J., Du, Y. C., Cheng, K. A., & Po, C. Y. (2016, June). *Development of a management system with RFID and QR code for matching and breeding in Taiwan pig farm*. 2016 13th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, Chiang Mai, Thailand.

Chen, T., Ding, K., Hao, S., Li, G., & Qu, J. (2020). Batch-based traceability for pork: A mobile solution with 2D barcode technology. *Food Control*, *107*, 106770. https://doi.org/10.1016/j.foodcont.2019.106770

Chen, Y., Fu, G., Zilberman, Y., Ruan, W., Ameri, S. K., Zhang, Y. S., Miller, E., & Sonkusale, S. R. (2017). Low cost smart phone diagnostics for food using paper-based colorimetric sensor arrays. *Food Control*, *82*, 227-232. https://doi.org/10.1016/j.foodcont.2017.07.003

Chung, M. (2016). Effective near advertisement transmission method for smart-devices using inaudible high-frequencies. *Multimedia Tools and Applications*, *75*(10), 5871-5886. https://doi.org/10.1007/s11042-015-2553-1

Conrado, J. A. M., Sequinel, R., Dias, B. C., Silvestre, M., Batista, A. D., & Petruci, J. F. D. S. (2021). Chemical QR code: a simple and disposable paper-based optoelectronic nose for the identification of olive oil odor. *Food Chemistry, 350*, 129243. https://doi.org/10.1016/j.foodchem.2021.129243

Costa, C., Antonucci, F., Pallottino, F., Aguzzi, J., Sarriá, D., & Menesatti, P. (2013). A review on agri-food supply chain traceability by means of RFID technology. *Food and Bioprocess Technology*, *6*(2), 353-366. https://doi.org/10.1007/s11947-012-0958-7

Dairy Reporter. (2018). Brazilian dairy boosts sales with SIG's QR connected pack. Retrieved from *https://www.dairyreporter.com/Article/2018/07/26/Brazilian-dairy-boosts-sales-with-SIG-s-QR-connected-pack*. Accessed December 12, 2022

Deng, M., & Feng, P. (2021). Research on a traceability scheme for a grain supply chain. *Journal of Sensors*, *2021*, 8860487. https://doi.org/10.1155/2021/8860487

Dey, S., Saha, S., Singh, A. K., & McDonald-Maier, K. (2021). FoodSQRBlock: Digitizing food production and the supply chain with blockchain and QR code in the cloud. *Sustainability*, *13*, 3486. https://doi.org/10.3390/su13063486

Dieline. (2012). The 'headline news' cup sleeve. Retrieved from *https://thedieline.com/blog/2012/5/22/the-headline-news-cup-sleeve.html.* Accessed July 2, 2022

Dong, Y., Fu, Z., Stankovski, S., Wang, S., & Li, X. (2020). Nutritional quality and safety traceability system for China's leafy vegetable supply chain based on fault tree analysis and QR code. *IEEE Access*, *8*, 161261-161275. https://doi.org/10.1109/ACCESS.2020.3019593.

Dou, X., & Li, H. (2008). Creative use of QR codes in consumer communication. *International Journal of Mobile Marketing*, *3*(2), 61-67.

Escobedo, P., Ramos-Lorente, C. E., Ejaz, A., Erenas, M. M., Martínez-Olmos, A., Carvajal, M. A., Garcia-Nunez, C., De Orbe-Paya, I., Capitan-Vallvey, L. F., & Palma, A. J. (2023). QRsens: Dual-purpose Quick Response code with built-in colorimetric sensors. *Sensors and Actuators B: Chemical*, *376*, 133001. https://doi.org/10.1016/j.snb.2022.133001

Fagerstrøm, A., Eriksson, N., Khamtanet, S., Jitkuekul, P., Sigurdsson, V., & Larsen, N. M. (2022). The relative impact of health communication conveyed via quick response codes: A conjoint experiment among young thai consumers doing grocery shopping. *Health Marketing Quarterly*, *40*(2), 206-225. https://doi.org/10.1080/07359683.2022.2085460

Food and Agriculture Organization of the United Nations (FAO). (2016). *Handbook on food labelling to protect consumers*. FAO: Rome Italy.

Fan, B., Qian, J., Wu, X., Du, X., Li, W., Ji, Z., & Xin, X. (2019). Improving continuous traceability of food stuff by using barcode-RFID bidirectional transformation equipment: Two field experiments. *Food Control*, *98*, 449-456. https://doi.org/10.1016/j.foodcont.2018.12.002

Food Navigator Europe. (2020). Danone on its blockchain 'first': 'Every individual baby formula pack can be traced back'. Retrieved from *https://www.foodnavigator.com/Article/2020/02/17/Danone-on-its-blockchain-first-Every-individual-baby-formula-pack-can-be-traced-back.* Accessed February 2, 2023

Gao, G., Xiao, K., & Chen, M. (2019). An intelligent IoT-based control and traceability system to forecast and maintain water quality in freshwater fish farms. *Computers and Electronics in Agriculture*, *166*, 105013. https://doi.org/10.1016/j.compag.2019.105013

GS1. (2023). Paving the way for a global migration to 2D barcodes. Retrieved from *https://www.gs1.org/resources/articles/paving-way-global-migration-2d-barcodes*. Accessed June 22, 2023

Hausman, A. V., & Siekpe, J. S. (2009). The effect of web interface features on consumer online purchase intentions. *Journal of Business Research*, *62*(1), 5-13. https://doi.org/10.1016/j.jbusres.2008.01.018

Hernando, R., & Macías, J. A. (2023). Development of usable applications featuring QR codes for enhancing interaction and acceptance: a case study. *Behaviour & Information Technology*, *42*(4), 360-378. https://doi.org/10.1080/0144929X.2021.2022209

Higgins, L. M., Wolf, M. M., & Wolf, M. J. (2014). Technological change in the wine market? The role of QR codes and wine apps in consumer wine purchases. *Wine Economics and Policy*, *3*(1), 19-27. https://doi.org/10.1016/j.wep.2014.01.002

Holbrook, M. B. (1978). Beyond attitude structure: Toward the informational determinants of attitude. *Journal of Marketing Research*, *15*(4), 545-556. https://doi.org/10.1177/002224377801500404

Hu, J. Y., Zhang, X., Moga, L. M., & Neculita, M. (2013). Modeling and implementation of the vegetable supply chain traceability system. *Food Control, 30*(1), 341-353. https://doi.org/10.1016/j.foodcont.2012.06.037

Huang, X. W., Zou X. B., Shi J. Y., Guo, Y. N., Zhao, J. W., Zhang, J. C., & Hao, L. M. (2014). Determination of pork spoilage by colorimetric gas sensor array based on natural pigments. *Food Chemistry*, *145*, 549-554. https://doi.org/10.1016/j.foodchem.2013.08.101

Huo, L., Zhu, J., Singh, P. K., & Pavlovich, P. A. (2021). Research on QR image code recognition system based on artificial intelligence algorithm. *Journal of Intelligent Systems*, *30*(1), 855-867. https://doi.org/10.1515/jisys-2020-0143

Islamipour, Z., Zare, E. N., Salimi, F., Ghomi, M., & Makvandi, P. (2022). Biodegradable antibacterial and antioxidant nanocomposite films based on dextrin for bioactive food packaging. *Journal of Nanostructure in Chemistry*, *12*(5), 991-1006. https://doi.org/10.1007/s40097-022-00491-4

Jiménez-Carvelo, A. M., Li, P., Erasmus, S. W., Wang, H., & van Ruth, S. M. (2023). Spatial-temporal event analysis as a prospective approach for signalling emerging food fraud-related anomalies in supply chains. *Foods*, *12*(1), 61. https://doi.org/10.3390/foods12010061

Kala, S., & Nalesh, S. (2022). Security and challenges in IoT-enabled systems. In P. Johri, A. Anand, J. Vain, J. Singh, & M. Quasim (Eds.), *System Assurances* (pp. 437-445). Academic Press.

Kamble, S. S., Gunasekaran, A., & Sharma, R. (2020). Modeling the blockchain enabled traceability in agriculture supply chain. *International Journal of Information Management*, *52*, 101967. https://doi.org/10.1016/j.ijinfomgt.2019.05.023

Karlsen, K. M., Donnelly, K. M., & Olsen, P. (2011). Granularity and its importance for traceability in a farmed salmon supply chain. *Journal of Food Engineering*, *102*(1), 1-8. https://doi.org/10.1016/j.jfoodeng.2010.06.022

Khanna, A., Jain, S., Burgio, A., Bolshev, V., & Panchenko, V. (2022). Blockchain-Enabled supply chain platform for Indian dairy industry: safety and traceability. *Foods*, *11*(17), 2716. https://doi.org/10.3390/foods11172716

Krishna, M. B., & Dugar, A. (2016). Product authentication using QR codes: a mobile application to combat counterfeiting. *Wireless Personal Communications, 90*(1), 381-398. https://doi.org/10.1007/s11277-016-3374-x

Latif, R. M. A., Farhan, M., Rizwan, O., Hussain, M., Jabbar, S., & Khalid, S. (2021). Retail level Blockchain transformation for product supply chain using truffle development platform. *Cluster Computing*, *24*, 1-16. https://doi.org/10.1007/s10586-020-03165-4

Li, H., Zhang, B., Zhang, L., Xue, Y., He, M., & Ren, C. (2016). A food traceability framework for dairy and other low-margin products. *IBM Journal of Research and Development*, *60*(5-6), 10-1. https://doi.org/10.1147/JRD.2016.2598610

Li, T., & Messer, K. D. (2019). To scan or not to scan: The question of consumer behavior and QR Codes on food packages. *Journal of Agricultural and Resource Economics*, *44*(2), 311-327.

Li, Z., Liu, G., Liu, L., Lai, X., & Xu, G. (2017). IoT-based tracking and tracing platform for prepackaged food supply chain. *Industrial Management & Data Systems*, *117*(9), 1906-1916. https://doi.org/10.1108/IMDS-11-2016-0489

Liang, K., Chen, X., He, R., Li, J., Okinda, C., Han, D., & Shen, M. (2019). Development and parameter optimization of automatic separation and identification equipment for grain tracing systems based on grain tracers with QR codes. *Computers and Electronics in Agriculture*, *162*, 709-718. https://doi.org/10.1016/j.compag.2019.04.039

Liang, W., Cao, J., Fan, Y., Zhu, K., & Dai, Q. (2015). Modeling and implementation of cattle/beef supply chain traceability using a distributed RFID-based framework in China. *PloS one*, *10*(10), e0139558. https://doi.org/10.1371/journal.pone.0139558

Lin, K., Chavalarias, D., Panahi, M., Yeh, T., Takimoto, K., & Mizoguchi, M. (2020). Mobile-based traceability system for sustainable food supply networks. *Nature Food*, *1*(11), 673-679. https://doi.org/10.1038/s43016-020-00163-y

Lin, S., Shi, Q., & Zhou, N. (2022). Construction of a traceability system for food industry chain safety information based on Internet of things technology. *Frontiers in Public Health*, *10*, 857039. https://doi.org/10.3389/fpubh.2022.857039

Lin, Y. S., Luo, S. J., & Chen, B. Y. (2013). Artistic QR code embellishment. *Computer Graphics Forum*, *32*(7), 137-146. https://doi.org/10.1111/cgf.12221

Liu, C., Li, J., Steele, W., & Fang, X. (2018). A study on Chinese consumer preferences for food traceability information using best-worst scaling. *PloS one*, *13*, e0206793. https://doi.org/10.1371/journal.pone.0206793

Lou, J. J., Andrechak, G., Riben, M., & Yong, W. H. (2011). A review of radio frequency identification technology for the anatomic pathology or biorepository laboratory: Much promise, some progress, and more work needed. *Journal of Pathology Informatics*, *2*(1), 34-44. https://doi.org/10.4103/2153-3539.83738

Magalhaes, D. R., Campo, M. D. M., & Maza, M. T. (2021). Knowledge, utility, and preferences for beef label traceability information: A cross-cultural market analysis comparing Spain and Brazil. *Foods*, *10*(2), Article 232. https://doi.org/10.3390/foods10020232

Marketing-interactive. (2020). Goodday Milk uses QR codes on packaging to raise awareness on Bornean orangutans. Retrieved from *https://www.marketing-interactive.com/goodday-milk-uses-qr-codes-on-packaging-to-raise-awareness-on-bornean-orangutans*. Accessed May 5, 2023

McFadden, B. R., & Lusk, J. L. (2018). Effects of the national bioengineered food disclosure standard: Willingness to pay for labels that communicate the presence or absence of genetic modification. *Applied Economic Perspectives and Policy*, *40*(2), 259-275. https://doi.org/10.1093/aepp/ppx040

Mehannaoui, R., Mouss, K. N., & Aksa, K. (2023). IoT-based food traceability system: Architecture, technologies, applications, and future trends. *Food Control*, *145*, 109409. https://doi.org/10.1016/j.foodcont.2022.109409

Mishra, N., Mistry, S., Choudhary, S., Kudu, S., & Mishra, R. (2020). *Food traceability system using blockchain and QR code*. IC-BCT 2019: Proceedings of the International Conference on Blockchain Technology. Springer Singapore.

Mobile Marketing. (2020a). Coca-Cola turns to WebAR for #Refreshwherevs campaign in South Africa. Retrieved from *https://mobilemarketingmagazine.com/coca-cola-turns-to-webar-for-refreshwherevs-campaign-in-south-africa*. Accessed May 18, 2022

Mobile Marketing. (2020b). Emmi gamifies its latest product promotion via Tetra Pak QR codes. Retrieved from *https://mobilemarketingmagazine.com/emmi-tetra-pak-qr-code-gamification-campaign-appetite-creative*. Accessed April 8, 2022

Morsy, M. K., Zór, K., Kostesha, N., Alstrom, T. S., Heiskanen, A., El-Tanahi, H., Sharoba, A., Papkovsky, D., Larsen, J., Khalaf, H., Jakobsen, M. H., & Emnéus, J. (2016). Development and validation of a colorimetric sensor array for fish spoilage monitoring. *Food Control*, *60*, 346-352. https://doi.org/10.1016/j.foodcont.2015.07.038

NFCW. (2019). Walmart combines blockchain and QR codes to let Chinese consumers verify source of fresh produce in stores. Retrieved from *https://www.nfcw.com/2019/07/02/363418/walmart-combines-blockchain-and-qr-codes-to-let-chinese-consumers-verify-source-of-fresh-produce-in-stores/*. Accessed January 26, 2024

Packaging Dive. (2023). QR code resurgence presents opportunity for food and beverage packaging. Retrieved from *https://www.packagingdive.com/news/qr-code-upc-barcode-smartlabel-smartphone-packaging/652235/#:~:text=In%20January%202022%2C%20new%20U.S.%20Department%20of%20Agriculture,QR%20codes%20included%20as%20one%20approved%20communication%20method*. Accessed January 27, 2024

Pan, J. S., Liu, T., Yan, B., Yang, H. M., & Chu, S. C. (2022). Using color QR codes for QR code secret sharing. *Multimedia Tools and Applications*, *81*(11), 15545-15563. https://doi.org/10.1007/s11042-022-12423-z

PayPal. (2023). QR code vs. barcode: What's the difference?. Retrieved from *https://www.paypal.com/us/brc/article/difference-between-qr-code-and-barcode*. Accessed January 27, 2024

Peak. (2019). Tracking technology now ensures your Champagne will be genuine. Retrieved from *https://www.thepeakmagazine.com.sg/gourmet-travel/connected-champagne-tracking-qr-rfid/.* Accessed January 7, 2023

Petersen, M., & Brockhaus, S. (2017). Dancing in the dark: Challenges for product developers to improve and communicate product sustainability. *Journal of Cleaner Production*, *161*, 345-354. https://doi.org/10.1016/j.jclepro.2017.05.127

Pena-Pereira, F., Lavilla, I., de la Calle, I., Romero, V., & Bendicho, C. (2023). Detection of gases and organic vapors by cellulose-based sensors. *Analytical and Bioanalytical Chemistry*, 1-22. https://doi.org/10.1007/s00216-023-04649-z

Peng, Y., Zhang, L., Song, Z., Yan, J., Li, X., & Li, Z. (2018). A QR code based tracing method for fresh pork quality in cold chain. *Journal of Food Process Engineering*, *41*(4), e12685. https://doi.org/10.1111/jfpe.12685

Popović, T., Krčo, S., Maraš, V., Hakola, L., Radonjić, S., van Kranenburg, R., & Šandi, S. (2021). A novel solution for counterfeit prevention in the wine industry based on IoT, smart tags, and crowd-sourced information. *Internet of Things*, *14*, 100375. https://doi.org/10.1016/j.iot.2021.100375

Qian, J., Du, X., Zhang, B., Fan, B., & Yang, X. (2017). Optimization of QR code readability in movement state using response surface methodology for implementing continuous chain traceability. *Computers and Electronics in Agriculture*, *139*, 56-64. https://doi.org/10.1016/j.compag.2017.05.009

Qian, J., Fan, B., Wu, X., Han, S., Liu, S., & Yang, X. (2017). Comprehensive and quantifiable granularity: A novel model to measure agro-food traceability. *Food Control*, *74*, 98-106. https://doi.org/10.1016/j.foodcont.2016.11.034

Qian, J. P., Xing, B., Zhang, B. H., & Yang, H. (2021). Optimizing QR code readability for curved agro-food packages using response surface methodology to improve mobile phone-based traceability. *Food Packaging and Shelf Life*, *28*, 100638. https://doi.org/10.1016/j.fpsl.2021.100638

Qian, J. P., Yang, X. T., Wu, X. M., Zhao, L., Fan, B. L., & Xing, B. (2012). A traceability system incorporating 2D barcode and RFID technology for wheat flour mills. *Computers and Electronics in Agriculture*, *89*, 76-85. https://doi.org/10.1016/j.compag.2012.08.004

Qiao, S., Wei, Z., & Yang, Y. (2013, October). *Research on vegetable supply chain traceability model based on two-dimensional barcode*. 2013 Sixth International Symposium on Computational Intelligence and Design, Hangzhou, China.

QR Code Press. (2016). KitKat QR code launched by Google and Nestlé. Retrieved from *https://www.qrcodepress.com/kitkat-qr-code-launched-google-nestle/8532131/*. Accessed July 8, 2022

Radu, A. E., Alexe, P., Pădure, Ș., Macri, A., & Belc, N. (2018). Perception of Romanian consumer on QR code as an extension of nutrition labelling. *Analele Universității" Dunărea de Jos" din Galați. Fascicula II, Matematică, fizică, mecanică teoretică/Annals of the" Dunarea de Jos" University of Galati. Fascicle II, Mathematics, Physics, Theoretical Mechanics*, *41*(2), 229-236. https://doi.org/10.35219/ann-ugal-math-phys-mec.2018.2.16

Reyes-Menendez, A., Palos-Sanchez, P. R., Saura, J. R., & Martin-Velicia, F. (2018). Understanding the influence of wireless communications and Wi-Fi access on customer loyalty: a behavioral model system. *Wireless Communications and Mobile Computing*, *2018*, 3487398. https://doi.org/10.1155/2018/3487398

Rogerson, M., & Parry, G. C. (2020). Blockchain: case studies in food supply chain visibility. *Supply Chain Management: An International Journal*, *25*(5), 601-614. https://doi.org/10.1108/SCM-08-2019-0300

Rotsios, K., Konstantoglou, A., Folinas, D., Fotiadis, T., Hatzithomas, L., & Boutsouki, C. (2022). Evaluating the use of QR codes on food products. *Sustainability*, *14*(8), 4437. https://doi.org/10.3390/su14084437

Saini, K., & Raj, P. (2022). Edge platforms, frameworks and applications. In P. Raj, K. Saini, & C. Surianarayanan, (Eds.), *Advances in Computers* (pp. 237-258). Elsevier.

Scanova. (2021). Food QR Code: Bringing Tech and Taste Together. Retrieved from *https://scanova.io/blog/food-qr-code/#3_Tata_Tea*. Accessed July 15, 2022

Scanova. (2018). GMO QR code: Everything you need to know about USDA's rule for food safety. Retrieved from *https://scanova.io/blog/gmo-qr-code/?utm_source=smb-smb-qr-codes-fda-bod&utm_medium=blog&utm_campaign=content*. Accessed December 15, 2022

Seino, K., Kuwabara, S., Mikami, S., Takahashi, Y., Yoshikawa, M., Narumi, H., Koganezaki, K., Wakabayashi, T., & Nagano, A. (2004, November). *Development of the traceability system which secures the safety of fishery products using the QR code and a digital signature*. Oceans' 04 MTS/IEEE Techno-Ocean, Kobe, Japan.

Shen, L., Hagen, J. A., & Papautsky, I. (2012). Point-of-care colorimetric detection with a smartphone. *Lab Chip*, *12*, 4240-4243. https://doi.org/10.1039/c2lc40741h

Shew, A. M., Snell, H. A., Nayga Jr, R. M., & Lacity, M. C. (2022). Consumer valuation of blockchain traceability for beef in the United States. *Applied Economic Perspectives and Policy*, *44*(1), 299-323. https://doi.org/10.1002/aepp.13157

Shin, D. H., Jung, J., & Chang, B. H. (2012). The psychology behind QR codes: User experience perspective. *Computers in Human Behavior*, *28*(4), 1417-1426. https://doi.org/10.1016/j.chb.2012.03.004

Shinde, S., Khanna, M., Kale, S., & Varghese, D. (2021, June). *ML-Based Smart Shopping System with Recipe Recommendation*. 2021 International Conference on Communication information and Computing Technology, Mumbai, India.

Soon, T. J. (2008). QR code. *Synthesis Journal*, 59-78.

Spence, M., Stancu, V., Elliott, C. T., & Dean, M. (2018). Exploring consumer purchase intentions towards traceable minced beef and beef steak using the theory of planned behavior. *Food Control*, *91*, 138-147. https://doi.org/10.1016/j.foodcont.2018.03.035

Srivastava, K., & Sharma, N. K. (2013). Service quality, corporate brand image, and switching behavior: The mediating role of customer satisfaction and repurchase intention. *Services Marketing Quarterly*, *34*(4), 274-291. https://doi.org/10.1080/15332969.2013.827020

Statista. (2022a). Main digital technologies used in the agriculture & food industry in Italy in 2019. Retrieved from *https://www.statista.com/statistics/1140394/technologies-in-the-agriculture-and-food-industry-italy/*. Accessed March 5, 2023

Statista. (2022b). Usage of scanned food QR codes among consumers in Canada as of September 2016. Retrieved from *https://www.statista.com/statistics/451716/usage-of-scanned-food-qr-codes-in-canada/*. Accessed October 19, 2022

Stuart, S. A. (2010). The relationship between mandatory and other food label information. *British Food Journal, 112*(1), 21-31. https://doi.org/10.1108/00070701011011173

Sunny, J., Undralla, N., & Pillai, V. M. (2020). Supply chain transparency through blockchain-based traceability: An overview with demonstration. *Computers & Industrial Engineering*, *150*, 106895. https://doi.org/10.1016/j.cie.2020.106895

Sutopo, A., Susmartini, S., & Herdiman, L. (2021). Designing a traceability system for rice distribution process using QR Code bassed Android application at perum bulog Subdivre III surakarta. *Jurnal Ilmiah Teknik Industri*, *20*(1), 131-140. https://doi.org/10.23917/jiti.v20i1.13746

Tan, A., Gligor, D., & Ngah, A. (2022). Applying blockchain for halal food traceability. *International Journal of Logistics Research and Applications*, *25*(6), 947-964. https://doi.org/10.1080/13675567.2020.1825653

Tang, Y., Dananjayan, S., Hou, C. J., Guo, Q. W., Luo, S. M., & He, Y. (2021). A survey on the 5G network and its impact on agriculture: Challenges and opportunities. *Computers and Electronics in Agriculture*, *180*, 105895. https://doi.org/10.1016/j.compag.2020.105895

Tanner, S. A., McCarthy, M. B., & O'Reilly, S. J. (2019). Digital labelling in the retail environment: a domain-specific innovativeness perspective. *International Journal of Retail & Distribution Management*, *47*(12), 1336-1352. https://doi.org/10.1108/IJRDM-08-2018-0175

Tarjan, L., Šenk, I., Tegeltija, S., Stankovski, S., & Ostojic, G. (2014). A readability analysis for QR code application in a traceability system. *Computers and Electronics in Agriculture*, *109*, 1-11. https://doi.org/10.1016/j.compag.2014.08.015

The Department of Islamic Development Malaysia. (2021). Draft Malaysia procedure for the recognition of foreign halal certification bodies 2021. Retrieved from *https://www.halal.gov.my/v4/pdf/DRAFT%20MALAYSIA%20PROCEDURE%20FOR%20THE%20RECOGNITION%20OF%20FOREIGN%20HALAL%20CERTIFICATION%20BODIES%202021.pdf*. Accessed January 26, 2024

The European Parliament and of the Council. (2021). Regulation (EU) No. 2021/2117 of the European Parliament and of the Council amending Regulations (EU) No. 1308/2013 Establishing a Common Organization of the Markets in Agricultural Products, (EU) No. 1151/2012 on Quality Schemes for Agricultural Products and Foodstuffs, (EU) No. 251/2014 on the Definition, Description, Presentation, Labelling and the Protection of Geographical Indications of Aromatized Wine Products and (EU) No. 228/2013 Laying Down Specific Measures for Agriculture in the Outermost Regions of the Union. Retrieved from *https://eur-lex.europa.eu/eli/reg/2021/2117/oj*. Accessed January 26, 2024

Tran, D., Broeckhoven, I., Hung, Y., Diem My, N. H., De Steur, H., & Verbeke, W. (2022). Willingness to pay for food labelling schemes in Vietnam: A choice experiment on water spinach. *Foods*, *11*(5), 722. https://doi.org/10.3390/foods11050722

van Ruth, S. M., Huisman, W., & Luning, P. A. (2017). Food fraud vulnerability and its key factors. *Trends in Food Science & Technology*, *67*, 70-75. https://doi.org/10.1016/j.tifs.2017.06.017

Varavallo, G., Caragnano, G., Bertone, F., Vernetti-Prot, L., & Terzo, O. (2022). Traceability platform based on green blockchain: an application case study in dairy supply chain. *Sustainability*, *14*, 3321. https://doi.org/10.3390/su14063321

Violino, S., Pallottino, F., Sperandio, G., Figorilli, S., Antonucci, F., Ioannoni, V., Fappiano, D., & Costa, C. (2019). Are the innovative electronic labels for extra virgin olive oil sustainable, traceable, and accepted by consumers?. *Foods*, *8*(11), 529. https://doi.org/10.3390/foods8110529

Violino, S., Pallottino, F., Sperandio, G., Figorilli, S., Ortenzi, L., Tocci, F., Vasta, S., Imperi, G., & Costa, C. (2020). A full technological traceability system for extra virgin olive oil. *Foods*, *9*(5), 624. https://doi.org/10.3390/foods9050624

Wang, A. M., Feng, A. X., Jiang, Z. H., Pan, X. M., & Yu, J. H. (2023). Femtosecond laser marking depth of field 3D code. *Infrared Physics & Technology*, *131*, 104680. https://doi.org/10.1016/j.infrared.2023.104680

Wang, L., Xu, L., Zheng, Z., Liu, S., Li, X., Cao, L., Li, J. B., & Sun, C. (2021). Smart contract-based agricultural food supply chain traceability. *IEEE Access*, *9*, 9296-9307. https://doi.org/10.1109/ACCESS.2021.3050112

Wang, Y. M., Tian, X. T., Zhang, H., Yang, Z. R., & Yin, X. B. (2018). Anticounterfeiting quick response code with emission color of invisible metal-organic frameworks as encoding information. *ACS Applied Materials & Interfaces*, *10*(26), 22445-22452. https://doi.org/10.1021/acsami.8b06901

Xiao, X., Fu, Z., Zhang, Y., Peng, Z., & Zhang, X. (2017). SMS-CQ: A quality and safety traceability system for aquatic products in cold-chain integrated WSN and QR code. *Journal of Food Process Engineering*, *40*(1), e12303. https://doi.org/10.1111/jfpe.12303

Xie, J., Wan, C., Tolón Becerra, A., & Li, M. (2022). Streamlining traceability data generation in apple production using integral management with machine-to-machine connections. *Agronomy*, *12*(4), 921. https://doi.org/10.3390/agronomy12040921

Xu, Y., Liu, Z., Liu, R., Luo, M., Wang, Q., Cao, L., & Ye, S. (2021). Inkjet-printed pH-sensitive QR code labels for real-time food freshness monitoring. *Journal of Materials Science*, *56*(33), 18453-18462. https://doi.org/10.1007/s10853-021-06477-x

Xue, G., Li, Y., Pan, H., Yang, L., Chen, Y. C., Ji, X., & Yu, J. (2022). ScreenID: Enhancing QRCode security by utilizing screen dimming feature. *IEEE/ACM Transactions on Networking*, *31*(2), 862-876. https://doi.org/10.1109/TNET.2022.3203044

Yang, F., Wang, K., Han, Y., & Qiao, Z. (2018). A cloud-based digital farm management system for vegetable production process management and quality traceability. *Sustainability*, *10*(11), 4007. https://doi.org/10.3390/su10114007

Yang, S. H., Phan, H. T. T., Hsieh, C. M., & Li, T. N. (2022). What intentions and interesting information can attract consumers to scan QR Code while buying eggs?. *Foods*, *11*(9), 1259. https://doi.org/10.3390/foods11091259

Yang, X. T., Qian, J. P., Li, J., Ji, Z. T., Fan, B. L., Xing, B., & Li, W. Y. (2016). A real-time agro-food authentication and supervision system on a novel code for improving traceability credibility. *Food Control, 66*, 17-26. https://doi.org/10.1016/j.foodcont.2016.01.032

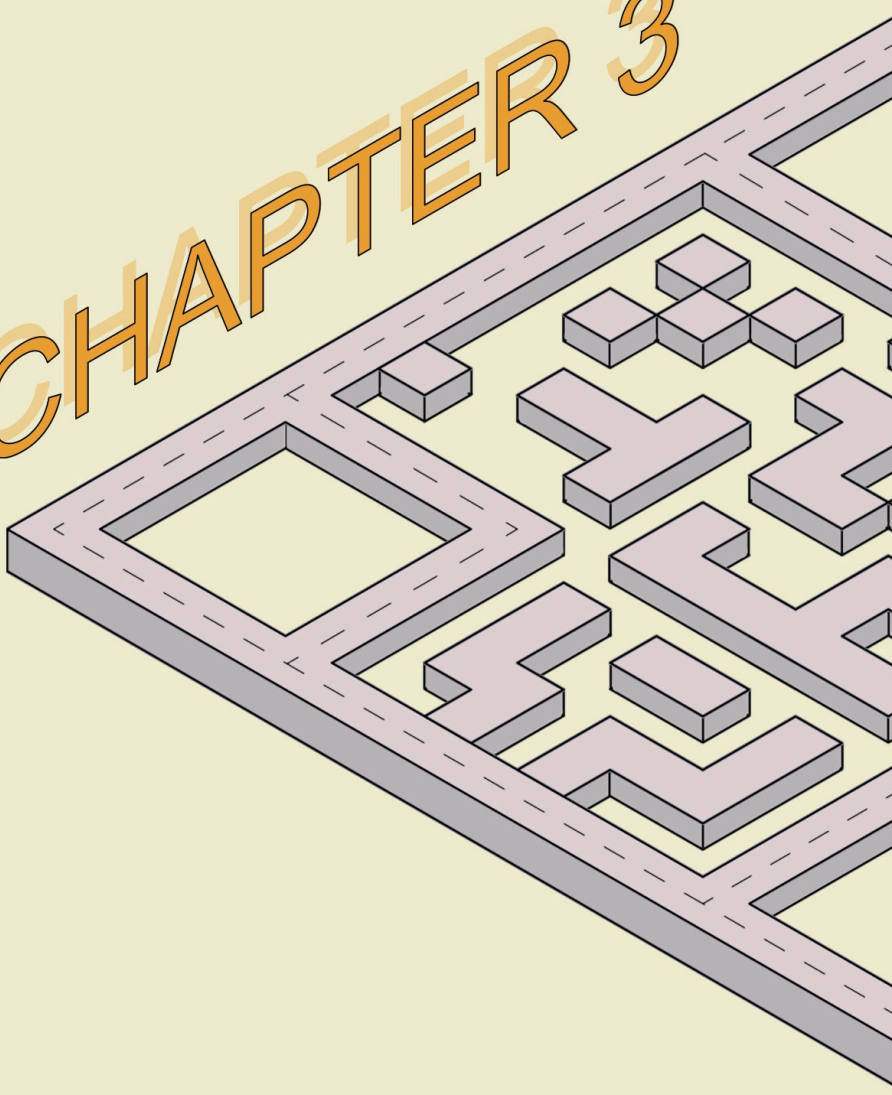
Zhang, Y., Wang, W., Yan, L., Glamuzina, B., & Zhang, X. (2019). Development and evaluation of an intelligent traceability system for waterless live fish transportation. *Food Control, 95*, 283-297. https://doi.org/10.1016/j.foodcont.2018.08.018

Zhang, Q., Yang, L., Han, Y., Wang, Z., Li, H., Sun, S., & Xu, Y. (2022). A pH-sensitive ESIPT molecule with aggregation-induced emission and tunable solid-state fluorescence multicolor for anti-counterfeiting and food freshness detection. *Chemical Engineering Journal*, *428*, 130986. https://doi.org/10.1016/j.cej.2021.130986

Zhang, Z., Yue, J., & Li, Z. (2014). A QR code traceability system for the aquatic products quality based on smartphone. *Sensor Letters*, *12*(3-4), 563-568. https://doi.org/10.1166/sl.2014.3159

Zheng, Q. J., Nayga, R. M., Yang, W., & Tokunaga, K. (2023). Do US consumers value genetically modified farmed salmon?. *Food Quality and Preference*, *107*, 104841. https://doi.org/10.1016/j.foodqual.2023.104841

CHAPTER 3



Chapter 3

Drivers, barriers, and strategies of identification technology implementation for wine authentication

This chapter has been published as:

Li, P., Moroni, L., Jadhav, M., Hettinga, K. A., & Erasmus, S. W. (2026). Drivers, barriers, and strategies of identification technology implementation for wine authentication. *Food Control*, *183*, 111954.

https://doi.org/10.1016/j.foodcont.2025.111954

Abstract

Wine is prone to food fraud vulnerability due to its intricate supply chain and high price. Identification technologies attached to wine products are considered to contribute to their authenticity. This view has obtained a wide consensus in the wine sector, but not all the products have implemented the identification technologies in business practice. There is a lack of empirical studies on drivers and barriers to identification technology implementation since the perceptions of the wine supply chain actors are unclear. Importantly, how to promote the drivers and mitigate the barriers is still unknown. In this study, the interviews were conducted with grape growers, winemakers, bottlers, and distributors from Italy and India to explore the drivers, barriers, and strategies influencing the implementation of identification technology in two diverse supply chains. The findings show that the drivers for implementing identification technologies are efficient traceability, consumer trust, regulatory compliance, brand enhancement, ease of use, counterfeiting risks, counterfeiting monitoring, and keeping competitive; the barriers include implementation costs, traditional mindset, antiquated production lines, lacking technicians, forged devices, no counterfeiting, low visibility, and unequal returns; the strategies are collaboration enhancement, cost optimization, regulatory support, multi-technology integration, simplified systems, raising awareness, and training programs. The results of this research can improve the identification technology utilities in the Italian and Indian wine sectors to enhance the supply chain integrity.

Keywords

Anti-counterfeiting; Food fraud; Motivation; QR code; Seals; Supply chain

3.1 Introduction

Wine is a popular aromatic beverage that has attracted increasing public attention (Liang et al., 2021). More consumers show strong preferences for premium wine and have an interest in buying and collecting expensive wine, which can reflect their higher social status (Agnoli et al., 2011). As an agricultural food product, the quality of wine is intrinsically linked to the characteristics of the grapes. Consequently, wine production is heavily dependent on and shaped by geographical factors (Acuti et al., 2017). Due to its unique climate and natural resources, the wine industry in Southern Europe and the Mediterranean region has thrived (Flores, 2018). Wine, one of the most traditional and characteristic Italian agricultural products, has a long history, possibly dating back to pre-Roman times (Pomarici et al., 2021). Italy has been the largest wine producer in the world in recent years (Ferrara et al., 2023), while the economic value, consumption, and export volume of Italian wines are also prominent globally (Rome Business School, 2024). In Italy, there are many wine brands regarded as premium, including *Nero d'Avola*, *Barolo*, *Brunello di Montalcino*, *Barbera*, *Montepulciano d'Abruzzo*, and *Primitivo* (Conti et al., 2024). In contrast, India represents an emerging wine market with significant development potential (Mehta et al., 2013). The country, particularly in regions such as Karnataka and Maharashtra, has optimal soil and a suitable climate for cultivating high-quality grapes and producing fine wines (Research and Markets, 2016; Sharma et al., 2020). The Indian wine market is expected to experience a volume growth rate of 3.3% domestically by 2026 (Starista, 2023), reflecting its increasing market scale.

Due to the different varieties, wine styles, and vintages, various differentiation strategies of production and marketing are implemented by the wine companies (Schäufele & Hamm, 2018). As a result, wine, as one of the most differentiated products in quality and price, is also one of the most counterfeited food products (Dal Bianco et al., 2018). The World Trade Organization (WTO) defines product counterfeiting as ‘unauthorized representation of a registered trademark carried on goods identical or similar to goods for which the trademark is registered, with a view to deceiving the purchaser into believing that he/she is buying the original goods’ (WTO, 2011). Different forms of counterfeiting, such as fraudulent origin claims, unauthorized wine-making and wine-bottling, and counterfeit premium brand labels, arise and pose a severe threat to the wine supply chain integrity (Aman et al., 2024; Danese et al., 2021). Due to high population density, the wine industry is dispersed among many small producers who may not have implemented anti-counterfeiting techniques (Castriota & Delmastro, 2015). Additionally, the wine distribution network is vast, and there are many vulnerable actors in the supply chain. As a result, wine is the most inspected product in Italy and also ranks number one in the proportion of irregularities

in the number of inspections (Rocchi et al., 2020). According to reports, counterfeiting of wine and alcoholic beverages results in an estimated annual loss of approximately $325 million (Gambero Rosso, 2025). A previous survey shows that most Italian wine consumers were aware of the counterfeit problem in the Italian wine markets, which affected their choice of wine purchasing (Villano et al., 2017). In India, counterfeit wines and beverages represent a major threat, resulting in an estimated loss of $3.18 billion in direct sales and a reduction of $2.61 billion in government tax revenues (Ambrosia, 2023). Counterfeiting wine not only damages the reputation and image of well-known wine brands but also increases financial loss and health risks for consumers, which forces the wine supply chain actors to implement anti-counterfeiting measures (Gupta & Sajnani, 2020).

Wine companies take some actions, such as implementing blockchain technology and authentication systems, to detect or prevent potential counterfeiting (Gayialis et al., 2022; Popović et al., 2021). Identification technologies can be regarded as identification tools for each bottle of wine, as well as authentication tools to enable customers and consumers to autonomously verify the products (Danese et al., 2021). Identification technologies, such as Quick Response (QR) codes and official seals, have been developed and implemented partly by wine supply chain actors to ensure the authenticity of their products (Agnusdei et al., 2022; Aman et al., 2024). Both the European Union (EU) and Indian Regulations (European Parliament and the Council, 2021; FSSAI, 2023) recommend that the full nutritional declaration and the list of ingredients for wine be made available electronically, including through QR codes, to provide consumers with specific, clear, transparent, and easily accessible digital information. Seals are used to protect the high-quality wines with a serial number as a sign of authenticity. The wine passing an official taste evaluation will be labelled with seals on the neck of the bottle to prevent any subsequent manipulation (Przyswa, 2014).

Although the principles of these technologies vary, they all guarantee the authenticity of wines to a certain extent and prevent counterfeiting. However, thus far, only a certain proportion of actors have implemented these technologies in wine supply chains. It is important to identify and understand the drivers and barriers to identification technology implementation in the wine supply chain to promote further usage of these technologies, yet there is a paucity of research on this topic. Therefore, this study aims to explore the drivers and barriers of identification technologies implementation from the perspective of wine supply chain actors in the Italian and Indian wine supply chain through semi-structured interviews, and to explore the effective strategies for overcoming the barriers to improve the use of these technologies. The selection of Italy and India enables a comparative analysis between a mature wine market with well-

established supply chains and a growing wine market facing different implementation challenges, thereby providing diverse insights into the implementation of identification technologies.

3.2 Theoretical background

3.2.1 Wine supply chain actors

The wine supply chain is a complex network that involves four main actors, including grape producers, winemakers, bottlers, and distributors, as depicted in **Fig 3.1**.



Fig. 3.1. The wine supply chain with different actors. Icons used from BioRender.com and flaticon.com.

Grape producers, generally farmers, work on grape production, mainly including plantation, harvesting, and delivery (Basso et al., 2020). The growing conditions (temperature, rainfall, solar radiation, and soil) and grape variety play a major role in the final quality and sensory attributes of wine (van Leeuwen, 2022). Thus, the origin of the grape can represent the identity of premium wine. Grape growers should record information on the origin and growth of the grapes. Winemakers include farm wineries and coop wineries. Winemaking is a complex process involving many operations, such as crushing, fermentation, aging, and blending (Unterkofler et al., 2020). Winemaking plays a crucial role in determining the final quality of wine because every step in the process directly impacts the wine's flavour, aroma, texture, and overall character. Except for a small number of wines sold in bulk, most wines are processed by the bottlers who are responsible for bottle filling, corking, capsuling, and labelling. Filling and packing represent the most intensive stage of the value chain, mainly due to the

significant investment in bottling lines. The bottlers have integrated other functions, such as storage of batches and providing wholesale services by connecting with the final distribution. The primary function of distributors is to purchase wines and transport them to various markets, including restaurants, liquor stores, and supermarkets. Wine distributors handle logistics, inventory, and marketing to ensure that wines from various regions and producers are readily accessible to buyers.

3.2.2 Identification technologies

3.2.2.1 QR codes

QR codes, a type of two-dimensional barcode, differ from conventional barcodes because they include two-dimensional scanning capabilities, allowing data to be read both horizontally and vertically. This unique feature enables QR codes to store much more information in a smaller area (Brabazon et al., 2014). Thus, QR codes are used primarily for commercial purposes to convey information to consumers that cannot be placed on the label. QR codes can be printed on bottle collars or paper labels of wine, and consumers can use their phones to access all the information linked to QR codes. A QR code, attached to wine bottles, can be linked to the traceability platform to enable consumers to trace the wine they intend to purchase, and can also have anti-counterfeiting functions with the mechanism of cross-checking with the verification code or detecting the spatial-temporal pattern of consumers' scanning (Li et al., 2024; Jiménez-Carvelo et al., 2023).

3.2.2.2 Seals

In Italy, the geographical indications certification system was created by the government and aims to differentiate vertically wine quality based on the origin (*Ministero dell'agricoltura, della sovranità alimentare e delle foreste*, 2024; Costanigro et al., 2019). The high-quality wine is remarked as DOC and DOCG, and the higher hierarchical levels of geographical indications might lead to a positive consumers' perception of the quality levels (Galletto et al., 2021). All the wines certified as DOC and DOCG will have an official seal, which is essential for maintaining and advancing the authenticity of wines (Agostino & Trivieri, 2014). Official seals carry an alphanumeric code, using which one can reconstruct the history of the wine, understand where it was produced, and confirm that it has undergone the entire DOC/DOCG certification process conducted by control bodies. In India, the anti-counterfeiting seals are attached to the wine bottle's capsule to guarantee original wine integrity. These seals typically display a unique numeric authentication code, which is visible to consumers. A unique authentication code printed on a seal allows verification of the wine's authenticity on the brand's official website. By entering this code on the

wine brand's official website—via an authentication system managed by the company—consumers can confirm the authenticity of wines.

3.3 Methods

3.3.1 Research approach

This study aims to identify and understand the drivers, barriers, and strategies of implementing identification technologies in the Italian and Indian wine supply chains through interaction and sharing of ideas and experiences of participants. A qualitative approach was implemented for this study, as it is well placed to summarize the different perspectives of participants on a particular topic and enable participants to express more perceptions on the subject by some complementary questions (Bryman, 2016; Lloyd & Gifford, 2024). The ethics approval for this study has been granted by the Research Ethics Committee of Wageningen University & Research (No. 2023-099).

3.3.2 Semi-structured interviews

The study involved conducting semi-structured, in-depth interviews with participants with working experience in the wine supply chain to explore their perspectives on drivers, barriers, and strategies of implementing identification technologies in practice. To ensure consistency in the main topics to be discussed by participants, an interview guide (provided as **Supplementary Table S3.1**) including open-ended questions was designed to encourage and stimulate participants to share relevant information. All the questions in the interview guide and supplementary non-leading questions aim to understand the cognitive responses and deep motivational reasons behind the decision of participants' companies to implement or not to implement identification technologies. Specifically, the questions involve background, implementation drivers, barriers faced, and potential strategies.

Before the interviews, one participant was recruited to conduct the pilot test to ensure the reliability of the interview guide and its suitability in gathering the information needed (Cardoso et al., 2023). Through a quality evaluation of the interview and the feedback from the participant after the interview, the interview questions were optimized and finalized after the research group discussion. This participant was not invited to participate in the formal interview phase with the test subjects.

3.3.3 Participant selection and recruitment

For a better understanding of the topic of this study, the participants working in companies with and without the identification technology implemented were invited to be interviewed. There were three approaches to looking for suitable participants: 1) using the social network of the authors in the field of wine practitioners; 2) targeting the

population identified on Google and LinkedIn; 3) using recommendations by previous participants (snowball sampling) (de Graeff et al., 2021). More than fifty suitable candidates were approached by email, and twenty-one Italian participants and eleven Indian participants accepted the invitation for the one-on-one interviews, which were performed in a period between November 2023 and January 2025. A follow-up email was sent to the participants to explain the main objectives of the study. Thirteen out of the total of twenty-one interviews were carried out in a face-to-face setting, while the others were conducted online via Microsoft Teams. **Table 3.1** shows an overview of the participants who were interviewed. Their extensive experience (more than 2 years) and management positions enable them to be participants in this field of research. Eligible participants were approached by phone and email with an information leaflet about the background and purpose of the study. All of the participants signed the introductory and consent form before the interviews. All the interviews lasted around 50 minutes and were conducted in local languages to remove the linguistic barriers. It is stated clearly that the opinions and statements of interviewees are personal and do not represent those of their companies.

The number of interviewees ultimately relied on reaching theoretical saturation (Cardoso et al., 2023), where little or no additional information or supplementary insights emerged, as more interviewees were incorporated into the study. To track the theoretical saturation, the changes in the list of collected interviewees' viewpoints were monitored to observe whether new insights occurred. The theoretical saturation was attained by the interviews, causing further recruitment of interviewees to be unnecessary.

3.3.4 Data collection and analysis

The recordings of interviews were transcribed verbatim in local languages with the participants' consent to guarantee accuracy and preserve the original responses of the conversations. In other words, the interview content, discourse structure, and interaction details between the interviewer and interviewees were kept entirely. The transcriptions were sent back to the participants to ask for their review of the accuracy of the transcriptions. The additional commentary on transcriptions was allowed to be provided by participants if necessary (Junnier, 2024). After the transcription was completed, they were translated into English by the authors. An in-depth analysis was then conducted to determine the core concepts that emerged from the interviews. This included a repetitive process of reading and analysing the responses and categorizing comparable parts.

Table 3.1. The characteristics of the participants.

Participant code	Organization type	Years of experience	Current position	Identification technologies implemented
IT1	Grape producers	40	Owner of an individual winery	Official seal
IT2	Grape producers	50	Owner of an individual winery	Official seal and QR code
IT3	Grape producers	9	Commercial director	Official seal and QR code
IT4	Grape producers	30	Owner of an individual winery	QR code
IT5	Grape producers	20	Owner of an individual winery	Official seal
IT6	Grape producers	14	Owner of an individual winery	QR code
IT7	Winemakers	7	Administrative	Official seal
IT8	Winemakers	12	Director	/
IT9	Winemakers	8	Oenologist and technician	Official seal
IT10	Winemakers	2	Director	Official seal
IT11	Winemakers	16	Director	Official seal and QR code
IT12	Bottlers	6	Director in the packaging department	QR code
IT13	Bottlers	15	Technical director	/
IT14	Bottlers	40	Administrative director	/
IT15	Bottlers	40	Owner of a packing company	/
IT16	Bottlers	10	Commercial director	QR code
IT17	Distributors	22	Commercial director	/
IT18	Distributors	22	Owner of a wine distribution company	QR code
IT19	Distributors	20	Commercial director	QR code
IT20	Distributors	32	Owner of a wine retailer agency	/
IT21	Distributors	35	Owner of a wine distribution company	Official seal
IN1	Grape producers	25	Owner of an individual winery	/
IN2	Grape producers	18	Owner of an individual winery	/
IN3	Grape producers	20	Owner of an individual winery	/
IN4	Winemakers & Bottlers	15	Oenologist and technician	QR code and seals
IN5	Winemakers & Bottlers	12	Production manager	QR code and seals
IN6	Winemakers & Bottlers	10	Oenologist and technician	QR code and seals

Table 3.1. Continued.

Participant code	Organization type	Years of experience	Current position	Identification technologies implemented
IN7	Winemakers & Bottlers	14	Oenologist and technician	QR code and seals
IN8	Distributors	12	Director	QR code
IN9	Distributors	8	Logistics director	QR code and seals
IN10	Distributors	10	Logistics director	QR code and seals
IN11	Distributors	11	Logistics director	QR code and seals

'/' indicates no identification technologies implemented. IT: participants from Italy, IN: participants from India.

The process started with reading the transcript thoroughly and several times to get immersed in the interview scenarios (Polit & Beck, 2004). The significant statements related to the theme were then extracted, summarized, and coded; as for the ambiguous statements, the unified standard of coding was set through discussion in the research team to capture both manifest and latent contents. This procedure was repeated for each interview. To enhance the validity of the findings, two researchers independently coded the interview data. Any discrepancies in coding were discussed and resolved through consensus. All the interviews were cross-checked to ensure the consistency and accuracy of coding (Frühauf et al., 2021). The findings and viewpoints were integrated and then sent back to the participants for validation. Similar contents and statements from different interviews were clustered into a group to define a particular theme (that was interpretive and generalizable) that could cover the overall meanings (Braun & Clarke, 2006). The analysis report was then produced by linking research questions, themes, and corresponding compelling extract examples (Vaismoradi et al, 2013).

The data processing and analyses were done using Excel (Version 2502, Microsoft Corporation) and Atlas.ti software (Version 24, Scientific Software Development GmbH).

3.4 Results

3.4.1 Drivers

Eight drivers were coded from the participants' statements as shown in **Fig. 3.2**. The drivers included efficient traceability, consumer trust, regulatory compliance, brand enhancement, ease of use, counterfeiting risks, counterfeiting monitoring, and keeping competitive.

The participants reported that the implementation of identification technologies contributes to the efficient traceability (ET) of food. *The identification technologies, including official seals and QR codes, could be seen essentially as a lock that opens up traceability information* (IT13) because they are unique and linked to the specific products by identity to ensure the accuracy of traceability (Matzembacher et al., 2018). IT17 explained that *the identification technologies and traceability platforms are welcomed by wine companies as it is easier to know where the product ends up, who gave it, etc*. For consumers, *traceability is often associated with higher product quality, as identification technologies convey the story behind the wine—its origin, grape variety, and production process* (IN6).

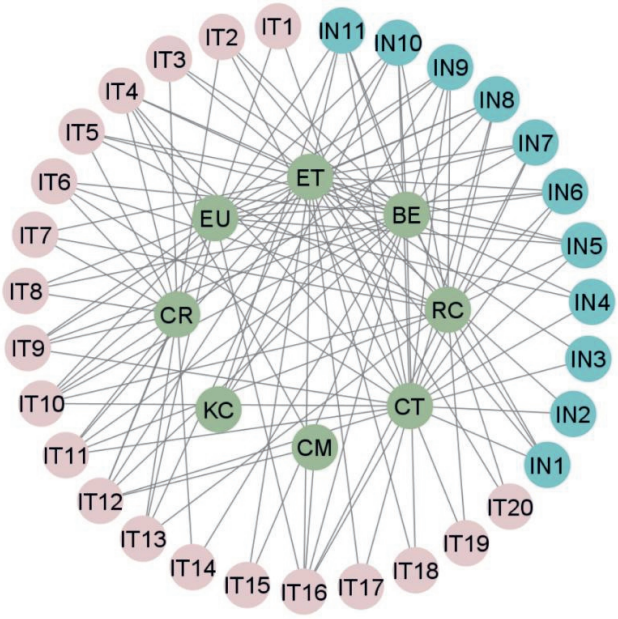


Fig. 3.2. The participants from Italy (IT1-IT21) and India (IN1-IN11) and their proposed drivers. ET: efficient traceability; CT: consumer trust; RC: regulatory compliance; BE: brand enhancement; EU: ease of use; CR: counterfeiting risks; CM: counterfeiting monitoring; KC: keeping competitive. The nodes indicate the participants and their proposed drivers, and the lines represent connections between participants and the drivers they identified or supported. Participants who did not propose any drivers do not appear in this figure.

More than half (22/32) of the participants mentioned the importance of identification technologies to consumer trust (CT). As consumer-friendly devices, QR codes and official seals are available to consumers exploring more product properties and verifying authenticity. Specifically, in Italy, only DOC and DOCG wines are allowed officially to attach the official seals, so consumers consider the official seals as a sign of authentic high-quality wines. *Official seals are a quality guarantee, as well as a form of authentication, and the customers recognize it as an added value* (IT1). As for QR codes, *they can be linked directly to the website or provide technical details about the wine, allowing the end-users to explore it calmly or have a simple visual inspection* (IT9). The identification technologies ensure the superior experience, excellent quality, and unique characteristics of wines, leading to consumers' high attachment and evaluation of the brands, which contributes to *long-term profitability and industry growth* (IN5).

The participants stated that another driver is *regulatory compliance* (RC) (IT11). Given that the participants are working in legitimate wine companies, their companies are obliged to adhere to stringent regulations and controls enforced by the government and authoritative third-party entities. Regulations can provide clear guidelines to standardize the utilization of identification technologies. *Currently, there is an Italian regulation to list the ingredients and the origin of the wine on the bottle, including putting the QR code that provides consumers with easy access to detailed product information* (IT20). For this reason, some companies are actively exploring or adjusting QR code implementation to be compliant with the regulation (IT5 and IT6). In addition, the official seal was introduced by the Italian government and distributed to the wine producers by third-party entities approved by the government to protect DOC and DOCG wines. Thus, *every bottle of DOC or DOCG genuine products in the market must have an official seal* (IT10). In India, *administrative regulations and export standards* have played a significant role in promoting the implementation of identification technologies (IN10).

Brand enhancement (BE) is considered one of the key drivers for implementing identification technologies. *These devices provide a means of authenticating wines, which consumers perceive as an added product value* (IT1). Consumers think the authentication information linked with these devices is reliable, as *they believe the authentication process is technologically advanced and reliable* (IT7). According to IT2, *identification technologies serve as a guarantee of quality and are well-received by consumers, who associate these devices with the product brand and wine quality*. This creates *a unique identity for the wine brand, as consumers familiar with the brand recognize and value the identification technologies* (IT2). IT4 further supports this view, highlighting that *such devices strengthen the connection between consumers and the brand by enhancing their recognition of both the brand and its quality*. The direct benefits of brand enhancement is *the positive influence on consumers' repurchase intentions, which contributes to sustained growth in product sales* (IN7).

Ease of use (EU) is a key reason for the implementation of identification technology, as it enhances consumer engagement in using devices. *Consumers make an effort to understand the wine they drink and authenticate it, and identification technologies are a simplified solution for consumers to access the digital authenticity information* (IN8). *Identification technologies have developed mature, and consumers can easily use them to access the useful information, which meets their requirements on information acquisition* (IT3). The devices are attached to the wine bottle, and customers, using their phones, can access all the linked information. IT1 emphasized that the popularity of mobile phones promotes consumers' familiarity with identification technologies.

With a large number of counterfeiting incidents in the wine market, many Italian participants showed that their wine products may face high counterfeiting risks (CR), although most of them had not yet received reports about any counterfeit wines illegally imitating their product packages or even re-bottling. These respondents were enthusiastic about solving this problem to protect their interests, so they have a positive attitude toward identifying devices (*Counterfeit is a tragedy, as well as a phenomenon that needs to be monitored, fought, and eradicated, and the identification technologies could assist in this effort*, IT11; *The issue of counterfeiting is very current, and we understand these new technologies can be useful*, IT3). IT2 proposed that the *Internet and online sales of wine further increase the risk of counterfeiting, as it is hard to track the authentic products*. Some participants think that the high-quality wine from well-known brands is prone to counterfeiting. IT4 emphasized that *for medium to large wine brands, the risk of counterfeiting is much higher*. This is because imitating high-priced wine often means huge profits which are tempting for offenders. A simple example proposed by IT12 is that *after a 1972 Amarone costing €150 is consumed and legally re-bottled by low-quality wine, it can still be resold at the original price*. However, IT13 had a different idea that instances of counterfeiting lower-value wine often occur, as *the wines with lower added value still achieve significant sales numbers, prompting counterfeiters to target them as well.*

Several participants identified counterfeiting monitoring (CM) as a key driver for the implementation of identification technologies. When consumers use the unique identification technologies attached to a wine bottle to access an authentication platform or website, the access data is recorded and displayed on a digital dashboard. *This data includes details such as which bottle's information was accessed, the time and location of access, and the frequency of access, providing insights into potential counterfeiting risks* (IT12). Alerts can be generated based on unusual access patterns. For instance, as highlighted by IT16, *if the same authentication information is accessed 100 times across 10 different countries within a two-hour period, it signals a high likelihood of counterfeiting*. Furthermore, IT4 pointed out that *these identification technologies enable wineries to track the destination of their products and gain valuable insights into customer distribution.*

Keeping competitive (KC) is also a factor driving supply chain actors to implement identification technologies. As IN9 noted, *staying competitive requires continuous adaptation to technological advancements in a rapidly evolving market. A company risks falling behind in a competitive market once it does not stay updated on the technology* (IN11).

3.4.2 Barriers

Participants proposed eight barriers as shown in **Fig. 3.3**. The barriers were coded as implementation costs, traditional mindset, antiquated production lines, lacking technicians, forged devices, no counterfeiting, low visibility, and unequal returns.

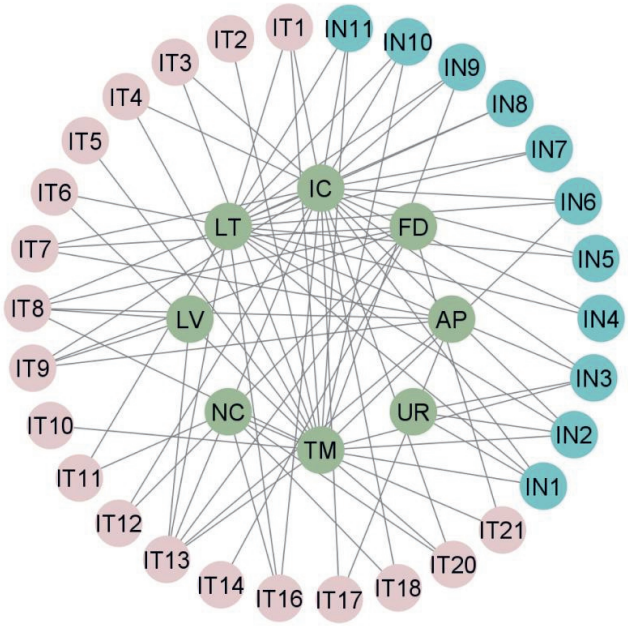


Fig. 3.3. The participants from Italy (IT1-IT21) and India (IN1-IN11) and their proposed barriers. IC: implementation costs; TM: traditional mindset; AP: antiquated production lines; LT: lacking technicians; FD: forged devices; NC: no counterfeiting; LV: low visibility; UR: unequal returns. The nodes indicate the participants and their proposed barriers, and the lines represent connections between participants and the barriers they identified or supported. Participants who did not propose any barriers do not appear in this figure.

Most participants consider the high implementation cost (IC) of identification technologies as one of the main barriers. *In addition to the cost of the equipment itself, the cost of operating and maintaining the production machines and validation platforms is not affordable for all companies* (IT17). The identification technology is relatively costly to implement, so *the actors must seriously evaluate the cost-benefit ratio* (IT3). As profit-oriented entities, the actors may not have an incentive to implement the identification technologies once the cost is considered to outweigh the benefits. *For large companies with high volumes or expensive products, identification technologies are cost-effective because it is feasible and reasonable to spread the cost over each expensive product to some extent* (IT18). *For companies on a small scale, a limited*

financial budget often leads to a cautious approach toward implementing identification technologies (IN6).

Some participants indicated that the traditional mindset (TM) on resistance to new technologies hinders the use of identification technologies. This conservative mindset, also known as *'old winemaking culture'*, means that *companies in the wine supply chain spend less money on technologies or equipment that do not lead to direct profits* (IT20). A lack of innovation awareness may not be rare, because *the wine industry, rooted in agriculture, is full of a traditional and conservative nature, including a lack of digital culture* (IT13). *Since traditional methods of information transmission continue to work well, some supply chain actors are less open to the implementation of identification technologies* (IN1). This has led companies to take a wait-and-see approach to the identification technology implementation, and they need time to assimilate these technologies and observe their effects and evolution. This condition is also gradually changing in a good way, as *a group of young entrepreneurs is replacing the older generation and representing the new frontier of the wine industry* (IT8). Younger generations consider identification technologies with a more open mind.

Antiquated production lines (AP) are thought to hinder the equipping of identification technologies. *Combining rapidly evolving technologies with production structures is always a challenge for small companies, especially those with less advanced bottling lines* (IT9). IT13 emphasized that *the additional steps in the bottling process, including printing and labelling QR codes, lead to a slowdown in production speed and pose operational challenges to companies*. The same concerns about the official seal equipping also trouble IT7. *The company's production line must decelerate to ensure precise application of official seals, as the addition of a seal increases the neck circumference by an extra centimetre and a half. Delays in seal delivery may result in machine jams.*

Several participants highlighted the impact of lacking technicians (LT) on the implementation of identification technologies. *Technicians are essential for constructing the authentication platforms linked to these devices* (IT16). *The complexity of the technology and a lack of necessary knowledge prevent supply chain actors from fully understanding how identification technologies function and how they might benefit from their use* (IN3). Additionally, the ongoing maintenance and regular updates of authentication platforms require significant technical expertise, which is challenging for non-technical staff to manage effectively. *This issue is particularly pronounced for grape growers, who often have limited technical capabilities and must provide complex information about grapes and vineyards* (IT11). As a result,

companies frequently rely on technicians or agricultural assistance centers (IT13), which increases labour costs and complicates the implementation process.

Offenders often attempt to improve the perceived quality of inferior wines by illegally copying and attaching identification technologies. The forged device (FD) is a serious problem that reduces a company's trust in the functionality and anti-counterfeiting performance of identification technologies, which further reduces their interest in implementation. *Both QR codes and official seals are a form of paper-based authentication and therefore less stringent* (IT9). Incidents of forged QR codes (Köhler & Pizzol, 2020) and official seals (Furlan & Vettori, 2021) have also been reported, meaning that, from a technical point of view, this is not difficult for the offenders. *Except for some participants, it is difficult for others to identify the authenticity of the identification technologies* (IT8). As for official seals, *once they are convincingly made by offenders, they had to be sent to the State Mint to verify their authenticity* (IT13). In addition, *it is possible that the authentication website linked to identification technologies is a copied version instead of the authentic one* (IT12). Given that there is no limit to counterfeiting, counterfeiting identification technologies place higher demands on the anti-counterfeiting making and mechanisms of the authentic devices.

Some participants think no counterfeiting (NC) exists in their products, so there is no need to use any identification technology for anti-counterfeiting. These participants worked in the Italian wine industry for a long time and trust the current business environment and their trading partners in the supply chain. *The highly regulated environment with effective control measures, coupled with good raw materials, historic companies, and well-operating businesses, can curb the emergence of counterfeiting* (IT20). Before they receive reports of counterfeiting, they do not realize the threat of counterfeiting, and the sense of urgency to implement the identification technologies is not strong. *Without this prerequisite, introducing any solution to anti-counterfeiting, no matter how effective, will not address a significant problem enough to prompt real action* (IT16).

A small number of participants identified the problem of low visibility (LV) of identification technologies. The possible reason is that *the identification technologies have a low visual impact and fail to engage consumers* (IT13). *Due to their small size, identification technologies may be overlooked by consumers when placed in the same field of view as other important information, such as alcohol content and vintage* (IT8). Consumer neglect of identification technologies also makes companies less interested in implementing them.

Indian participants highlighted the issue of unequal returns (UR) in the implementation of identification technologies. *Wineries seem to capture the majority of the benefits,*

including improved reputation, profit margins, and enhanced market access (IN1). This perceived imbalance may discourage other supply chain actors, especially grape growers, from actively engaging with such technologies. *Only if these technologies can bring recognition or better pricing for the grapes, grape growers are active in implementing them* (IN3).

3.4.3 Strategies

Seven different types of strategies were identified and proposed as collaboration enhancement, cost optimization, regulatory support, multi-technology integration, simplified systems, raising awareness, and training programs, as shown in **Fig. 3.4**.

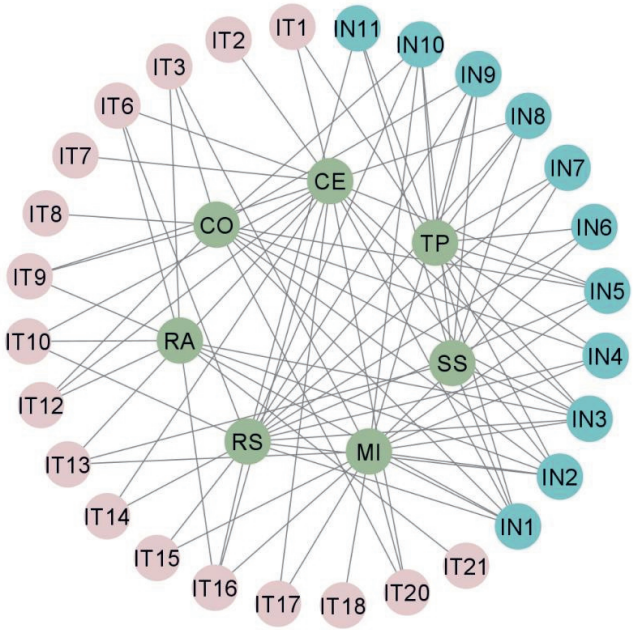


Fig. 3.4. The participants from Italy (IT1-IT21) and India (IN1-IN11) and their proposed strategies. CE: collaboration enhancement; CO: cost optimization; RS: regulatory support; MI: multi-technology integration; SS: simplified systems; RA: raising awareness; TP: training programs. The nodes indicate the participants and their proposed strategies, and the lines represent connections between participants and the strategies they identified or supported. Participants who did not propose any strategies do not appear in this figure.

Collaboration enhancement (CE) among entities in the Italian wine supply chains is considered a possible approach for improving the implementation rate of identification technologies. The entities understand the importance of identification technologies in ensuring product authenticity and collaborate with others to lead to wider and more

efficient use of these technologies. *Only if every entity implements the devices, the wine supply chain is an authenticated process that is tracked from start to end* (IT10). IT7 emphasized that all entities using the devices need to work together to build a very well-organized collaboration mechanism to clarify authority and responsibility. Specifically, *it should be clear who can use the devices, who has access to the database linked to the devices, and who should guarantee the transparency of the data*. In addition, IT13 highlights that collaboration with law enforcement agencies, in addition to supply chain actors, was essential to combating counterfeiting, including forged identification technologies.

Given the high cost associated with the implementation of identification technologies, the wine industry should prioritize cost optimization (CO) strategies to make these technologies more accessible to small companies. Costs are primarily related to the development, implementation, and maintenance of the authentication system, but *the costs become more manageable once the project is underway and more producers join* (IT12). IN3 pointed out that wineries, as the primary beneficiaries of identification technology implementation, are in a strategic position to take the lead in promoting the widespread implementation of the technologies. Participants also emphasized the role of consortia, joined by many wine companies, in providing systems that can be available for multi-party. *The consortia can connect with technology companies and provide feasible solutions to all member companies* (IT8).

Regulatory support (RS) is also of paramount importance. Government and regulatory agencies can encourage identification technology implementation and strengthen regulation through policy enactment, incentive implementation, and supervision. Identification technologies are just tools against counterfeiting, and supervision and policing are still the practical actions that are necessary to prevent counterfeiting. The IT10 claimed that *the company had signed memoranda of understanding with the Finance Police, Office for Fraud Repression, and Customs and Monopoly Agency, which have a responsibility to achieve product identification and official seal control*. It is recommended that the financial incentives and supports, such as low-interest loans, should be tilted toward small companies (IT6) and grape growers (IN2), as they often face more financial and managerial difficulties in implementing identification technologies.

From a technical perspective, authentication technology involving identification technologies can operate effectively and efficiently through multi-technology integration (MI). Many Italian and Indian participants highlighted the potential of incorporating blockchain technology with authentication systems. *Blockchain enables the inclusion of a "campaign notebook" facilitating secure and immutable record-*

keeping (IT15). *It also allows for the certification of every stage in the supply chain process, thereby enhancing transparency within the wine supply chain* (IT17). Additionally, IT16 emphasized the use of AI-based security image technology to prevent unauthorized copying of paper-based identification technologies. *This technology incorporates a special security graphic into the identification technologies, which undergoes a significant loss of approximately 50% of its information when the original image is copied, ensuring its authenticity.*

Simplified systems (SS) linked with identification technologies are more readily accepted by supply chain actors (IN8). For broader implementation to occur, these systems must be designed with practical implementation in mind and be scalable to different contexts within the supply chain. *Scalable systems that function effectively without the need for frequent modifications or technical adjustments are especially valued* (IN7), as they enhance technology usability and lower technological barriers.

Raising awareness (RA) of anti-counterfeiting among supply chain actors is crucial to promoting the implementation of identification technologies. All actors must realize that they are participants in this campaign against counterfeiting in one way or another, directly or indirectly, and *the identification technologies contribute to this process as the technological basis for achieving this goal* (IT10). According to IT6, *actors in the wine supply chain should prioritize quality and strategic positioning over quantity to be committed to the battle against counterfeiting in various ways*. However, as IT16 highlights, *if combating counterfeiting is not established as a priority by these actors, the effectiveness of identification technologies may be rendered irrelevant, as they are unlikely to implement them*. IT10 further underscores the importance of developing the capacity to address potential counterfeiting incidents, arguing that *the detection of counterfeiting is only meaningful when followed by appropriate actions*. *When authentication systems identify potential counterfeiting, supply chain actors must respond by implementing measures such as suspending or, in severe cases, removing non-compliant individuals or business partners from the supply chain, which are essential for optimizing the structure and integrity of the supply chain* (IT10). Furthermore, improving consumers' awareness is also considered one of the effective strategies. This is because consumer demand for wine authentication can contribute to the supply of identification technologies by food companies. Consumers must be participants in the wine authentication process (IT10). However, one of the reasons for the current low usage of identification technologies by consumers is their lack of understanding and awareness of the devices (IT9). Identification technologies can only work effectively with consumers if they notice and recognize the devices and have the relevant knowledge (IT21). Educating consumers is essential, and *they must be*

vigilant to the authenticity of the wines and should be able to initially authenticate the product through the use of the devices (IT12).

Training programs (TP) with pilot projects are a key strategy to gradually promote the implementation of identification technologies. Tailored training programs for wine supply chain actors cannot only *address the knowledge gap* (IN11), but also *enable them to understand how the technology makes their jobs easier* (IN4). *Especially by sharing successful experiences from practical cases in the local supply chain, it can enhance confidence and stimulate implementation willingness* (IN5).

3.5 Discussion

The drivers, barriers, and strategies to identification technology implementation were explored through semi-structured interviews from the perspectives of wine supply chain actors. The following sections analyze and discuss the primary perspectives expressed by the interviewed participants.

3.5.1 Drivers of implementation

Traceability is a widely recognized application of identification technologies (Li et al., 2024). In this study, the driver 'efficient traceability' was proposed by most Italian participants and all Indian participants, meaning that the wine supply chain actors attach importance to the wine traceability. Given that wine is deeply tied to its geographical origins, and specific regions are renowned for their unique grape varieties and winemaking traditions (Unwin, 2005), traceability serves as a means of establishing provenance. By providing detailed information on grape origin and product movement throughout the supply chain, traceability enhances its perceived value (Palade & Popa, 2014), which was acknowledged by most interviewees.

The majority of participants identified consumer trust and regulatory compliance as key drivers. Given that consumer trust directly influences sales and revenue of wines (Shapiro & I. Gómez, 2014) and legal compliance forms the basis of a company's legitimate operation (Meloni et al., 2019), these factors are highly valued by various actors across the supply chain. Prior research (Adamashvili et al., 2024) has also demonstrated that wine consumers and customers tend to trust identification technologies, which in turn enhances their trust in the wine products equipped with such technologies. Furthermore, the regulations in Italy (European Parliament and the Council, 2021) and India (FSSAI, 2023) have been issued that promote the use of identification technologies on wine bottles, reinforcing the institutional push toward transparency in the wine sector.

Many participants highlighted brand enhancement as a key driver for implementing identification technologies. In the wine sector, implementing identification technologies is identified as a feasible approach for product differentiation (Higgins et al., 2014). By integrating identification technologies, wine companies can project an image of transparency, quality assurance, and modernity—attributes that appeal to both domestic and international consumers and customers (Brabazon et al., 2014). Thus, the wine companies, especially those seeking to position their wines as premium, value the potential of identification technologies for brand enhancement. Additionally, in increasingly competitive markets, these attributes are not only desirable but essential for maintaining competitive advantage. Thus, keeping competitive is also identified as a key driver.

The majority of participants identified ease of use as a key factor influencing the implementation of identification technologies. This finding is supported by prior research, which highlights the importance of usability in consumer engagement. For instance, Violino et al. (2019) and Habashneh et al. (2024) demonstrated that consumers place high value on the ability to easily access product information via QR codes. The absence of technical barriers facilitates user interaction, allowing consumers to obtain the information effortlessly. Consequently, the simplicity of identification technologies contributes to their acceptance and implementation across the supply chain.

Only grape producers, winemakers, and bottlers from Italy mentioned the driver counterfeiting risks, and the possible reason for this is that distributors are usually not brand owners and do not receive reports of counterfeiting from consumers or customers. This driver was proposed by only a few Indian participants, possibly because of the differences in market maturity and brand value compared to Italy. Italian internationally recognized wine regions and brands enjoy strong global visibility and premium positioning, making them more susceptible to counterfeiting risks (Bernetti et al., 2006).

Several Italian participants noted the driver counterfeiting monitoring. The ability of these technologies to capture and display access spatial-temporal data—such as the time, location, and frequency of access—offers a proactive tool to detect abnormal patterns and assess potential counterfeiting threats. At present, a few studies (Jiménez-Carvelo et al., 2022; Popović et al., 2021; Rogerson & Parry, 2020) have demonstrated the practical feasibility of this approach.

3.5.2 Barriers to implementation

As for barriers, the participants' concerns center on implementation costs and traditional mindset. The application of identification technologies causes an increase in the overall cost, profit erosion, and budgetary constraints, so implementation cost was the most central concern shared by all actors (Li et al., 2024). It is worthwhile to note that all the Italian and Indian grape growers mentioned a traditional mindset, probably because grape production is a traditional part of farming, and grape growers are influenced by long traditions and have become less open to new technologies (Adjei et al., 2017; Khan et al., 2020). A prior study has also confirmed that multiple factors, including social and cultural influences, play a significant role in shaping supply chain actors' resistance to the implementation of digital technologies (Thompson & Rust, 2023).

In practice, the implementation of identification technologies continues to face two operational challenges. The first challenge is that antiquated production lines constrain the integration and implementation of such technologies. The application of identification technologies typically requires the incorporation of additional steps into the production process, including printing QR codes or placing official seals accurately (Przyswa, 2014). These tasks demand a high level of automation, precision, and consistency, which places considerable strain on outdated production systems that lack such capabilities. Additionally, within the Italian wine supply chain, personnel with the necessary technical skills are lacking (Mitchell et al., 2014). A similar challenge may be even more pronounced in countries like India, where the shortage of technical talent is compounded by the risk of brain drain—a common issue in developing economies (Khadria, 2002). The need to hire technical participants further increases the overall cost of implementing identification technologies, thereby exacerbating concerns among wine producers about the financial burden of implementation.

The counterfeiting of identification technologies poses a substantial threat to the implementation of such technologies by wine companies, ultimately undermining their perceived value. Fundamentally, forged devices erode corporate trust in the anti-counterfeiting capabilities of identification technologies, further lowering their willingness to invest in and implement these devices. From a technical perspective, identification technologies are relatively vulnerable to replication (Lo et al., 2019; Njuguna & Ndia, 2025). Prior studies (Furlan & Vettori, 2021; Köhler & Pizzol, 2020) have documented incidents of forged QR codes and seals, indicating that these technologies present a relatively low barrier to entry for counterfeiters.

Many food companies remain hesitant to implement identification technologies, and two key reasons for this reluctance are no counterfeiting threats and low visibility.

Some participants believe their products are not at risk of being counterfeited and, therefore, see no need for anti-counterfeiting measures. As a result, identification technologies are perceived as non-essential, prompting these firms to invest less in identification technologies. Moreover, low consumer engagement is another critical factor contributing to companies' skepticism about the necessity of such technologies. Even if a company is willing to invest in identification technologies, the effectiveness of these systems largely depends on active participation from consumers (Trivedi et al., 2020). Once consumers do not engage with the devices, the potential drivers, including enhanced brand value, increased consumer trust, and competitive differentiation, are diminished. This, in turn, further undermines the company's motivation to implement these devices.

The issue of unequal profit allocation, as highlighted by grape growers in India, influences their willingness to implement the technology. The additional value generated through the implementation of identification technologies is frequently captured by winemakers and brand owners, rather than being equitably redistributed to the grape growers. As a result, grape growers lack sufficient incentive to invest time and resources in collecting, uploading, and maintaining the data required to support these systems.

3.5.3 Implementation strategies

Collaboration enhancement and cost optimization are two frequently mentioned strategies among participants. Enhanced collaboration is a prerequisite for the effective implementation of identification technologies. From a systems perspective, the successful operation of these technologies relies on coordinated actions across all the supply chain actors (Bejlegaard et al., 2021). Moreover, once implementation begins, the entry of more enterprises into the system enables cost-sharing mechanisms, thereby making the overall expense more manageable.

Regulatory support plays a critical role in facilitating the implementation of identification technologies. Governmental bodies and regulatory agencies can drive the diffusion of these technologies by enacting supportive policies, providing financial or operational incentives, and reinforcing supervision mechanisms (Cooke, 2017).

From a technical standpoint, multi-technology integrity and simplified systems enhance the feasibility and appeal of identification technology implementation. The integration of multi-technology allows systems to function with greater efficiency, accuracy, and security (Chengxin et al., 2007). Notably, participants from Italy and India have emphasized the value of incorporating blockchain technology into information platforms linked to identification technologies. Blockchain enables secure, immutable

record-keeping, improving the supply chain transparency (Hellani et al., 2021). Furthermore, simplified and scalable technical systems are more easily implemented by supply chain actors (Kleppmann, 2017). When identification technologies are paired with user-friendly and adaptable systems, they reduce the technical complexity associated with implementation, thus promoting broader implementation across the supply chain.

Raising awareness of anti-counterfeiting among supply chain participants is a critical factor in promoting the implementation of identification technologies. Many supply chain participants may lack a full understanding of the risks associated with counterfeit products or the operational advantages offered by authentication technologies. Taking targeted measures and providing communication initiatives can bridge this knowledge gap, enhancing actors' awareness of the necessity of implementing identification technologies.

Training programs play a pivotal role in facilitating the implementation of identification technologies. Training, particularly those combined with pilot projects, serves as an effective strategy to bridge the knowledge gap among supply chain actors (Foroughi,2021). Showcasing successful local case studies during training sessions can boost participants' confidence in the technology's reliability and visualize the advantages and applicability of identification technologies within their specific operational contexts (Johnson & Helms, 2008)

3.5.4 Divergences of viewpoints

Twenty-one Italian participants and eleven Indian participants were interviewed in this study, and there were some differences in their insights. Some possible influences could be the cause of the heterogeneity of viewpoints. The contrasting views of participants from Italy and India highlight the significant role that national context plays in shaping actors' perceptions of identification technologies. Participants had different working years, positions, and experiences, which led to inherently subjective differences in their insights on this research theme. Furthermore, participants had different insights into wine counterfeiting, which inevitably influenced their different attitudes towards the identification technologies used for counterfeiting. Most of the participants were opposed to counterfeiting, while one participant had a different opinion. This participant believed that counterfeiting could help them expand the visibility of their wine brand to some extent, as counterfeits may be sold in more places. The thought influenced the participant's perceptions of the need for the implementation of identification technologies for counterfeiting. Whether or not the company has already implemented identification technologies may also have an impact on a participant's insights. If the devices are implemented, this may lead to a predisposition

towards seeing these devices as advantageous and efficient due to the participants' personal experiences. This may result in an excessively optimistic description of the significance of these technologies, so overshadowing any possible downsides or limits that have not yet been observed or recognized by these groups. Conversely, participants may not have an intuitive sense of the advantages of the identification technologies if they are not used in practice. Given that the participants think of the research themes based on the practical conditions of their companies and the feasibility of implementing identification technologies, the size of the company was also one of the factors influencing the participants' insights. According to the participants' statements, companies of different sizes have different counterfeiting risk perceptions and concerns about the implementation cost of the devices. Larger firms face fewer resource limitations, enabling them to allocate more significant resources to innovative activities (Frigon et al., 2020).

Drivers and barriers have coexisted and been concomitant for a long time. For example, counterfeiting risks drive the implementation of identification technologies, while no risk makes companies feel that it is unnecessary to implement identification technologies. Strategies can enhance drivers to some extent. For example, regulatory support can encourage more companies to implement identification technologies for counterfeiting, as they must take action to comply with regulations. Strategies can also mitigate particular barriers. For instance, cost optimization can address the company's concerns about the high cost of implementing identification technologies, and the current status of the low utilization of identification technologies can also be changed by educating consumers.

3.5.5 Limitations and prospects

The participants provided insights into the barriers and strategies, and the degree of difficulty in barrier eradication and strategy implementation needs to be discussed in depth, to provide clear guidance on the identification technology implementation for companies. In other words, it is important to determine which barriers may be readily resolved and which are intrinsically more difficult to establish successful strategies in the wine business.

Although the technological challenges associated with implementing anti-counterfeiting solutions might be substantial, they are often resolvable concerns (Moldabayev, 2024). Technological advancements, infrastructural enhancements, and improved technical assistance may alleviate several technical barriers (Awasthi & Sukula, 2023). These difficulties are often more manageable since they include concrete solutions, such as updating technology, enhancing software, or offering staff training. Modifying rooted behaviours, traditions, or attitudes within the wine business

may pose significant difficulties. This resistance is ingrained in personal convictions or industry culture, making it more difficult to tackle (Thompson & Rust, 2023). Overcoming cultural resistance requires sustained efforts, such as education and communication (Xue et al., 2024). Also, changing the regulatory framework may be difficult (Skjong, 2009). The wine business has a diverse array of actors, each with distinct interests, goals, and power levels (Bregoli et al., 2016). Coordinating these varied interests towards shared objectives may be complex, particularly when actors have contradictory aims or when there is insufficient communication and cooperation across the supply chain (Kanda & Deshmukh, 2008).

Subjectivity has a role in the process of analysing and interpreting information since qualitative research focuses on the subjective examination and interpretation of non-numerical data. The presence of subjectivity in research may lead to bias since the researcher's viewpoints, experiences, and assumptions might impact the study. The qualitative approach of this study does not allow for the necessary quantification of the importance of each driver, barrier, and strategy. The methods combining qualitative and quantitative research can be used in future studies to deepen our understanding of the research theme (de Hooge et al., 2018).

The identification technologies that the study aims at are QR codes and seals as a broad term, are discussed by all of the participants. Given the differences in technical principles, costs, practical applications, and corresponding regulations, each identification technology should be explored individually in future studies.

As with many qualitative studies, the research findings offer valuable and in-depth insights, although their generalizability across different contexts or countries may be limited (Lopez-Gonzalez et al., 2021). Nevertheless, these findings contribute important perspectives that can inform future research in diverse settings. All participants provided valuable perspectives on the themes, but their insights were established based on the current state of development of the Italian and Indian wine industry, which led to cultural and social dependencies in their insights. Specifically, the Italian and Indian wine industry is deeply rooted in cultural traditions that strongly shape actors' attitudes toward the use of digital technologies. This rich cultural context provides valuable insights, although perspectives and actions may vary in other wine-producing regions with different cultural backgrounds. In addition, the study’s findings may be affected by the existing regulatory system and regulations, such as the new labelling European regulation about the ingredient list, which supports QR codes as a digital tool and may stimulate the acceptance of this technology. Future research should broaden its scope beyond the Italian and Indian wine business to include other

geographical and cultural contexts. This extension facilitates comprehension of how distinct cultural contexts influence the implementation of anti-counterfeiting measures.

All topics revolve around identification technologies used for counterfeiting. Counterfeiting is always a sensitive topic for supply chain actors (Hamelin et al., 2013). In fact, some participants hesitated to provide information that might expose confidential facts or problems associated with counterfeiting. A simple example is that once a company admits that its wine products are being counterfeited in the marketplace, it triggers consumer distrust of that brand of all the wines. Some participants were reluctant to provide such information, which may limit the accuracy of the data.

3.6 Conclusions

The qualitative research approach was used in the study to explore drivers and barriers of identification technologies aiming at counterfeiting in the Italian and Indian wine supply chains and provide strategies on how to improve the implementation rate. The actor theory was introduced, and the different actors with various experiences in the wine supply chain and identification technology implementation are involved in the study to provide more comprehensive viewpoints, which makes the results more convincing. The results of the interviews highlight that the drivers for identification technology implementation are efficient traceability, consumer trust, regulatory compliance, brand enhancement, ease of use, counterfeiting risks, counterfeiting monitoring, and keeping competitive. The identified barriers include implementation costs, traditional mindset, antiquated production lines, lacking technicians, forged devices, no counterfeiting, low visibility, and unequal returns. The collaboration enhancement, cost optimization, regulatory support, multi-technology integration, simplified systems, raising awareness, and training programs are considered feasible strategies by participants. Although there are some barriers to implementing identification technologies for anti-counterfeiting in the short term, Italian and Indian wine supply chain actors should be aware that implementing anti-counterfeiting technologies should be a long-term development strategy for their companies. However, improving and promoting technology always requires time and resource investment. Ultimately, embracing such technologies can significantly enhance the transparency and integrity of the wine supply chain, helping to protect all the supply chain actors from counterfeiting.

References

Acuti, D., Magherini, L., Mazzoli, V., Bandinelli, R., Donvito, R., Rinaldi, R., & Aiello, G. (2017). QR code and the wine sector: What contents? An exploratory research study on the wine industry. In *Business Models and ICT Technologies for the Fashion Supply Chain: Proceedings of IT4Fashion 2016 6* (pp. 293-304). Springer International Publishing.

Adamashvili, N., Spada, A., Fiore, M., & Tricase, C. (2024). What about QR codes on wine bottles? A statistical analysis of technology's influence on purchase decisions among Italian wine consumers. *Socio-Economic Planning Sciences*, *96*, 102088. https://doi.org/10.1016/j.seps.2024.102088

Adjei, P. O. W., Kosoe, E. A., & Forkuor, D. (2017). Facts behind the myth of conservative rurality: major determinants of rural farmers' innovation adoption decisions for sustainable agriculture. *GeoJournal*, *82*, 1051-1066. https://doi.org/10.1007/s10708-016-9728-9

Agnoli, L., Begalli, D., & Capitello, R. (2011). Generation Y's perception of wine and consumption situations in a traditional wine-producing region. *International Journal of Wine Business Research*, *23*(2), 176-192. https://doi.org/10.1108/17511061111143025

Agostino, M., & Trivieri, F. (2014). Geographical indication and wine exports. An empirical investigation considering the major European producers. *Food Policy*, *46*, 22-36. https://doi.org/10.1016/j.foodpol.2014.02.002

Agnusdei, G. P., Coluccia, B., Elia, V., & Miglietta, P. P. (2022). IoT technologies for wine supply chain traceability: potential application in the Southern Apulia Region (Italy). *Procedia Computer Science*, *200*, 1125-1134. https://doi.org/10.1016/j.procs.2022.01.312

Aman, A., Jain, V., Radia, A., Awsarkar, R., Garg, B., & Kapoor, R. (2024, October). Safeguarding Authenticity: A Blockchain-Driven Approach to Combat Liquor Counterfeiting with QR Code and Holograph Seal Integration. In *2024 IEEE International Conference on Blockchain and Distributed Systems Security (ICBDS)* (pp. 1-21). IEEE.

Ambrosia. (2023). Anti-counterfeiting technologies to stop fake alcohol market. Retrieved from *https://www.ambrosiaindia.com/2023/12/anti-counterfeiting-technologies-to-stop-fake-alcohol-market/*. Accessed April 27, 2025

Awasthi, S., & Sukula, S. K. (2023). Breaking barriers: technological innovations for enhancing access to opportunities. *International Journal of Research in Library Science*, *9*(4), 11-22. https://doi.org/10.26761/IJRLS.9.4.2023.1695

Basso, F., Guajardo, M., & Varas, M. (2020). Collaborative job scheduling in the wine bottling process. *Omega*, *91*, 102021. https://doi.org/10.1016/j.omega.2018.12.010

Bejlegaard, M., Sarivan, I. M., & Waehrens, B. V. (2021). The influence of digital technologies on supply chain coordination strategies. *Journal of Global Operations and Strategic Sourcing*, *14*(4), 636-658. https://doi.org/10.1108/JGOSS-11-2019-0063

Bernetti, I., Casini, L., & Marinelli, N. (2006). Wine and globalisation: changes in the international market structure and the position of Italy. *British Food Journal*, *108*(4), 306-315. https://doi.org/10.1108/00070700610657146

Brabazon, T., Winter, M., & Gandy, B. (2014). *Digital wine: How QR codes facilitate new markets for small wine industries*. Singapore: Springer.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77-101. https://doi.org/10.1191/1478088706qp063oa

Bregoli, I., Hingley, M., Del Chiappa, G., & Sodano, V. (2016). Challenges in Italian wine routes: managing actor networks. *Qualitative Market Research: An International Journal*, *19*(2), 204-224. https://doi.org/10.1108/QMR-02-2016-0008

Bryman, A. (2016). *Social research methods*. Oxford University Press.

Cardoso, B. J., Amaral, A. R., Gaspar, A. R., & Gomes, Á. (2023). Exploring energy efficiency barriers and drivers in the Portuguese water sector. *Energy*, 284, 128725. https://doi.org/10.1016/j.energy.2023.128725

Castriota, S., & Delmastro, M. (2015). The economics of collective reputation: Evidence from the wine industry. *American Journal of Agricultural Economics*, *97*(2), 469-489. https://doi.org/10.1093/ajae/aau107

Chengxin, Y., Mingwen, C., Mingzhi, C., Shiguang, L., & Shaolin, L. (2007, August). Study and Prospect on Integrated Multi-technology in Logistics. In *2007 IEEE International Conference on Automation and Logistics* (pp. 871-875). IEEE.

Cooke, P. (2017). 'Digital tech'and the public sector: what new role after public funding?. *European Planning Studies*, *25*(5), 739-754. https://doi.org/10.1080/09654313.2017.1282067

Conti, M. E., Rapa, M., Simone, C., Calabrese, M., Bosco, G., Canepari, S., & Astolfi, M. L. (2024). From land to glass: An integrated approach for quality and traceability assessment of top Italian wines. *Food Control*, *158*, 110226. https://doi.org/10.1016/j.foodcont.2023.110226

Costanigro, M., Scozzafava, G., & Casini, L. (2019). Vertical differentiation via multi-tier geographical indications and the consumer perception of quality: The case of Chianti wines. *Food Policy*, *83*, 246-259. https://doi.org/10.1016/j.foodpol.2019.01.008

Dal Bianco, A., Boatto, V., Trestini, S., & Caracciolo, F. (2018). Understanding consumption choice of prosecco wine: an empirical analysis using Italian and German Homescan data. *Journal of Wine Research*, *29*(3), 190-203. https://doi.org/10.1080/09571264.2018.1506322

Danese, P., Mocellin, R., & Romano, P. (2021). Designing blockchain systems to prevent counterfeiting in wine supply chains: a multiple-case study. *International Journal of Operations & Production Management*, *41*(13), 1-33. https://doi.org/10.1108/IJOPM-12-2019-0781

de Graeff, N., Jongsma, K. R., & Bredenoord, A. L. (2021). Participants' moral views on gene drive technologies: a qualitative interview study. *BMC Medical Ethics*, *22*, 1-15. https://doi.org/10.1186/s12910-021-00588-5

de Hooge, I. E., van Dulm, E., & van Trijp, H. C. (2018). Cosmetic specifications in the food waste issue: Supply chain considerations and practices concerning suboptimal food products. *Journal of Cleaner Production*, *183*, 698-709. https://doi.org/10.1016/j.jclepro.2018.02.132

European Parliament and of the Council, 2021. European Parliament and of the Council Regulation (EU) No. 2021/2117 of the European Parliament and of the Council amending regulations (EU) No. 1308/2013 Establishing a common Organization of the Markets in agricultural products, (EU) No. 1151/2012 on quality Schemes for agricultural Products and foodstuffs, (EU) No. 251/2014 on the definition, description, presentation, labelling and the protection of geographical indications of aromatized wine products and (EU) No. 228/2013 laying down specific measures for agriculture in the outermost regions of the union (2021). Retrieved from *https://eur-lex.europa.eu/eli/reg/2021/2117/oj*, Accessed January 26, 2025

Ferrara, C., Migliaro, V., Ventura, F., & De Feo, G. (2023). An economic and environmental analysis of wine packaging systems in Italy: A life cycle (LC) approach. *Science of the Total Environment*, *857*, 159323. https://doi.org/10.1016/j.scitotenv.2022.159323

Food Safety and Standard Authority of India (FSSAI). (2023). *Inclusion of QR Codes on Food Products for Accessibility by Visually Impaired Individuals*. New Delhi.

Flores, S. S. (2018). What is sustainability in the wine world? A cross-country analysis of wine sustainability frameworks. *Journal of Cleaner Production*, *172*, 2301-2312. https://doi.org/10.1016/j.jclepro.2017.11.181

Foroughi, A. (2021). Supply chain workforce training: addressing the digital skills gap. *Higher Education, Skills and Work-Based Learning*, *11*(3), 683-696. https://doi.org/10.1108/HESWBL-07-2020-0159

Frigon, A., Doloreux, D., & Shearmur, R. (2020). Drivers of eco-innovation and conventional innovation in the Canadian wine industry. *Journal of Cleaner Production*, *275*, 124115. https://doi.org/10.1016/j.jclepro.2020.124115

Frühauf, A., Heußner, J., Niedermeier, M., & Kopp, M. (2021). Participant views on therapeutic climbing—A multi-perspective, qualitative study. *International Journal of Environmental Research and Public Health*, *18*(7), 3535. https://doi.org/10.3390/ijerph18073535

Furlan, I., & Vettori, M. (2021). Il comandante. Bracconieri, malfattori e altre storie. Antilia.

Galletto, L., Caracciolo, F., Boatto, V., Barisan, L., Franceschi, D., & Lillo, M. (2021). Do consumers really recognise a distinct quality hierarchy amongst PDO sparkling wines? The answer from experimental auctions. *British Food Journal*, *123*(4), 1478-1493. https://doi.org/10.1108/BFJ-07-2020-0625

Gambero Rosso. (2025). Counterfeiting of wine and alcoholic beverages: losses for Italy exceed €300 million annually. Retrieved from *https://www.gamberorossointernational.com/news/counterfeiting-of-wine-and-alcoholic-beverages-losses-for-italy-exceed-e300-million-annually/*. Accessed June 17, 2025

Gayialis, S. P., Kechagias, E. P., Papadopoulos, G. A., & Kanakis, E. (2022, September). A smart-contract enabled blockchain traceability system against wine supply chain counterfeiting. In *IFIP International Conference on Advances in Production Management Systems* (pp. 477-484). Cham: Springer Nature Switzerland.

Gupta, V., & Sajnani, M. (2020). Risk and benefit perceptions related to wine consumption and how it influences consumers' attitude and behavioural intentions in India. *British Food Journal*, *122*(8), 2569-2585. https://doi.org/10.1108/BFJ-06-2019-0464

Habashneh, A., Assayed, A., & AlMajali, A. (2023). Using Blockchain for Agro-Food Traceability: A Case Study from Olive Oil Industry. In *Industry 4.0 Technologies: Sustainable Manufacturing Supply Chains: Volume 1—Theory, Challenges, and Opportunity* (pp. 35-45). Singapore: Springer Nature Singapore.

Hamelin, N., Nwankwo, S., & El Hadouchi, R. (2013). 'Faking brands': consumer responses to counterfeiting. *Journal of Consumer Behaviour, 12*(3), 159-170. https://doi.org/10.1002/cb.1406

Hellani, H., Sliman, L., Samhat, A. E., & Exposito, E. (2021). On blockchain integration with supply chain: Overview on data transparency. *Logistics*, *5*(3), 46. https://doi.org/10.3390/logistics5030046

Higgins, L. M., Wolf, M. M., & Wolf, M. J. (2014). Technological change in the wine market? The role of QR codes and wine apps in consumer wine purchases. *Wine Economics and Policy*, *3*(1), 19-27. https://doi.org/10.1016/j.wep.2014.01.002

Jiménez-Carvelo, A. M., Li, P., Erasmus, S. W., Wang, H., & van Ruth, S. M. (2022). Spatial-temporal event analysis as a prospective approach for signalling emerging food fraud-related anomalies in supply chains. *Foods*, *12*(1), 61. https://doi.org/10.3390/foods12010061

Johnson, L. A., & Helms, M. M. (2008). Keeping it local: Incorporating a local case study in the business curriculum. *Education+ Training*, *50*(4), 315-328. https://doi.org/10.1108/00400910810880551

Junnier, F. (2024). Action and understanding in the semi-structured research interview: Using CA to analyse European research scientists' attitudes to linguistic (dis) advantage. *Journal of English for Academic Purposes*, *68*, 101355. https://doi.org/10.1016/j.jeap.2024.101355

Kanda, A., & Deshmukh, S. G. (2008). Supply chain coordination: perspectives, empirical studies and research directions. *International journal of production Economics*, *115*(2), 316-335. https://doi.org/10.1016/j.ijpe.2008.05.011

Khadria, B. (2002). *Skilled labour migration from developing countries: Study on India*. ILO.

Khan, N., Fahad, S., Naushad, M., & Faisal, S. (2020). Grape production critical review in the world. *Available at SSRN 3595842*.

Kleppmann, M. (2017). *Designing data-intensive applications: The big ideas behind reliable, scalable, and maintainable systems*. " O'Reilly Media, Inc.".

Köhler, S., & Pizzol, M. (2020). Technology assessment of blockchain-based technologies in the food supply chain. *Journal of cleaner production*, *269*, 122193. https://doi.org/10.1016/j.jclepro.2020.122193

Li, P., Yang, J., Jiménez-Carvelo, A. M., & Erasmus, S. W. (2024). Applications of food packaging quick response codes in information transmission toward food supply chain integrity. *Trends in Food Science & Technology*, *146*, 104384. https://doi.org/10.1016/j.tifs.2024.104384

Liang, Z., Zhang, P., Zeng, X. A., & Fang, Z. (2021). The art of flavored wine: Tradition and future. *Trends in Food Science & Technology*, *116*, 130-145. https://doi.org/10.1016/j.tifs.2021.07.020

Lloyd, S., & Gifford, R. (2024). Qualitative research and the future of environmental psychology. *Journal of Environmental Psychology*, *97*, 102347. https://doi.org/10.1016/j.jenvp.2024.102347

Lo, S. K., Xu, X., Wang, C., Weber, I., Rimba, P., Lu, Q., & Staples, M. (2019). Digital-physical parity for food fraud detection. In *Blockchain-ICBC 2019: Second International Conference, Held as Part of the Services Conference Federation, SCF 2019, San Diego, CA, USA, June 25-30, 2019, Proceedings 2* (pp. 65-79). Springer International Publishing.

Lopez-Gonzalez, H., Rius-Buitrago, A., Jimenez-Murcia, S., & Griffiths, M. D. (2021). The utilization and perception of sports betting participants (‘tipsters’) among sports bettors with gambling problems: A qualitative focus group interview study. *International Gambling Studies*, *21*(2), 238-254. https://doi.org/10.1080/14459795.2020.1844270

Matzembacher, D. E., do Carmo Stangherlin, I., Slongo, L. A., & Cataldi, R. (2018). An integration of traceability elements and their impact in consumer's trust. *Food Control*, *92*, 420-429. https://doi.org/10.1016/j.foodcont.2018.05.014

Mehta, R., K. Sharma, N., & Swami, S. (2013). A typology of Indian hypermarket shoppers based on shopping motivation. *International Journal of Retail & Distribution Management*, *42*(1), 40-55. https://doi.org/10.1108/IJRDM-06-2012-0056

Meloni, G., Anderson, K., Deconinck, K., & Swinnen, J. (2019). Wine regulations. *Applied Economic Perspectives and Policy*, *41*(4), 620-649. https://doi.org/10.1093/aepp/ppz025

Ministero dell'agricoltura, della sovranità alimentare e delle foreste. Retrieved from *https://www.politicheagricole.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/20839*. Accessed September 26, 2024

Mitchell, R., Boyle, B., Burgess, J., & McNeil, K. (2014). “You Can't Make a Good Wine without a Few Beers”: Gatekeepers and knowledge flow in industrial districts. *Journal of Business Research*, *67*(10), 2198-2206. https://doi.org/10.1016/j.jbusres.2014.01.007

Moldabayev, A. (2024). Digital technologies against counterfeit products: opportunities and challenges. Endless light in science, 97-107.

Njuguna, D., & Ndia, J. G. (2025). Quick Response Code Security Attacks and Countermeasures: A Systematic Literature Review.

Palade, M., & Popa, M. E. (2014). Wine traceability and authenticity-a literature review.

Polit, D. F., & Beck, C. T. (2004). *Nursing research: Principles and methods*. Lippincott Williams & Wilkins.

Pomarici, E., Corsi, A., Mazzarino, S., & Sardone, R. (2021). The Italian wine sector: Evolution, structure, competitiveness and future challenges of an enduring leader. *Italian Economic Journal*, *7*(2), 259-295. https://doi.org/10.1007/s40797-021-00144-5

Popović, T., Krčo, S., Maraš, V., Hakola, L., Radonjić, S., van Kranenburg, R., & Šandi, S. (2021). A novel solution for counterfeit prevention in the wine industry based on IoT, smart tags, and crowd-sourced information. *Internet of Things*, *14*, 100375. https://doi.org/10.1016/j.iot.2021.100375

Przyswa, E. (2014). Protecting your wine. *Stop counterfeiters from selling cheap imitations of your premium brand. Wines and Vines*, 38-47.

Research and Markets. (2016). India wine market overview, Retrieved from *www.researchandmarkets.com/reports/2113184/wine-in-india*. Accessed April 21, 2025

Rocchi, B., Romano, D., Sadiddin, A., & Stefani, G. (2020). Assessing the economy-wide impact of food fraud: A SAM-based counterfactual approach. *Agribusiness*, *36*(2), 167-191. https://doi.org/10.1002/agr.21633

Rogerson, M., & Parry, G. C. (2020). Blockchain: case studies in food supply chain visibility. *Supply Chain Management: An International Journal*, *25*(5), 601-614. https://doi.org/10.1108/SCM-08-2019-0300

Rome Business School. (2024). Italy in the Global Wine Market: evolution and prospects. *https://romebusinessschool.com/blog/the-global-wine-market-will-reach-350-billion-in-2024-with-italy-as-the-2nd-largest-producer-behind-france/.*Accessed June 17, 2025

Schäufele, I., & Hamm, U. (2018). Organic wine purchase behaviour in Germany: Exploring the attitude-behaviour-gap with data from a household panel. *Food Quality and Preference*, *63*, 1-11. https://doi.org/10.1016/j.foodqual.2017.07.010

Shapiro, M., & I. Gómez, M. (2014). Customer satisfaction and sales performance in wine tasting rooms. *International Journal of Wine Business Research*, *26*(1), 45-60. https://doi.org/10.1108/IJWBR-09-2012-0026

Sharma, P., Singh, S., & Misra, R. (2020). Wine-related lifestyle segmentation in the context of urban Indian consumers. *International Journal of Wine Business Research*, *32*(4), 503-522. https://doi.org/10.1108/IJWBR-05-2019-0036

Skjong, R. (2009). Regulatory framework. In *Risk-based ship design: methods, tools and applications* (pp. 97-151). Berlin, Heidelberg: Springer Berlin Heidelberg.

Statista. (2023). Wine. Retrieved from *https://www.statista.com/outlook/cmo/alcoholic-drinks/wine/india*. Accessed April 5, 2025

Thompson, B. S., & Rust, S. (2023). Blocking blockchain: Examining the social, cultural, and institutional factors causing innovation resistance to digital technology in seafood supply chains. *Technology in Society*, *73*, 102235. https://doi.org/10.1016/j.techsoc.2023.102235

Trivedi, R., Teichert, T., & Hardeck, D. (2020). Effectiveness of pull-based print advertising with QR codes: Role of consumer involvement and advertisement appeal. *European Journal of Marketing*, *54*(1), 145-167. https://doi.org/10.1108/EJM-06-2018-0383

Unterkofler, J., Muhlack, R. A., & Jeffery, D. W. (2020). Processes and purposes of extraction of grape components during winemaking: Current state and perspectives. *Applied Microbiology and Biotechnology*, *104*(11), 4737-4755. https://doi.org/10.1007/s00253-020-10558-3

Unwin, T. (2005). *Wine and the vine: an historical geography of viticulture and the wine trade*. Routledge.

Vaismoradi, M., Turunen, H., & Bondas, T. (2013). Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. *Nursing & health sciences*, *15*(3), 398-405. https://doi.org/10.1111/nhs.12048

van Leeuwen, C. (2022). Terroir: The effect of the physical environment on vine growth, grape ripening, and wine sensory attributes. In *Managing Wine Quality* (pp. 341-393). Woodhead Publishing.

Villano, C., Lisanti, M. T., Gambuti, A., Vecchio, R., Moio, L., Frusciante, L., Aversano, R., & Carputo, D. (2017). Wine varietal authentication based on phenolics, volatiles and DNA markers: State of the art, perspectives and drawbacks. *Food Control*, *80*, 1-10. https://doi.org/10.1016/j.foodcont.2017.04.020

Violino, S., Pallottino, F., Sperandio, G., Figorilli, S., Antonucci, F., Ioannoni, V., Fappiano, D., & Costa, C. (2019). Are the innovative electronic labels for extra virgin olive oil sustainable, traceable, and accepted by consumers? *Foods, 8*(11), 529. https://doi.org/10.3390/foods8110529

WTO, World Trade Organization: Glossary: Counterfeit Definition. 2011.

Xue, Z., Nasir, N. S. M., Cheng, Y., Wu, W., & Cao, Y. (2024). Overcoming resistance to innovation: Strategies and change management. *Journal of Business Innovation, 9*(1), 32.

Supplementary material

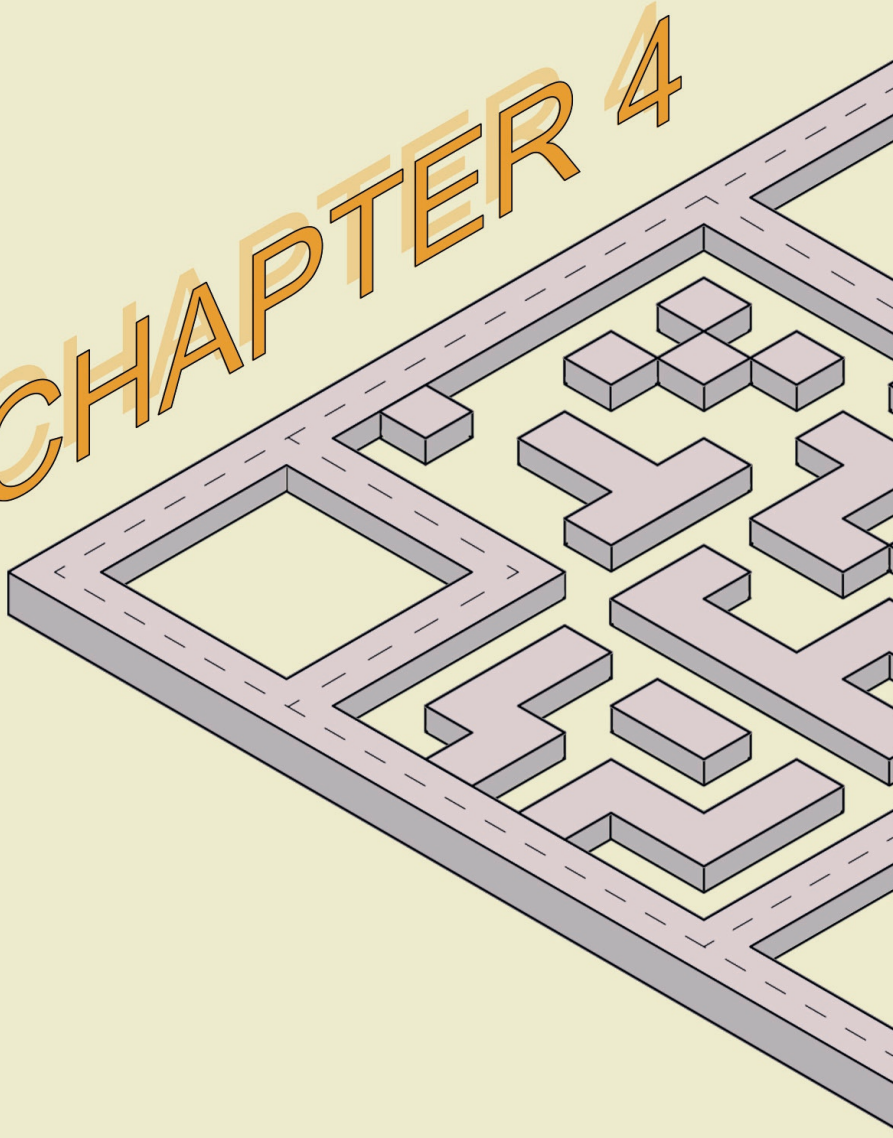
Table S3.1. Semi-structured interview guide.

Section 1 Introduction	
Section 2 Background and Perception	
Questions	Possible follow-up questions
1. Could you tell me about your position inside the company? 2. How long you have been working in the company? 3. How long are you working in the sector? What's your experience? 4. Could you also provide some background information about the company you represent/ Can you please describe your company to me? 5. Is your company utilizing the identification technologies for anti-counterfeiting?	1. Could you provide a brief overview of the identification technologies for anti-counterfeiting that your company currently employs?
Section 3 Drivers	
Questions	Possible follow-up questions
1. What do you think are the drivers of identification technology implementation for anti-counterfeiting?	1. Is the implementation of these technologies influenced by any factors related to economics, regulation and market? 2. How much do you think using anti-counterfeiting technology may reduce the dangers of counterfeiting goods or fraudulent activity in the wine supply chain?
Section 4 Barriers	
Questions	Possible follow-up questions
1. What do you think are the barriers to identification technology implementation for anti-counterfeiting?	1. Are there challenges in acquiring the necessary skills or participants, and how are these addressed? 2. Are there tensions between preserving tradition and embracing technological advancements? 3. Are there concerns about the complexity of integrating these devices into existing wine production and logistics practices? 4. Are there concerns about the economic feasibility of implementing these technologies? 5. Are there challenges in communicating and collaborating with other actors in the wine supply chain regarding implementing these technologies?

Table S3.1. Continued.

Section 5 Strategies	
Questions	Possible follow-up questions
1. What are the effective ways (strategies), in your opinion, for Italian wine supply chain actors to overcome these obstacles of using identification technologies to stop counterfeiting in the Italian wine supply chain?	1. Did you experience any cases where these strategies have been used? 2. In the future, how do you see the role of increasing identification technology utilization in wine production and logistics to further strengthen the safeguarding of the authenticity of Italian wine?
Section 6 End	

CHAPTER 4



Chapter 4

Factors influencing consumers' behavioral intention to use authentication QR codes on food packages

This chapter is prepared for submission as:

Pengfei Li, Tongzhe Li, Hongmei Liu, Sanne Kouwenberg, Kasper A. Hettinga, Sara W. Erasmus. Factors influencing consumers' behavioral intention to use authentication Quick Response (QR) codes on food packages

Abstract

Public concerns regarding the authenticity of various food types have existed for a long time, leading to the need to develop tools to prevent and detect food fraud. Quick Response (QR) codes on food packages that assist in the authentication of food products have been used to guarantee the expected food quality and safety. Exploring the factors that influence consumers' behavioral intention to use such food authentication QR codes will contribute to shedding light on how to further promote the use of such tools by designing tailored strategies. In this study, the Technology Acceptance Model was used as the theoretical construct that merges the two external variables of authenticity awareness and facilitating conditions. Structural Equation Modeling and Artificial Neural Networks were constructed to explore the relationship between the consumers' behavioral intention to use the authentication QR code and its relevant factors. The survey covered 484 Chinese and 312 British participants to test the proposed hypotheses. The results showed that all hypotheses proposed in the theoretical model are supported based on both Chinese and British responses. Perceived usefulness and perceived ease of use were identified as the factors significantly influencing Chinese and British consumers' attitudes, while attitude is the most significant factor of behavioral intention. Attitude also significantly influenced authenticity awareness, and facilitating conditions significantly affected the perceived ease of use. This study offers valuable insights into the relationship between factors and consumers' behavioral intention to use authentication QR codes, supporting the broader adoption of such QR codes.

Keywords

Artificial neural networks; Food authenticity; Quick Response code; Structural equation modeling; Technology acceptance model

4.1 Introduction

Food authenticity refers to the quality of food being genuine, with its nature, identity, origin, and claims accurately represented and meeting expected characteristics (FAO & WHO, 2018). The issue of food authenticity has attracted global attention, because of its implications for food safety and economics (Brigante et al., 2022). Consumers are inclined to buy authentic food, which underscores the significance of safety assurance, high product quality, and ethical values (Loebnitz & Grunert, 2022). Food fraud involves intentional deception for economic profit through practices such as mislabeling, adulteration, substitution, and counterfeiting (Robson et al., 2021). Food fraud undermines the food supply chain integrity and leads to severe economic losses and potential health risks. As a common type of food fraud, counterfeiting involves substituting a high-quality product with a lower-quality one and false labels to gain an illegal economic benefit (Jiménez-Carvelo et al., 2022). Counterfeiting, posing a severe threat to food authenticity, is detrimental to the business by damaging the public image, and misleads consumers into believing they are purchasing authentic food products being worth the price (Brooks et al., 2021). Effective research and innovation in food authenticity and anti-counterfeiting technology will be helpful in protecting consumers' rights, boosting consumer confidence, and supporting the healthy and stable growth of the food industry (Su et al., 2024). Some food companies, especially those producing foods on a large scale, have implemented authentication systems to guarantee the authenticity of food products (Li et al., 2024).

The Quick Response (QR) code, as one of the most often used two-dimensional (2D) codes, can hold a large amount of data in a small space due to the linked information stored in horizontal and vertical directions (Saranya et al., 2016). QR codes can be recognized optically by the built-in software of common devices, such as smartphones with cameras, and are regarded as a convenient and user-friendly technology because of no need to manually introduce data on the smartphone (Sanz-Valero et al., 2016). QR codes have been widely used as an efficient tool to transfer various types of digital food information to consumers, including traceability, quality evaluation, marketing, and authenticity. In recent years, QR codes linked to authentication systems have provided consumers with a more reliable way to verify the authenticity of food products (Li et al., 2024). Consumers can scan the QR code on the packages by using their smartphones to access the food authenticity information provided by the authentication system (Huque et al., 2015). In practice, authentication QR codes play a significant role in fighting food anti-counterfeiting and have for instance been used to guarantee the authenticity of infant formula (Food Navigator Europe, 2020), wine (Popović et al., 2021), and champagne (Peak, 2019), which have high requirements for quality and safety.

Through using QR code-based authentication, consumers can verify the authenticity of food products and enhance their trust in brands. However, despite the obvious technological advantages of authentication QR codes, their application is still in the early stages, and many food companies have not incorporated the technology into their products. One possible reason is that consumers have a low intention to use QR codes, which limits the willingness of companies to promote this technology (Liu et al., 2018). In addition, previous studies just focused on the proposal of the concept regarding authenticating food by using QR codes and optimizing the authentication mechanism. There is a paucity of research on the application of authentication QR codes, which to some extent restricts companies from gaining a deeper understanding of users' behavioral intentions and barriers to its use. Exploring the potential factors influencing consumers' behavioral intention to use authentication QR codes will contribute to the development of targeted improvement measures to promote the popularization and use of the technology.

The study aims to investigate the factors that influence consumers' behavioral intention to use authentication QR codes. The hypotheses are proposed to construct the theoretical model based on the classic Technology Acceptance Model (TAM), which is merged with two expanded variables: authenticity awareness and facilitating conditions. A hybrid Structural Equation Modeling and Artificial Neural Networks (SEM-ANN) model is used to examine the relationship between consumers' behavioral intention and its factors. Specifically, the technology acceptance model is used to examine the influence of factors on consumers' behavioral intention to use authentication QR codes, while the artificial neural networks model can rank the relative importance of these significant factors.

4.2 Conceptual framework and hypotheses development

Technology Acceptance Model (Davis et al., 1989) is one of the most widely cited models for technology adoption (Chong, 2013). In its simplest form, perceived ease of use (PEOU), perceived usefulness (PU), and attitude (AT) are used to explore behavioral intention (BI) (Gbongli et al., 2019). The technology acceptance model can be regarded as the foundation framework where other relevant factors that may explain the relations of interest are allowed to be incorporated, to improve the effectiveness of the model (Unal & Uzun, 2021).

Perceived usefulness and perceived ease of use are the standard variables in the technology acceptance model (Rahman et al., 2017). In this study, perceived usefulness denotes the extent to which an individual believes that using an authentication QR code is helpful in achieving the goal of authenticating food products. Perceived ease of use refers to the extent to which an individual considers that using

an authentication QR code will require minimal effort. The previous studies on the technology acceptance model revealed that perceived ease of use has direct effects on perceived usefulness (Abdullah et al., 2016; Ria et al., 2024). This is because the decision of an individual on the usefulness of a technology is influenced by how easy an individual perceives it to be (Suki & Ramayah, 2010).

The traditional technology acceptance model incorporates attitude and behavioral intention as its two primary variables. Consumers' attitude towards authentication QR codes is regarded as the extent to which an individual perceives a positive or negative feeling about the technology and represents the way consumers respond to authentication QR codes. Behavioral intention refers to an individual's subjective probability of engaging in a specific behavior (Kumar et al., 2020). Attitude is considered an assessment of behavior (Ahmmadi et al., 2021), and several studies have identified attitude as a significant predictor of behavioral intention (Namahoot & Rattanawiboonsom, 2022; Szopiński, 2016), as consumers with a positive attitude toward a technology are more likely to adopt it.

In the technology acceptance model, attitude, as a mediator between the two variables (perceived usefulness and perceived ease of use) and intentions, plays a central role in the acceptance and utilization of a technique (Dwivedi et al., 2019). In prior studies, it was found that there was a strong correlation between perceived usefulness and attitude toward innovative technology adoption (Abdullah et al., 2016; Mullins & Cronan, 2021). The authentication QR code can provide consumers with food authenticity information, potentially leading to a positive attitude and a high intention to use it. Several studies have found that perceived ease of use positively affects attitude (Gbongli et al., 2019; Ma et al., 2023). The ease of use of technology leads to the users' quick engagement and builds confidence in using it.

Based on this conceptual framework, the following hypotheses (H) are proposed:

- H1: Perceived ease of use positively impacts perceived usefulness.
- H2: Perceived usefulness positively impacts attitude toward using.
- H3: Perceived ease of use positively impacts attitude toward using.
- H4: Attitude toward using positively impacts behavioral intention.

Authenticity awareness (AA) refers to the consumers' attention to food authenticity. In the context of authentication technology used in practice, the technology helps consumers finish the food authenticity evaluation, which reinforces consumers' habit of checking for authentication and enhances their awareness of product authenticity (Nunes et al., 2021). When consumers trust a certain authentication technology, they

may perceive it as a valuable and reliable way to verify product legitimacy, making them more conscious of the importance of authentic products (Charlebois et al., 2016).

Consumers with authenticity awareness take actions to authenticate food products they want to purchase and are alert to the potential counterfeiting of food products (Charlebois et al., 2016). They can use their experience and knowledge to identify food authenticity and are more interested in food authentication tools, which can meet their requirements for authenticity information acquisition (Kendall et al., 2019). Thus, it is expected that authenticity awareness will positively affect behavioral intention to use authentication QR codes because the device can provide the useful authentication information they are concerned about.

Based on the conceptual framework, the following hypotheses (H) are proposed:

- H5: Attitude toward using positively impacts authenticity awareness.
- H6: Authenticity awareness positively impacts behavioral intention to use.

Facilitating conditions (FC) are defined as the level of convenience and control toward resources when using a certain technology (Man et al., 2025). Resources refer to the organizational tools or individual skills needed to carry out the behavior (Moreira & Rodrigues, 2023). QR code-related resources may include the device (smartphone), internet connectivity, and basic knowledge of using QR codes (Del Rosario-Raymundo, 2017). Facilitating conditions can provide the necessary support, causing users to experience fewer obstacles (Kamal et al., 2020). When these resources are readily available, the technology can be used more smoothly. Facilitating conditions can increase users' confidence, making the technology feel more intuitive and manageable (Miltgen et al., 2013). Facilitating conditions can turn into obstacles when access to essential resources is limited or scarce (Mahardika et al., 2019). In other words, once consumers do not have the facilitating conditions to scan QR codes, the scanning process is almost impossible to complete, which may reduce their intention to use. Thus, effective facilitating conditions may improve consumers' behavioral intention to use authentication QR codes.

Based on this conceptual framework, the following hypotheses (H) are proposed:

- H7 Facilitating conditions positively impact perceived ease of use.
- H8 Facilitating conditions positively impact behavioral intention to use.

Combining all the proposed theoretical hypotheses, a structural model is constructed to identify the relationship between the factors (perceived usefulness, perceived ease of use, attitude, authenticity awareness, and facilitating conditions) and the consumers' behavioral intention to use, as depicted in **Fig. 4.1**.

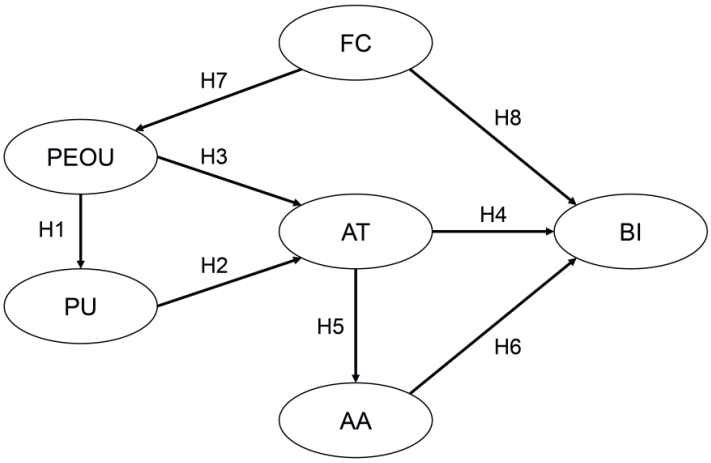


Fig. 4.1. The proposed model with variables and hypotheses (H1 to H8). BI: behavioral intention, AT: attitude, PU: perceived usefulness, PEOU: perceived ease of use, AA: authenticity awareness, FC: facilitating conditions.

4.3 Methods

4.3.1 Data collection

A survey questionnaire was designed and included demographic questions, experience in using QR codes, and scale items of relevant variables to test the hypotheses in this study. The questionnaire was originally designed in English and then translated into a Chinese version for the Chinese participants. Since authentication QR codes have not yet been widely adopted in the market, many consumers may lack experience with this tool, resulting in unclear understanding and perceptions. Therefore, an example image and a brief introduction to authentication QR codes were provided before presenting the scale items. Due to the varying vulnerability of fraud in different food types, specifying food type may influence the consistency of consumers' perception of the scale items. Therefore, at the end of the questionnaire, the item regarding food types arising in their mind while filling out the questionnaire was set, which can indirectly indicate which type of food consumers think is more necessary to adopt authentication QR codes for.

A pre-survey was conducted before the formal research to ensure the scientific rationality of the questionnaire. Twenty participants were recruited through the authors' social media to explore their understanding of the questionnaire content and the logic and coherence of the scale items. According to the participants' feedback, the questionnaire was revised and finalized. The complete questionnaire in both Chinese and English versions is shown in **Supplementary Text 4.1**.

Chinese and British consumers were selected for this study due to the distinct social, regulatory, and technological contexts. In China, food fraud remains a persistent economic and social issue, and the insufficient information disclosure, weak institutional governance, and poor regulatory instrument designs pose a challenge to China's food safety systems (Zhu et al., 2019). Chinese consumers have a sense of insecurity and uncertainty about the food system and may be more sensitive to food fraud (Soon & Liu, 2020). At the same time, Chinese consumers are highly accustomed to QR code technology, as it is widely used for mobile payments in daily life (Zhong & Moon, 2022). This technological familiarity may influence their perceptions and acceptance of QR code-based authentication systems. In contrast, the UK has a more established regulatory framework, exemplified by the Food Safety (General Food Hygiene) Regulations 1995 (HMSO, 1995), which mandate the implementation of food safety management systems. British consumers, thus, may experience a greater sense of trust and security in their food system. These contextual differences offer a valuable foundation for cross-regional comparison and contribute to a deeper understanding of consumer behavior toward authentication QR codes.

Given the merits of the online survey (Zhao et al., 2024), a cross-sectional online survey was conducted from August to October 2024 among Chinese and British adults (aged 18 years or older) on the panels maintained by two popular panel providers: Wenjuanxing for Chinese respondents and Dynata for British respondents. Wenjuanxing (https://www.wjx.cn/), the largest online survey platform in China (Wang et al., 2020), and Dynata (https://www.dynata.com/), the largest-reaching global market research firm (Cook et al., 2024), and maintain well-established respondent panels. Both organizations manage their panels in full compliance with applicable data protection and privacy regulations. The members of Wenjuanxing received an email invitation containing a brief introduction to the study and a link to the survey and those who were interested could access and complete the questionnaire through the survey website (Zheng & Zheng, 2014). Similarly, during the study period, Dynata panelists who logged into their accounts were invited to participate in the survey if they met the eligibility criteria (Johnson et al., 2025). Participants received incentives from Wenjuanxing and Dynata in accordance with each platform’s standard compensation policies.

To determine an appropriate sample size, the minimum number of respondents was evaluated to meet the requirement for the statistical analysis of the structural equation model. Following Kline's recommendation (Kline, 2023), a minimum of 100-200 respondents is necessary. The sample size can also be determined following the rule of thumb (Leguina, 2015), which suggests a 1:5 ratio (17 items × 5 = 105). Finally, 484 Chinese respondents and 312 British respondents remained as the samples after

excluding surveys with incomplete responses or inconsistent data. The demographic characteristics of these samples are shown in **Table 4.1**. The criteria for incomplete and invalid questionnaires are provided in **Supplementary Text 4.2**.

Most Chinese respondents were between the ages of 25 and 44. Of the Chinese respondents, 52% were female, with more than 95% receiving tertiary education. The age distribution of respondents in the UK is relatively balanced (each age group accounting for approximately 17%), and female respondents made up 52% of the sample. The middle-income group accounts for the majority of respondents in China and the UK (87% and 65%, respectively). 87% of the Chinese respondents hold a bachelor's degree, while half of the British respondents completed a high school education. In terms of experience in scanning QR codes, 99% of Chinese respondents and 88% of British respondents have experience. Among the Chinese respondents, 87% scanned QR codes on food packages, while just under half (46%) of British respondents had the experience.

The ethics approval for this study has been granted by the Research Ethics Committee of Wageningen University & Research (No. 2024-113).

4.3.2 Data analysis

Structural Equation Modeling (SEM), a confirmatory technique, is used to test the theoretical models and verify the proposed hypotheses and integrates confirmatory factor analysis, regression analysis, and path analysis (Klemelä, 2018). In this study, structural equation modeling was employed to assess both the measurement model and the structural model. Confirmatory Factor Analysis (CFA) was used to validate the reliability and validity of the designed scale items by examining the relationships between latent variables and the observed variables. The structural model tests the hypothesized relationships between latent variables, enabling an evaluation of the theoretical framework in **Fig. 4.1**. The multigroup analyses are employed to examine group differences. For the interpretation of the results, it is important to consider that structural equation modeling performs well in identifying linear relationships between variables but oversimplifies the complexity of the human decision-making process (Çakıt et al., 2020).

Table 4.1. Sample demographics and experience in using QR codes.

Demographics	Chinese respondents (N=484)		British respondents (N=312)	
	Number	Percentage (%)	Number	Percentage (%)
Age				
18-24 years	33	6.82	44	14.10
25-34 years	269	55.58	57	18.27
35-44 years	141	29.13	51	16.35
45-54 years	28	5.78	62	19.87
55-64 years	9	1.86	57	18.27
More than 65 years	4	0.83	41	13.14
Gender				
Male	233	48.14	149	47.76
Female	251	51.86	163	52.24
Other	0	0.00	0	0.00
Prefer not to say	0	0.00	0	0.00
Household income				
Low income	19	3.93	72	23.08
Middle income	420	86.78	203	65.06
High income	40	8.26	25	8.01
Prefer not to say	5	1.03	12	3.85
Education level				
Primary school	0	0.00	1	0.32
Middle school	1	0.21	10	3.21
High school	20	4.13	156	50.00
Bachelor's degree	422	87.19	82	26.28
Master's degree	40	8.26	42	13.46
Doctorate or professional degree	0	0.00	14	4.49
Prefer not to say	1	0.21	7	2.24

N: Sample size.

Table 4.1. Continued.

Demographics	Chinese respondents (N=484)		British respondents (N=312)	
	Number	Percentage (%)	Number	Percentage (%)
Household size				
1	5	1.03	77	24.68
2	14	2.89	96	30.77
3	266	54.96	62	19.87
4	96	19.84	47	15.07
5+	101	20.87	25	8.01
Prefer not to say	2	0.41	5	1.60
Experience in scanning QR codes				
Yes	477	98.55	275	88.14
No	6	1.24	32	10.26
I do not remember	1	0.21	5	1.60
Frequency of scanning QR codes				
Never	6	1.24	32	10.26
Less than once a month	34	7.02	151	48.40
Several times a month	113	23.35	91	29.16
Every week	175	36.16	32	10.26
Daily	156	32.23	6	1.92
Experience in scanning QR codes on food packages				
Yes	420	86.78	145	46.47
No	47	9.71	130	41.67
I do not remember	17	3.51	37	11.86

N: Sample size.

Considering the advantages and disadvantages of structural equation modeling and artificial neural networks, a hybrid model is widely popular and has been applied in exploring the adoption of new technologies (Ala'a et al., 2024; Yin et al., 2023). To be specific, structural equation modeling is used to validate the proposed model, and significant variables derived from structural equation modeling are used as the input units to the artificial neural networks, which captures their complex nonlinear relationships and assesses the relative importance of each variable (Sternad Zabukovšek et al., 2019). A deep artificial neural network with two hidden layers was used (Hong et al., 2017). Choosing an appropriate activation function and the number of nodes in the hidden layer is an important consideration. The Sigmoid function was employed in the hidden and output layers due to its superior performance (Rane et al., 2024). All inputs and outputs were normalized to the range of [0, 1] to retain the original features of the data and improve model performance (Li et al., 2023). The indicator root mean square of error (RMSE) is used to measure the accuracy of artificial neural network models (Namasudra et al., 2023). The cross-validation methods with a 9:1 ratio for training and testing the collected data were applied to reduce overfitting in the artificial neural network model (Liébana-Cabanillas et al., 2017). The prediction accuracy of the artificial neural network model was evaluated by calculating the RMSE for the 10 networks. AMOS 21 and SPSS Statistics 28.0 were used to construct the structural equation modeling and artificial neural network model and conduct confirmatory factor analysis.

4.4 Results

4.4.1 Measurement model

Pearson correlations among the variables were shown in **Supplementary Fig. S4.1**. The results showed that most variables were significantly correlated, supporting the appropriateness of the proposed structural model.

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was evaluated to assess the suitability of the data for factor analysis. As shown in **Table 4.2**, all scales had a Cronbach's α value above 0.5 ensuring sufficient reliability for confirmatory purposes (Ongena et al., 2020). The factor loading for each item was above 0.6, indicating a strong model (Kiyabo & Isaga, 2020).

The value of average variance extracted (AVE) for each latent variable exceeded 0.50, except that of perceived ease of use in the model of Chinese responses (0.48), while 0.36 was the threshold of AVE for acceptable convergent validity (Io et al., 2023; Yu et al., 2024), meaning that convergent validity was adequately achieved. The values of

composite reliability (CR) were above 0.7, indicating that the two structural models had good performance on internal consistency and validity (Albahri et al., 2021).

Discriminant validity indicated the degree to which the measures of a specific construct were distinct from the measures of other constructs within the same model (Ausawanetmanee et al., 2024). As shown in **Fig. 4.2**, for models based on Chinese and British responses, all the variables had a positive correlation. The square root of AVE shown along the diagonal for each variable was greater than its correlation coefficients with other variables, meaning that the model demonstrated decent discriminant validity. Thus, the structural model was statistically acceptable.

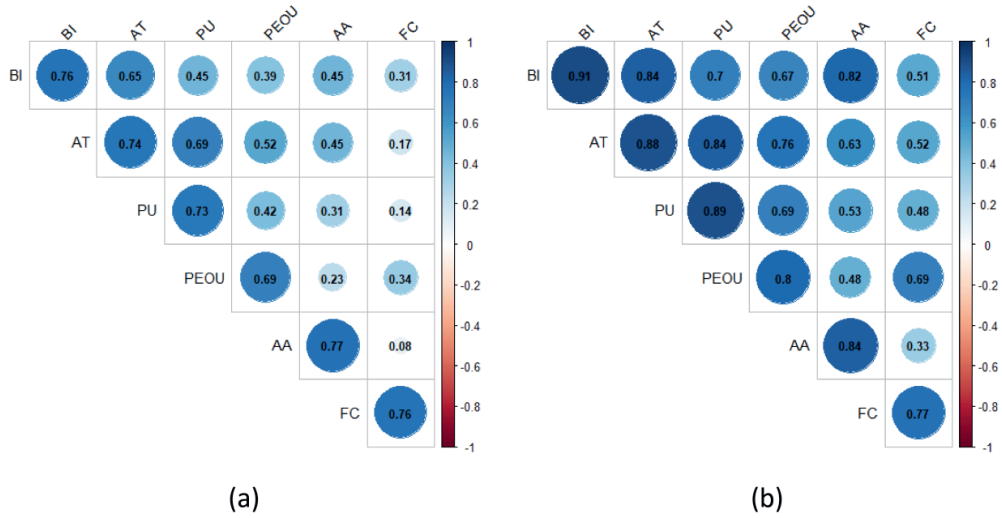


Fig. 4.2. The result of discriminant validity for models based on a) Chinese responses and b) British responses. The size and intensity of the circles indicated the level of the correlation. BI: behavioral intention, AT: attitude, PU: perceived usefulness, PEOU: perceived ease of use, AA: authenticity awareness, FC: facilitating conditions.

Various model fit indices and their criteria were used to assess the model's goodness-of-fit with the given dataset. The indices were primarily influenced by sample size, so no unified standards existed (Pejić Bach et al., 2023); however, some ideal and acceptable standards recognized by most of the studies are listed in **Table 4.3**.

Table 4.2. Measurement questions and descriptive statistics of variables.

Variables/Scale items	Source	Chinese responses						British responses					
		ñ	SD	Ld.	α	CR	AVE	ñ	SD	Ld.	α	CR	AVE
BI													
1. Assuming I have access to the authentication QR codes on food packaging, I intend to use it.	Venkatesh & Bala (2008)	4.20	0.55	0.81	0.58	0.74	0.58	3.29	0.88	0.91	0.83	0.91	0.83
2. Assuming I have access to the authentication QR codes on food packaging, I predict I would use it.		4.26	0.59	0.72				3.32	0.96	0.92			
AT													
1. The use of QR codes for food authentication is a good idea.	Bashir (2022)	4.36	0.61	0.73	0.71	0.78	0.54	3.95	0.84	0.87	0.76	0.91	0.78
2. I am positive about QR codes for food authentication.		4.34	0.62	0.76				3.82	0.86	0.76			
3. I like the idea of a QR code for food authentication.		4.25	0.66	0.73				3.84	0.92	0.92			
PU													
1. I find using QR codes for food authentication to be advantageous.	Ausawanetmanee et al. (2024)	4.25	0.66	0.70	0.70	0.77	0.53	3.56	0.94	0.89	0.76	0.92	0.80
2. I find using QR codes for food authentication to be useful.		4.24	0.63	0.72				3.70	1.01	0.92			
3. I find the reward of using QR codes for food authentication to be high.		3.96	0.67	0.77				3.36	1.07	0.87			

BI: behavioral intention, AT: attitude, PU: perceived usefulness, PEOU: perceived ease of use, AA: authenticity awareness, FC: facilitating conditions, ñ: mean, SD: standard deviation, Ld.: loading, α: Cronbach's α, CR: composite reliability, AVE: average variance extracted.

Table 4.2. Continued.

Variables/Scale items	Source	Chinese responses						British responses					
		ñ	SD	Ld.	α	CR	AVE	ñ	SD	Ld.	α	CR	AVE
PEOU													
1. I find the QR codes for food authentication to be easy to use.	Bashir (2022); Venkatesh & Bala (2008)	4.40	0.56	0.70	0.68	0.73	0.48	3.87	0.90	0.83	0.72	0.84	0.64
2. It is easy to learn how to authenticate food products by using authentication QR codes.		4.42	0.56	0.74				3.91	0.85	0.79			
3. Acquiring food authentication information by using authentication QR codes requires minimal effort.		4.30	0.59	0.62				3.89	0.90	0.77			
AA													
1. I often check the authenticity of food products I intend to buy.	Zhao et al. (2024)	4.13	0.81	0.70	0.71	0.81	0.60	2.87	1.13	0.80	0.73	0.87	0.70
2. I often try to find the authenticity information of food products.		4.14	0.68	0.84				2.95	1.20	0.91			
3. I think it is necessary to authenticate food products before purchase.		4.25	0.64	0.77				3.25	1.08	0.80			
FC													
1. I have the devices (e.g. smartphones) necessary to use the authentication QR codes.	Koay & Ang (2024); Liang et al. (2022)	4.61	0.49	0.78	0.70	0.80	0.57	4.32	0.93	0.79	0.70	0.82	0.60
2. There is Internet connectivity available to the device to use the authentication QR codes.		4.59	0.50	0.80				4.21	0.97	0.77			
3. I have the knowledge necessary to use an authentication QR code.		4.44	0.54	0.69				4.18	0.97	0.77			

BI: behavioral intention, AT: attitude, PU: perceived usefulness, PEOU: perceived ease of use, AA: authenticity awareness, FC: facilitating conditions, ñ: mean, SD: standard deviation, Ld.: loading, α: Cronbach's α, CR: composite reliability, AVE: average variance extracted.

The CMIN/df (Chi-square mean/degrees of freedom) of the two models were 1.82 and 2.82, lower than 3.0; the Root Mean Square Error of the Approximation (RMSEA) were 0.04 and 0.08, lower than 0.1; the Goodness of Fit Index (GFI), Normed Fit Index (NFI), Comparative Fit Index (CFI), and Incremental Fit Index (IFI) were above 0.9; Adjusted Goodness of Fit Index (AGFI) were above 0.8. The results implied that the two models, based on Chinese and British responses, demonstrated a good fit, although not all indicators have reached the ideal level.

Overall, the structural models have met all of the required discriminant and convergent validity standards.

4.4.2 Structural model

Paths between two latent variables were interpreted as standardized weights, and the statistical significance of each path coefficient was measured using t-tests. The results of the analysis for the proposed model are shown in **Fig. 4.3**.

The results of the study support all the proposed relationships in the structural model (**Fig. 4.1**) based on the Chinese and British responses. structural equation modeling analysis for Chinese responses indicated that perceived usefulness had a statistically significant effect on attitude (β=0.575), while attitude had a statistically significant effect on authenticity awareness, as well as the variable behavioral intention (β=0.52). It was worth noting that authenticity awareness and facilitating conditions significantly influenced behavioral intention, although the impact was relatively weak with standardized coefficients just above 0.2. For British responses, the effect of facilitating conditions on behavioral intention was statistically significant at the 5% level but was relatively weak, with a standardized coefficient of 0.098.

Indirect effects were analyzed to assess the role of perceived usefulness in the relationship between perceived ease of use and attitude, as well as the role of authenticity awareness between attitude and behavioral intention. The findings, presented in **Table 4.4**, showed that none of the indirect effects confidence intervals contained zero, meaning that indirect effects of two paths existed. A higher level of perceived ease of use increased perceived usefulness, which in turn had a positive effect on consumers' attitude toward authentication QR codes. Moreover, a higher level of attitude enhanced authenticity awareness, subsequently positively influencing behavioral intention to use authentication QR codes. Given that both direct, indirect, and total effects were significant, partial mediation occurred in perceived usefulness between perceived ease of use and attitude, as well as authenticity awareness between attitude and behavioral intention.

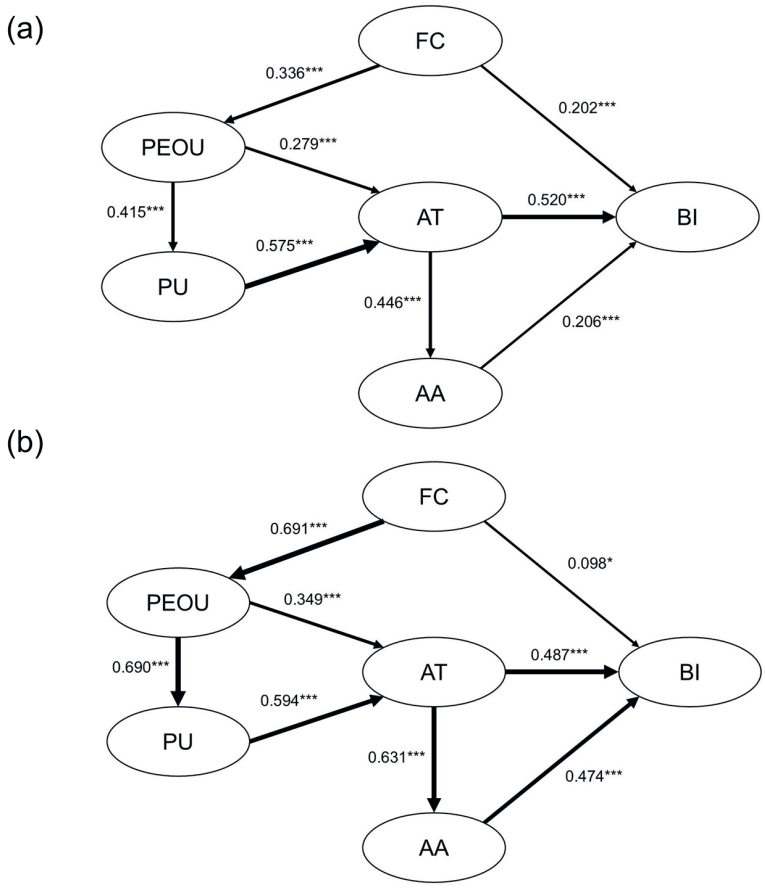


Fig. 4.3. Results of the structural model based on a) Chinese responses and b) British responses. * $p < .05$, *** $p < .001$. The thickness of the arrows between two variables corresponds to the standardized path coefficients. BI: behavioral intention, AT: attitude, PU: perceived usefulness, PEOU: perceived ease of use, AA: authenticity awareness, FC: facilitating conditions.

4.4.3 Multigroup analyses

The data from Chinese and British responses are combined, and subgroups are defined by gender and nationality and treated as single homogeneous groups. This enables to gain insight into group differences and the moderating effect of these two variables on structural path coefficients. Genders and nationality are dichotomous categorical variables: gender was classified as male or female, while nationality was categorized as Chinese or British. The structural model was estimated separately for each subgroup, including assessments of path coefficients and their statistical significance. The results are presented in **Table 4.5**.

The results indicate that all path coefficients are statistically significant in both the full sample and within each subgroup. For genders, no statistically significant differences were observed between male and female respondents across any of the structural paths, suggesting that gender does not moderate the relationships among the variables in the model. However, subgroup analysis revealed several statistically significant differences in path coefficients between Chinese and British responses. Specifically, significant differences were found in the following paths: perceived ease of use → perceived usefulness, attitude → authenticity awareness, authenticity awareness → behavioral intention, and facilitating conditions → perceived ease of use. These findings suggest that nationality moderates these four relationships.

4.4.4 Artificial Neural Networks model

Based on the verified hypotheses in the structural model (**Fig. 4.1**), two separate artificial neural network models were constructed: in Model 1, perceived usefulness and perceived ease of use were specified as inputs while attitude was the output; in Model 2, attitude, authenticity awareness, and facilitating conditions were input to predict behavioral intention.

The average RMSE values of the artificial neural network model 1 of Chinese responses were 0.0771 (SD=0.0027) on the training sets and 0.0749 (SD=0.0056) on the testing sets, meaning the results were relatively accurate. The average RMSE values of the artificial neural network model 2 were 0.0801 (SD=0.0037) for training sets and 0.0741 (SD=0.0090) for testing sets. In addition, the average RMSE values were 0.0914 (SD=0.0052) in the training phase and 0.0897 (SD=0.0226) in the testing phase for model 1 of British responses. In model 2, the average RMSE for the training model was 0.0855 (SD=0.0052) while the testing model was 0.0760 (SD=0.0189). The results of ten individual artificial neural network models are presented in **Supplementary Table S4.1**. The artificial neural network models exhibited high prediction accuracy, showing low average RMSE on both training and testing datasets. Thus, the artificial neural network model was regarded as reliable in capturing the numerical relationships between inputs and outputs.

The importance of a predictor reflected the extent to which the network's predicted value varies with different predictor values. Normalized importance values were determined by dividing each importance value by the highest importance value and expressing it as a percentage, allowing for an examination of the contribution of each predictor (Chong, 2013; Zhao et al., 2024).

Table 4.3. Results of fit indexes and their threshold.

	Absolute fit index			**Incremental relative fit index**			**Parsimonious index**
	CMIN/df	RMSEA	GFI	NFI	CFI	IFI	AGFI
Ideal threshold	≤3.0	≤0.08	≥0.9	≥0.9	≥0.9	≥0.9	≥0.9
References	Yan et al. (2023)	Yan et al. (2023)	Dash & Paul (2021)	Yan et al. (2023)	Yan et al. (2023)	Yan et al. (2023)	Yan et al. (2023)
Acceptable threshold	≤5.0	≤0.10	≥0.8	≥0.8	≥0.8	≥0.8	≥0.8
References	Dash & Paul (2021)	Polanco-García et al. (2021)	Yan et al. (2023)	Chen et al. (2024)	Chen et al. (2024)	Chen et al. (2024)	Tseng et al. (2022)
Value (Chinese responses)	1.82	0.04	0.95	0.93	0.97	0.97	0.93
Value (British responses)	2.82	0.08	0.90	0.93	0.95	0.95	0.86

CMIN/df: Chi-square mean/degrees of freedom, RMSEA: Root Mean Square Error of the Approximation, GFI: Goodness of Fit Index, NFI: Normed Fit Index, CFI: Comparative Fit Index, IFI: Incremental Fit Index, GFI: Goodness of Fit Index, AGFI: Adjusted Goodness of Fit Index.

Table 4.4. Evaluation of indirect effects.

Path	Effect	Chinese responses			British responses		
		Standardized coefficients β	Bias-corrected 95% CI		Standardized coefficients β	Bias-corrected 95% CI	
			Lower	Upper		Lower	Upper
PEOU→PU →AT	Indirect effects	0.239	0.155	0.335	0.410	0.331	0.499
	Total effects	0.517	0.387	0.645	0.759	0.684	0.824
AT→AA→BI	Indirect effects	0.092	0.044	0.155	0.300	0.222	0.390
	Total effects	0.612	0.489	0.727	0.787	0.703	0.856

BI: behavioral intention, AT: attitude, PU: perceived usefulness, PEOU: perceived ease of use, AA: authenticity awareness, CI: confidence interval.

Table 4.5. The results of multigroup analysis for path coefficients between groups by gender and nationality.

Path	Standardized coefficients	Standardized coefficients between groups by gender			Standardized coefficients between groups by nationality		
	Full sample (N=796)	Male (N=382)	Female (N=414)	*p* value	Chinese (N=484)	British (N=312)	*p* value
PEOU → PU	0.675***	0.694***	0.665***	0.205	0.415***	0.690***	**0.007**
PU→AT	0.619***	0.615***	0.617***	0.358	0.575***	0.594***	0.989
PEOU → AT	0.318***	0.341***	0.295***	0.602	0.279***	0.349***	0.613
AT→BI	0.438***	0.441***	0.427***	0.880	0.520***	0.487***	0.861
AT→AA	0.665***	0.678***	0.653***	0.685	0.446***	0.631***	**0.028**
AA→BI	0.473***	0.477***	0.473***	0.814	0.206***	0.474***	**0.000**
FC→ PEOU	0.615***	0.617***	0.625***	0.238	0.336***	0.691***	**0.000**
FC→BI	0.141***	0.136***	0.153***	0.359	0.202***	0.098*	0.083

* $p < .05$, *** $p < .001$, meaning the standardized coefficients were statistically significant at the 5% or 1‰ level. BI: behavioral intention, AT: attitude, PU: perceived usefulness, PEOU: perceived ease of use, AA: authenticity awareness, FC: facilitating conditions, N: sample size. The *p* values reflect the level of statistical significance between two subgroups, with values below 0.05 indicating statistically significant differences. All *p* values below 0.05 have been highlighted in bold.

For Chinese responses, in the artificial neural network model 1, the factor perceived usefulness was found to be twice as important as perceived ease of use (normalized importance 50%) in influencing attitude. In Model 2, the most significant factor in predicting behavioral intention was attitude, followed by authenticity awareness with 71% normalized importance and facilitating conditions with 34% relative importance. For model 1 of British responses, it was found that perceived usefulness was the most important factor of attitude, while the normalized importance of perceived ease of use was 73%. In Model 2, the order of importance towards behavioral intention in descending order was attitude, followed by authenticity awareness (92%) and facilitating conditions (27%). The results of the sensitivity analysis for two artificial neural network models based on Chinese and British responses are provided in **Supplementary Table S4.2**.

4.4.5 Food types

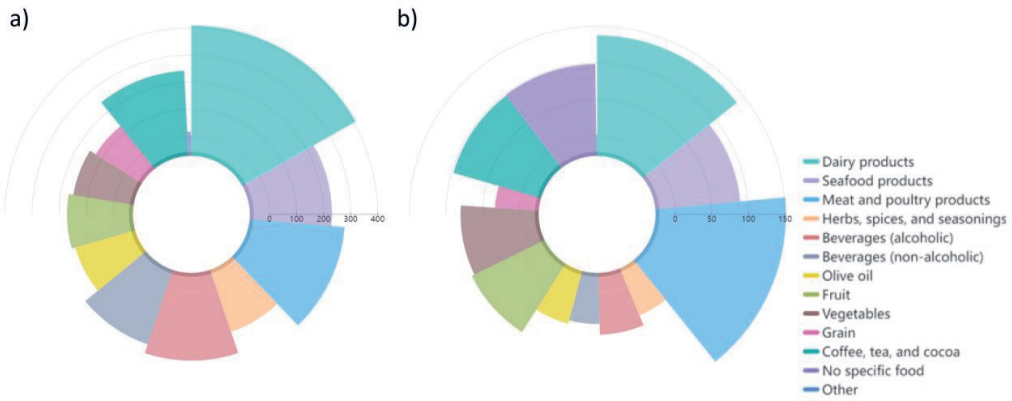


Fig. 4.4. The quantity and proportion of each food category mentioned by a) Chinese responses and b) British responses. Varying arc lengths and radians for each food type show the quantity and proportion of items appearing in the responses, respectively.

The quantity and proportion of food types arising in the minds of the respondents while filling out the questionnaire are shown in **Fig. 4.4**. In the responses from China, dairy products (17%) and meat and poultry products (12%) were the most frequently mentioned food categories that came to respondents' minds when filling out the questionnaire. These were followed by alcoholic beverages (10%), coffee, tea, and cocoa (10%), seafood products (10%), and non-alcoholic beverages (9%). Other food categories were also mentioned to some extent. Only 18 participants did not consider any food category. Dairy products (14%) and meat and poultry products (16%) were also the most common food categories arising in the British respondents' minds, although their rank varied compared to Chinese responses. Next were coffee, tea, and

cocoa (10%), seafood products (9%), fruit (9%), and vegetables (8%). The remaining food categories were below 6% for Chinese and British. It was worth noting that 101 responses mentioned that no food category was considered.

4.5 Discussion

4.5.1 Overview of results and their modelled relations

There were similarities and differences between Chinese and British consumers' responses to the intention to use authentication QR codes based on the results of the SEM-ANN model. The hybrid model based on the expanded technology acceptance model has shown satisfactory levels of explanatory power concerning both Chinese and British consumers' behavioral intentions to use authentication QR codes. These effects between variables are positive and significant, and as a result, all the hypotheses are supported by Chinese and British responses.

The model has also explained how perceived usefulness and perceived ease of use have shaped consumers' attitudes towards authentication QR codes, as attitude is one of the most important factors of intention (**Fig. 4.3**). To be specific, among direct paths to attitude, perceived usefulness was influenced the most (β=0.575 and 0.594), followed by perceived ease of use (β=0.279 and 0.349). The artificial neural network models showed the same results, and the relative importance of perceived ease of use on attitude was 50% for Chinese responses and 73% for British responses (**Table 4.7**). This indicates that perceived usefulness has a greater impact on Chinese and British consumers' attitudes towards authentication QR codes than perceived ease of use.

The SEM-ANN model results revealed that attitude had the strongest influence on consumers' behavioral intention to use authentication QR codes, followed by authenticity awareness and facilitating conditions. The rank of importance of attitude, authenticity awareness, and facilitating conditions is the same for both Chinese and British responses. However, some minor differences were observed. Compared to Chinese consumers, authenticity awareness was more influential in affecting British consumers' behavioral intention and its path coefficient (β=0.474) was slightly lower than that of attitude (β=0.487) (**Fig. 4.3**). The results of the artificial neural network model show similar findings as the normalized importance of authenticity awareness was 92%, while the normalized importance of attitude was 100% (**Table 4.7**). This indicates that British consumers with higher authenticity awareness are more likely to have the intention to use authentication QR codes. In addition, for British responses, the path coefficient of the hypothesis that facilitating conditions positively impact behavioral intention is 0.098 ($p < 0.05$), meaning that facilitating conditions have a slightly significant impact on British consumers' intention to use authentication QR

codes. Penetration rates of smartphones in China and the UK in 2022 were 68% and 82%, meaning that most British consumers have the tool to scan QR codes (Statista, 2022). High penetration rates of smartphones in the UK highlight the widespread access to mobile internet, digital services, and mobile-based applications, which reduces the constraint of facilitating conditions on behavioral intention. The accessibility of facilitating conditions may be taken for granted by British consumers, so facilitating conditions are not taken into consideration as a vital influencing factor of behavioral intention.

A noteworthy result is the finding that the TAM-based hypotheses (H1 to H4) were all supported by our data (**Fig. 4.3**), which is in line with other studies regarding the intention to use various types of QR codes (Ausawanetmanee et al., 2024; Bashir, 2022; Kim & Woo, 2016). Specifically, the findings of the study corroborate those of Kim and Woo (2016) and Bashir (2022), who found that perceived ease of use was critical in determining perceived usefulness. Higher perceived ease of use can enhance the value of technology, while lower perceived ease of use may mask the advantages of the technology itself.

The importance of perceived usefulness on attitude (H2) is confirmed, which aligns with prior technology acceptance model research (Ausawanetmanee et al., 2024). Authentication QR codes on food packages is considered an innovative technology, its usefulness is closely related to its advantages. A previous study showed that the most important reason why consumers do not scan QR codes is that the majority of consumers are unaware of the usefulness of QR codes (Liu et al., 2018). The possibility of consumers adopting QR codes depends to some extent on the sense of gratification they obtain by using it (Higgins et al., 2014). Only if the useful information is linked to the QR code, the consumer's information needs can be satisfied and their experience of scanning can be improved substantially (Li et al., 2024). When consumers lack the understanding of, or familiarity with, QR codes, they will ignore the technology (Yang et al., 2022).

Perceived ease of use is a key factor in determining attitude (H3), which is also supported by previous studies about the intention to use novel technology (Ausawanetmanee et al., 2024; Bashir, 2022). The previous design (Luo et al., 2024) demonstrates that perceived ease of use is equivalent to the user-friendly design of the system. Consumers will be attracted to the authentication QR code to some extent if it is not complicated. Authentication QR codes remain a relatively innovative technology in the food sector, and most food companies are still in the early stage of implementation of such tools (Li et al., 2024), while consumers may delay supporting such a new technology due to their concerns with the complexity of the operation.

Consistent with previous research findings, attitude is one of the most influential factors in the behavioral intention to use technology in the original technology acceptance model (Bradford et al., 2022). It means that, once the consumers develop a positive attitude toward authentication QR codes, the behavioral intention to use it will follow. It also reflects the importance of attitude on behavioral intention. Spence et al. (2018) found that attitude towards a specific technology had the strongest relationship and was the main factor of intention, which is consistent with the findings of this study. In detail, compared to authenticity awareness and facilitating conditions, the attitude has a more significant impact on behavioral intention with high path coefficients and importance.

The findings also show that attitude positively impacts authenticity awareness, meaning that the hypothesis that attitude toward using positively impacts authenticity awareness is supported. Once consumers have a positive attitude toward authentication QR codes and regard it as a reliable technology to acquire food authenticity information, their awareness of authenticity will be enhanced. The consumers' positive perception of authentication QR codes may deepen their understanding of food authentication and foster their engagement, trust, and habit of authenticating food products. Furthermore, the confirmation of H6 shows that consumers with higher authenticity awareness are more inclined to use authentication QR codes. Consumers have been shown to pay more attention to product authenticity due to their concerns about health, disappointment risk, and integrity (Hamelin et al., 2013). Various studies have indicated that consumers have a high willingness to use a device to self-authenticate food, especially when they distrust the information on food packages itself (Charlebois et al., 2016; Kendall et al., 2019).

The findings of this study also support hypotheses H7 and H8, that facilitating conditions have a positive effect on perceived ease of use and behavioral intention. Acceptance of hypothesis H8 aligns with the results of Liang (2022) who demonstrates that facilitating conditions will positively influence consumers' intention to use a new technology. Yang et al. (2022) proposed that the facilitating conditions play an essential role in the intention to use QR codes among consumers, which aligns with this study’s findings. The more accessible the facilitating conditions, the stronger the behavioral intention to adopt a technology (Madan & Yadav, 2016). A previous study by Li and Messer (2019) showed that in an artificial marketplace selling oysters, only 1.2% of participants used their own devices to scan QR code labels. The proportion increased to 52.6% once a QR-scanning smartphone was provided for free access. Access to an internet connection is essential for consumers to obtain food authenticity information by scanning authentication QR codes. Providing free internet access can encourage consumers to use their mobile devices in retail stores (Reyes-Menendez et al., 2018).

However, the conclusion of this study contradicts Koay's (2024) assertion that facilitating conditions are not a vital factor in the consumers' intention to use QR codes in a restaurant menu. The possible reason for different findings is that WiFi services provided by the majority of restaurants and the popularity of smartphones always ensure the widespread accessibility of essential resources for consumers scanning QR codes in restaurants (Saranya et al., 2016).

4.5.2 Food type influence

Dairy products and meat and poultry products are the two main food types appearing in the respondents' minds when they fill out the questionnaire. They are also the typical food categories that are considered the most susceptible to fraud (Hong et al., 2017). Differences in per capita consumption and historical food safety incidents between China and the UK may lead to different levels of attention toward different food types (Jin et al., 2023). Dairy products are a significant food category in both China and the UK and have been subject to fraud in the past (Handford et al., 2016; Jin et al., 2023). Compared to British respondents, Chinese respondents consider dairy products more frequently than meat and poultry products. The adulteration of milk with Melamine is one of the most infamous food safety incidents in China, which as a result, evokes consumers' profound risk awareness and lasting concerns about dairy products (Li et al., 2021). Both Chinese and British consumers attach great importance to the safety and quality of meat products (Parrott & Walley, 2017). Foot and Mouth crisis (Chanchaidechachai et al., 2021) in 2001 and the Horsemeat scandal (Barnett et al., 2016) in 2013 amplified British consumers' concerns about meat authenticity, while the outbreak of H7N9 Avian Flu (Shi et al., 2023) in China also triggered the consumers' distrust of meat authenticity. The Food Standards Scotland's Scottish Food Crime and Incidents Unit (SFCIU), alongside a joint UK Food Crime Strategic Assessment with the Food Standards Agency's (FSA) National Food Crime Unit, have considered meat being targeted by food fraudsters and assessed it as high risk (Brooks et al., 2021). Alcoholic beverages, non-alcoholic beverages, coffee, tea, and cocoa, seafood products, fruit, and vegetable are the most common types of food reported in counterfeit incident reports in the Decernis Food Fraud Databases (Decernis, 2021). The incidents make consumers aware of food safety threats, leading them to prefer authentic foods that offer quality and safety assurances.

The types of food that appear in consumers' minds when filling out questionnaires to some extent reflect their belief regarding the food types that should be attached with authentication QR codes. These results imply that it makes sense to equip authentication QR codes on the packages of all these food types. Among them, meat

and poultry products and dairy products may be the product types that should equip authentication QR codes the most.

4.5.3 Research implications

QR code authentication serves as a novel tool in the fight against food fraud, addressing the growing consumer demand for food authenticity. By providing a direct and easily accessible way to verify the authenticity of food products, this technology can help consumers make informed decisions about food purchases. To expand its adoption, the factors influencing consumers' behavioral intention to use authentication QR codes are explored in this study. Insights into these factors allow technology developers in food companies to optimize QR code-based authentication systems, ensuring they align with consumer preferences, usability expectations, and authentication requirements. This study offers several practical implications for actors aiming to promote the use of authentication QR codes in the food sector. Firstly, the user-friendly system enables quick and accessible adoption of authentication QR codes, as consumers can effectively access and utilize the information linked to the authentication QR code. Secondly, food companies should adopt a focused marketing strategy to promote the usefulness of authentication QR codes to potential users while simultaneously refining the authentication mechanism to ensure the reliability and accuracy of the information provided, thereby enhancing their practical value. Furthermore, raising consumers' awareness of food authenticity is an important approach to promoting the use of authentication QR codes. By leveraging these insights, companies can introduce incentives to increase consumer engagement with authentication tools. Such measures can not only boost the frequency and likelihood of use but also enhance authenticity awareness and cultivate the consumers' habit of authenticating food, which transforms consumers into active participants in safeguarding the integrity of the food supply chain.

4.5.4 Research limitations

The limitations of this study should be taken into account when interpreting its results. Firstly, all respondents completed the questionnaire online, with many using their mobile phones, suggesting that a considerable number had access to a scanning tool and internet connection. This factor may have influenced the results to some extent, but this was unavoidable. Secondly, a multi-method research approach can be used in future studies, including interviews and observations, to explore in-depth the reasons affecting consumers' intention to use authentication QR codes. Additionally, this study used a cross-sectional design, aiming to explore the correlations among various key variables. The future research can draw causal effects by incorporating a time dimension into a randomized experimental design to better capture how consumer

perception and intentions on authentication QR codes change over time. Lastly, although this study incorporated data from both China and the United Kingdom to enhance the robustness and generalizability of the findings, extending the results to other national contexts still needs to be carefully treated. Before promoting the technology in additional countries, it is essential to prioritize an understanding of local consumers' perceptions and behaviors to ensure that the advantages can be fully recognized and effectively leveraged in various contexts.

4.6 Conclusions

Following a comprehensive theoretical analysis, five variables (attitude, perceived usefulness, perceived ease of use, authenticity awareness, and facilitating conditions) were proposed that may influence behavioral intention to use authentication QR codes, with eight hypotheses. The factors of behavioral intention to use authentication QR codes include basic technology acceptance model constructs, extended with two variables of authenticity awareness and facilitating conditions. The study tested the hypotheses regarding consumers' intention to scan the authentication QR codes on food packages based on Chinese and British responses. Two methods, including structural equation modeling and artificial neural networks, were conducted for hypotheses evaluation and provided in-depth and comprehensive insights in these relations. Based on the results of the structural equation modeling, all the hypotheses were validated. The results show that perceived usefulness and perceived ease of use are important factors influencing consumers' attitudes towards authentication QR codes, and to use the tool. The results of the ANN models show that the variables have a nonlinear relationship. perceived usefulness is the main factor influencing attitude, which influenced most of the intention to use authentication QR codes.

The study provides evidence-based insights into factors improving consumers intention to use authentication QR codes. Understanding these factors can help food enterprises effectively position the authentication QR code as a value-adding feature in food packaging. Understanding these factors can help food enterprises effectively position authentication QR codes as a value-adding feature in food packaging, and the cross-regional approach also offers practical implications for global brands aiming to implement the technology in diverse markets.

The major contribution of this study lies in its integrated methodological approach and theoretical extension of the TAM framework, offering both practical value on authentication QR code promotion. By identifying key drivers of technology adoption in food authentication, the study supports the development of targeted strategies to increase consumer engagement with authentication tools, ultimately supporting food authenticity and supply chain integrity.

References

Abdullah, F., Ward, R., & Ahmed, E. (2016). Investigating the influence of the most commonly used external variables of TAM on students' Perceived Ease of Use (PEOU) and Perceived Usefulness (PU) of e-portfolios. *Computers in Human Behavior*, *63*, 75-90. https://doi.org/10.1016/j.chb.2016.05.014

Ahmmadi, P., Rahimian, M., & Movahed, R. G. (2021). Theory of planned behavior to predict consumer behavior in using products irrigated with purified wastewater in Iran consumer. *Journal of Cleaner Production*, *296*, 126359. https://doi.org/10.1016/j.jclepro.2021.126359

Ala'a, M., Ramayah, T., & Al-Sharafi, M. A. (2024). Exploring the impact of cybersecurity on using electronic health records and their performance among healthcare professionals: A multi-analytical SEM-ANN approach. *Technology in Society*, *77*, 102592. https://doi.org/10.1016/j.techsoc.2024.102592

Albahri, A. S., Alnoor, A., Zaidan, A. A., Albahri, O. S., Hameed, H., Zaidan, B. B., Peh, S. S., Zain, A. B., Siraj, S. B., Alamoodi, A. H. & Yass, A. A. (2021). Based on the multi-assessment model: towards a new context of combining the artificial neural network and structural equation modeling: a review. *Chaos, Solitons & Fractals*, *153*, 111445. https://doi.org/10.1016/j.chaos.2021.111445

Ausawanetmanee, P., Thavorn, J., Chandrachai, A., Klongthong, W., Vchirawongwin, V., & Ekgasit, S. (2024). Consumer acceptance of an innovative Bio-QR code traceability system for edible bird's nest. *Journal of Open Innovation: Technology, Market, and Complexity*, *10*(1), 100169. https://doi.org/10.1016/j.joitmc.2023.100169

Barnett, J., Begen, F., Howes, S., Regan, A., McConnon, A., Marcu, A., Rowntree, S., & Verbeke, W. (2016). Consumers' confidence, reflections and response strategies following the horsemeat incident. *Food Control*, *59*, 721-730. https://doi.org/10.1016/j.foodcont.2015.06.021

Bashir, H. (2022). Leveraging technology to communicate sustainability-related product information: Evidence from the field. *Journal of Cleaner Production*, *362*, 132508. https://doi.org/10.1016/j.jclepro.2022.132508

Brigante, F. I., Mas, A. L., Erban, A., Fehrle, I., Martinez-Seidel, F., Kopka, J., Wunderlin, D. A. & Baroni, M. V. (2022). Authenticity assessment of commercial bakery products with chia, flax and sesame seeds: Application of targeted and untargeted metabolomics results from seeds and lab-scale cookies. *Food Control*, *140*, 109114. https://doi.org/10.1016/j.foodcont.2022.109114

Bradford, H., McKernan, C., Elliott, C., & Dean, M. (2022). Consumer purchase intention towards a quick response (QR) code for antibiotic information: an exploratory study. *npj Science of Food*, *6*(1), 23. https://doi.org/10.1038/s41538-022-00136-4

Brooks, C., Parr, L., Smith, J. M., Buchanan, D., Snioch, D., & Hebishy, E. (2021). A review of food fraud and food authenticity across the food supply chain, with an examination of the impact of the COVID-19 pandemic and Brexit on food industry. *Food Control*, *130*, 108171. https://doi.org/10.1016/j.foodcont.2021.108171

Çakıt, E., Karwowski, W., Murata, A., & Olak, A. J. (2020). Application of structural equation modeling (SEM) and an adaptive neuro-fuzzy inference system (ANFIS) for assessment of safety culture: An integrated modeling approach. *Safety*, *6*(1), 14. https://doi.org/10.3390/safety6010014

Chanchaidechachai, T., de Jong, M. C., & Fischer, E. A. (2021). Spatial model of foot-and-mouth disease outbreak in an endemic area of Thailand. *Preventive Veterinary Medicine*, *195*, 105468. https://doi.org/10.1016/j.prevetmed.2021.105468

Charlebois, S., Schwab, A., Henn, R., & Huck, C. W. (2016). Food fraud: An exploratory study for measuring consumer perception towards mislabeled food products and influence on self-authentication intentions. *Trends in Food Science & Technology*, *50*, 211-218. https://doi.org/10.1016/j.tifs.2016.02.003

Chen, Q., Liang, C., Zhao, Y., Kong, J., Zhang, H., Yan, X., & Zhang, H. (2024). The mediating role of coping styles in illness perception and self-management in patients with obstructive sleep apnea. *Sleep Medicine*, *113*, 349-356. https://doi.org/10.1016/j.sleep.2023.12.003

Chong, A. Y. L. (2013). Predicting m-commerce adoption determinants: A neural network approach. *Expert Systems with Applications*, *40*(2), 523-530. https://doi.org/10.1016/j.eswa.2012.07.068

Cook, J., Sapia, M., Walker, C., & Pittaoulis, M. (2024). Dysphagia Prevalence in Brazil, UK, China, and Indonesia and Dysphagic Patient Preferences. *Healthcare*, *12*(18), 1827. https://doi.org/10.3390/healthcare12181827

Dash, G., & Paul, J. (2021). CB-SEM vs PLS-SEM methods for research in social sciences and technology forecasting. *Technological Forecasting and Social Change*, *173*, 121092. https://doi.org/10.1016/j.techfore.2021.121092

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management Science*, *35*(8), 982-1003. https://doi.org/10.1287/mnsc.35.8.982

Decernis. (2021). Decernis' food fraud database. Retrieved from *http://decernis.com/solutions/food-fraud-database/*. Accessed on June 8, 2021

Del Rosario-Raymundo, M. R. (2017). QR codes as mobile learning tools for labor room nurses at the San Pablo Colleges Medical Center. *Interactive Technology and Smart Education*, *14*(2), 138-158. https://doi.org/10.1108/ITSE-02-2017-0015

Dwivedi, Y. K., Rana, N. P., Jeyaraj, A., Clement, M., & Williams, M. D. (2019). Re-examining the unified theory of acceptance and use of technology (UTAUT): Towards a revised theoretical model. *Information Systems Frontiers*, *21*, 719-734. https://doi.org/10.1007/s10796-017-9774-y

Food and Agriculture Organization of United Nations (FAO) & World Health Organization (WHO). Codex committee on food import and export inspection and certification systems. Discussion paper on food integrity and food authenticity, Brisbane, Australia (2018), pp. 1-7.

Food Navigator Europe. (2020). Danone on its blockchain 'first': 'Every individual baby formula pack can be traced back'. Retrieved from *https://www.foodnavigator.com/Article/2020/02/17/Danone-on-its-blockchain-first-Every-individual-baby-formula-pack-can-be-traced-back*. Accessed February 2, 2023

Gbongli, K., Xu, Y., & Amedjonekou, K. M. (2019). Extended technology acceptance model to predict mobile-based money acceptance and sustainability: A multi-analytical structural equation modeling and neural network approach. *Sustainability*, *11*(13), 3639. https://doi.org/10.3390/su11133639

Handford, C. E., Campbell, K., & Elliott, C. T. (2016). Impacts of milk fraud on food safety and nutrition with special emphasis on developing countries. *Comprehensive Reviews in Food Science and Food Safety*, *15*(1), 130-142. https://doi.org/10.1111/1541-4337.12181

Hamelin, N., Nwankwo, S., & El Hadouchi, R. (2013). 'Faking brands': consumer responses to counterfeiting. *Journal of Consumer Behaviour*, *12*(3), 159-170. https://doi.org/10.1002/cb.1406

Haykin, S. (1998). *Neural networks: a comprehensive foundation*. Prentice Hall PTR.

Higgins, L. M., Wolf, M. M., & Wolf, M. J. (2014). Technological change in the wine market? The role of QR codes and wine apps in consumer wine purchases. *Wine Economics and Policy*, *3*(1), 19-27. https://doi.org/10.1016/j.wep.2014.01.002

Hong, E., Lee, S. Y., Jeong, J. Y., Park, J. M., Kim, B. H., Kwon, K., & Chun, H. S. (2017). Modern analytical methods for the detection of food fraud and adulteration by food category. *Journal of the Science of Food and Agriculture*, *97*(12), 3877-3896. https://doi.org/10.1002/jsfa.8364

Hong, W., Thong, J. Y., Chasalow, L. C., & Dhillon, G. (2011). User acceptance of agile information systems: A model and empirical test. *Journal of management information systems*, *28*(1), 235-272. https://doi.org/10.2753/MIS0742-1222280108

HMSO. (1995). *Food safety (General food hygiene) regulations*. London: Her Majesty's Stationery Office.

Huque, S. M. R., Hossain, S. T., & Rana, M. B. (2015, October). Trustworthiness of Organic Produces in Urban Market Innovation through Quick Response (QR) Code. In *Regional Conference on Marketing & Innovation in Organic Farming*. International Federation of Organic Agriculture Movements (IFOAM) Organics International.

Io, L., Wang, Q., Wong, O. L., Li, Z., & Zhong, J. (2023). Development and psychometric properties of the Chinese invalidating family scale. *Family Process*, *62*(3), 1161-1175. https://doi.org/10.1111/famp.12818.

Jiménez-Carvelo, A. M., Li, P., Erasmus, S. W., Wang, H., & van Ruth, S. M. (2022). Spatial-temporal event analysis as a prospective approach for signalling emerging food fraud-related anomalies in supply chains. *Foods*, *12*(1), 61. https://doi.org/10.3390/foods12010061

Jin, S., Cao, Y., Jones, G., Li, W., & Frewer, L. J. (2023). Consumers' purchase intentions towards traced foods: A comparative analysis between the United Kingdom and China. *Food Control*, *152*, 109828. https://doi.org/10.1016/j.foodcont.2023.109828

Johnson, J. A., Janssen, M. F., Al Sayah, F., Bailey, H., Gandhi, M., Golicki, D., Gutacker. N., Lubetkin, E., Mulhern, B., Dermawan Purba, F., Ramos-Goñi, J. M., Scott, D., Short, H., Sullivan, T., Viney., R., Yang, Z., & Zárate, V. (2025). EuroQol data for assessment of population health needs and instrument evaluation (EQ-DAPHNIE): a study for enhancing population health assessment. *Quality of Life Research*, 1-14. https://doi.org/10.1007/s11136-025-03983-2

Kamal, S. A., Shafiq, M., & Kakria, P. (2020). Investigating acceptance of telemedicine services through an extended technology acceptance model (TAM). *Technology in Society*, *60*, 101212. https://doi.org/10.1016/j.techsoc.2019.101212

Kendall, H., Clark, B., Rhymer, C., Kuznesof, S., Hajslova, J., Tomaniova, M., Brereton, P., & Frewer, L. (2019). A systematic review of consumer perceptions of food fraud and authenticity: A European perspective. *Trends in Food Science & Technology*, *94*, 79-90. https://doi.org/10.1016/j.tifs.2019.10.005

Kim, Y. G., & Woo, E. (2016). Consumer acceptance of a quick response (QR) code for the food traceability system: Application of an extended technology acceptance model (TAM). *Food Research International*, *85*, 266-272. https://doi.org/10.1016/j.foodres.2016.05.002

Kiyabo, K., & Isaga, N. (2020). Entrepreneurial orientation, competitive advantage, and SMEs' performance: application of firm growth and personal wealth measures. *Journal of Innovation and Entrepreneurship*, *9*(1), 12. https://doi.org/10.1186/s13731-020-00123-7

Klemelä, J. (2018). Multivariate data analysis. *Nonparametric finance*, 95-120. https://doi.org/10.1002/9781119409137.ch4

Kline, R. B. (2023). *Principles and practice of structural equation modeling*. Guilford publications.

Koay, K. Y., & Ang, K. (2024). Understanding consumers' intentions to use QR code menus in the post-COVID-19 pandemic. *British Food Journal*, *126*(5), 2172-2186. https://doi.org/10.1108/BFJ-10-2023-0880

Kumar, J. A., Bervell, B., Annamalai, N., & Osman, S. (2020). Behavioral intention to use mobile learning: Evaluating the role of self-efficacy, subjective norm, and WhatsApp use habit. *IEEE Access*, *8*, 208058-208074. https://doi.org/10.1109/ACCESS.2020.3037925

Kumaraswamy, B. (2021). Neural networks for data classification. In *Artificial intelligence in data mining* (pp. 109-131). Academic Press.

Leguina, A. (2015). A primer on partial least squares structural equation modeling (PLS-SEM). *International Journal of Research & Method in Education, 38*(2), 220-221. https://doi.org/10.1080/1743727X.2015.1005806

Li, P., Yang, J., Jiménez-Carvelo, A. M., & Erasmus, S. W. (2024). Applications of food packaging quick response codes in information transmission toward food supply chain integrity. *Trends in Food Science & Technology*, 104384. https://doi.org/10.1016/j.tifs.2024.104384

Li, Q., Cheng, R., & Ge, H. (2023). Short-term vehicle speed prediction based on BiLSTM-GRU model considering driver heterogeneity. *Physica A: Statistical Mechanics and its Applications*, *610*, 128410. https://doi.org/10.1016/j.physa.2022.128410

Li, S., Wang, Y., Tacken, G. M., Liu, Y., & Sijtsema, S. J. (2021). Consumer trust in the dairy value chain in China: The role of trustworthiness, the melamine scandal, and the media. *Journal of Dairy Science*, *104*(8), 8554-8567. https://doi.org/10.3168/jds.2020-19733

Li, T., & Messer, K. D. (2019). To Scan or Not to Scan. *Journal of Agricultural and Resource Economics*, *44*(2), 311-327.

Liang, Y., Lee, S. H., & Workman, J. E. (2022). How do consumers perceive mobile self-checkout in fashion retail stores?. *International Journal of Retail & Distribution Management*, *50*(6), 677-691. https://doi.org/10.1108/IJRDM-08-2020-0299

Liébana-Cabanillas, F., Marinković, V., & Kalinić, Z. (2017). A SEM-neural network approach for predicting antecedents of m-commerce acceptance. *International Journal of Information Management*, *37*(2), 14-24. https://doi.org/10.1016/j.ijinfomgt.2016.10.008

Liu, C., Li, J., Steele, W., & Fang, X. (2018). A study on Chinese consumer preferences for food traceability information using best-worst scaling. *PloS one*, *13*(11), e0206793. https://doi.org/10.1371/journal.pone.0206793

Loebnitz, N., & Grunert, K. G. (2022). Let us be realistic: The impact of perceived brand authenticity and advertising image on consumers' purchase intentions of food brands. *International Journal of Consumer Studies*, *46*(1), 309-323. https://doi.org/10.1111/ijcs.12679

Luo, J., Ahmad, S. F., Alyaemeni, A., Ou, Y., Irshad, M., Alyafi-Alzahri, R., Alsanie, G. & Unnisa, S. T. (2024). Role of perceived ease of use, usefulness, and financial strength on the adoption of health information systems: The moderating role of hospital size. *Humanities and Social Sciences Communications*, *11*(1), 1-12. https://doi.org/10.1057/s41599-024-02976-9

Ma, C., Wu, J., Sun, H., Zhou, X., & Sun, X. (2023). Enhancing user experience in digital payments: A hybrid approach using SEM and neural networks. *Finance Research Letters*, *58*, 104376. https://doi.org/10.1016/j.frl.2023.104376

Madan, K., & Yadav, R. (2016). Behavioural intention to adopt mobile wallet: a developing country perspective. *Journal of Indian Business Research*, *8*(3), 227-244. https://doi.org/10.1108/JIBR-10-2015-0112

Mahardika, H., Thomas, D., Ewing, M. T., & Japutra, A. (2019). Experience and facilitating conditions as impediments to consumers' new technology adoption. *The International Review of Retail, Distribution and Consumer Research*, *29*(1), 79-98. https://doi.org/10.1080/09593969.2018.1556181

Man, S. S., Ding, M., Li, X., Chan, A. H. S., & Zhang, T. (2025). Acceptance of highly automated vehicles: The role of facilitating condition, technology anxiety, social influence and trust. *International Journal of Human-Computer Interaction*, *41*(6), 3684-3695. https://doi.org/10.1080/10447318.2024.2316389

Miltgen, C. L., Popovič, A., & Oliveira, T. (2013). Determinants of end-user acceptance of biometrics: Integrating the "Big 3" of technology acceptance with privacy context. *Decision support systems*, *56*, 103-114. https://doi.org/10.1016/j.dss.2013.05.010

Moreira, D. A. A., & Rodrigues, D. M. (2023). Management by Skills as a Strategic tool to Maintain Organizational Sustainability. *Revista De Gestão Social E Ambiental*, *17*(9), 1-16. https://doi.org/10.24857/rgsa.vl7n9-022

Mullins, J. K., & Cronan, T. P. (2021). Enterprise systems knowledge, beliefs, and attitude: A model of informed technology acceptance. *International Journal of Information Management*, *59*, 102348. https://doi.org/10.1016/j.ijinfomgt.2021.102348

Namahoot, K. S., & Rattanawiboonsom, V. (2022). Integration of TAM model of consumers' intention to adopt cryptocurrency platform in Thailand: the mediating role of attitude and perceived risk. *Human Behavior and Emerging Technologies*, *2022*(1), 9642998. https://doi.org/10.1155/2022/9642998

Namasudra, S., Dhamodharavadhani, S., & Rathipriya, R. (2023). Nonlinear neural network based forecasting model for predicting COVID-19 cases. *Neural Processing Letters*, 1-21. https://doi.org/10.1007/s11063-021-10495-w

Nunes, J. C., Ordanini, A., & Giambastiani, G. (2021). The concept of authenticity: What it means to consumers. *Journal of Marketing*, *85*(4), 1-20. https://doi.org/10.1177/0022242921997081

Ongena, Y. P., Haan, M., Yakar, D., & Kwee, T. C. (2020). Patients' views on the implementation of artificial intelligence in radiology: development and validation of a standardized questionnaire. *European radiology*, *30*, 1033-1040. https://doi.org/10.1007/s00330-019-06486-0

Parhi, R., & Nowak, R. D. (2020). The role of neural network activation functions. *IEEE Signal Processing Letters*, *27*, 1779-1783. https://doi.org/10.1109/LSP.2020.3027517

Parrott, P., & Walley, K. (2017). Consumer Attitudes to Poultry Meat: A Comparative Study of the UK and China. In *Poultry Quality Evaluation* (pp. 313-334). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-100763-1.00013-1

Peak. (2019). Tracking technology now ensures your Champagne will be genuine. Retrieved from *https://www.thepeakmagazine.com.sg/gourmet-travel/connected-champagne-tracking-qr-rfid/*. Accessed January 7, 2023

Pejić Bach, M., Topalović, A., & Turulja, L. (2023). Data mining usage in Italian SMEs: an integrated SEM-ANN approach. *Central European Journal of Operations Research*, *31*(3), 941-973. https://doi.org/10.1007/s10100-022-00829-x

Polanco-García, M., Granero, R., Gallart, L., García-Lopez, J., & Montes, A. (2021). Confirmatory factor analysis of the International Pain Outcome questionnaire in surgery. *Pain Reports*, *6*(1), e903. https://doi.org/10.1097/pr9.0000000000000903.

Popović, T., Krčo, S., Maraš, V., Hakola, L., Radonjić, S., van Kranenburg, R., & Šandi, S. (2021). A novel solution for counterfeit prevention in the wine industry based on IoT, smart tags, and crowd-sourced information. *Internet of Things*, *14*, 100375. https://doi.org/10.1016/j.iot.2021.100375

Rahman, M. M., Lesch, M. F., Horrey, W. J., & Strawderman, L. (2017). Assessing the utility of TAM, TPB, and UTAUT for advanced driver assistance systems. *Accident Analysis & Prevention*, *108*, 361-373. https://doi.org/10.1016/j.aap.2017.09.011

Rane, C., Tyagi, K., Kline, A., Chugh, T., & Manry, M. (2024). Optimizing performance of feedforward and convolutional neural networks through dynamic activation functions. *Evolutionary Intelligence*, *17*(5), 4083-4093. https://doi.org/10.1007/s12065-024-00973-0

Reyes-Menendez, A., Palos-Sanchez, P. R., Saura, J. R., & Martin-Velicia, F. (2018). Understanding the Influence of Wireless communications and Wi-Fi access on customer loyalty: A behavioral model system. *Wireless Communications and Mobile Computing*, *2018*(1), 3487398. https://doi.org/10.1155/2018/3487398

Ria, T. Z., Khan, M., & De, U. K. (2024). Students' attitude towards use of ICT as tool of learning: a structural equation modeling (SEM) approach. *SN Social Sciences*, *4*(6), 1-20. https://doi.org/10.1007/s43545-024-00907-8

Robson, K., Dean, M., Haughey, S., & Elliott, C. (2021). A comprehensive review of food fraud terminologies and food fraud mitigation guides. *Food Control*, *120*, 107516. https://doi.org/10.1016/j.foodcont.2020.107516

Sanz-Valero, J., Álvarez Sabucedo, L. M., Wanden-Berghe, C., & Santos Gago, J. M. (2016). QR codes: outlook for food science and nutrition. *Critical Reviews in Food Science and Nutrition*, *56*(6), 973-978. https://doi.org/10.1080/10408398.2012.742865

Saranya, K., Reminaa, R. S., & Subhitsha, S. (2016, March). Modern applications of QR-Code for security. In *2016 IEEE International Conference on Engineering and Technology (ICETECH)* (pp. 173-177). IEEE. https://doi.org/10.1109/ICETECH.2016.7569235

Shi, J., Zeng, X., Cui, P., Yan, C., & Chen, H. (2023). Alarming situation of emerging H5 and H7 avian influenza and effective control strategies. *Emerging Microbes & Infections*, *12*(1), 2155072. https://doi.org/10.1080/22221751.2022.2155072

Soon, J. M., & Liu, X. (2020). Chinese consumers' risk mitigating strategies against food fraud. *Food Control*, *115*, 107298. https://doi.org/10.1016/j.foodcont.2020.107298

Spence, M., Stancu, V., Elliott, C. T., & Dean, M. (2018). Exploring consumer purchase intentions towards traceable minced beef and beef steak using the theory of planned behavior. *Food Control*, *91*, 138-147. https://doi.org/10.1016/j.foodcont.2018.03.035

Statista. (2022). Penetration rate of smartphones in selected countries 2022. Retrieved from *https://www.statista.com/statistics/539395/smartphone-penetration-worldwide-by-country/*. Accessed on Dec 3, 2024

Sternad Zabukovšek, S., Kalinic, Z., Bobek, S., & Tominc, P. (2019). SEM-ANN based research of factors' impact on extended use of ERP systems. *Central European Journal of Operations Research*, *27*, 703-735. https://doi.org/10.1007/s10100-018-0592-1

Su, G., Yu, C., Liang, S., Wang, W., & Wang, H. (2024). Multi-omics in food safety and authenticity in terms of food components. *Food Chemistry*, *437*, 137943. https://doi.org/10.1016/j.foodchem.2023.137943

Suki, N. M., & Ramayah, T. (2010). User acceptance of the e-government services in Malaysia: structural equation modeling approach. *Interdisciplinary Journal of Information, Knowledge, and Management*, *5*, 395-413.

Szopiński, T. S. (2016). Factors affecting the adoption of online banking in Poland. *Journal of Business Research*, *69*(11), 4763-4768. https://doi.org/10.1016/j.jbusres.2016.04.027

Tan, G. W. H., Ooi, K. B., Leong, L. Y., & Lin, B. (2014). Predicting the drivers of behavioral intention to use mobile learning: A hybrid SEM-Neural Networks approach. *Computers in Human Behavior*, *36*, 198-213. https://doi.org/10.1016/j.chb.2014.03.052

Tseng, K. C., Chen, C. C., Huang, J. M., Chow, T. H., & Hsu, C. H. (2022). The behavioral intention and influencing factors of medical staff toward COVID-19 vaccinations. *Healthcare*, *10, 628*. https://doi.org/10.3390/healthcare10040628

Unal, E., & Uzun, A. M. (2021). Understanding university students' behavioral intention to use Edmodo through the lens of an extended technology acceptance model. *British Journal of Educational Technology*, *52*(2), 619-637. https://doi.org/10.1111/bjet.13046

Venkatesh, V., & Bala, H. (2008). Technology acceptance model 3 and a research agenda on interventions. *Decision Sciences*, *39*(2), 273-315. https://doi.org/10.1111/j.1540-5915.2008.00192.x

Wang, J., Jing, R., Lai, X., Zhang, H., Lyu, Y., Knoll, M. D., & Fang, H. (2020). Acceptance of COVID-19 Vaccination during the COVID-19 Pandemic in China. *Vaccines*, *8*(3), 482. https://doi.org/10.3390/vaccines8030482

Yan, H., Shang, H., & Liu, H. (2023). The role and influencing factors of government performance evaluation: A test of Chinese public officials' perceptions in Gaoming district. *Chinese Public Administration Review*, *14*(4), 199-223. https://doi.org/10.1177/15396754231195575

Yang, S. H., Phan, H. T. T., Hsieh, C. M., & Li, T. N. (2022). What intentions and interesting information can attract consumers to scan QR Code while buying eggs?. *Foods*, *11*(9), 1259. https://doi.org/10.3390/foods11091259

Yin, Y. C., Ahmed, J., Nee, A. Y. H., & Hoe, O. K. (2023). The rural consumer adoption of sustainable energy: a PLS-SEM-ANN approach of conceptual model development and cross-country validation of Pakistan and Malaysia. *Environmental Science and Pollution Research*, *30*(3), 5881-5902. https://doi.org/10.1007/s11356-022-22271-x

Yu, Y., Zhang, L., Liu, Y., Zhang, L., & Guo, N. (2024). Translation and validation of the Breastfeeding Motivation Scale in China. *International Breastfeeding Journal*, *19*(1), 2. https://doi.org/10.1186/s13006-023-00610-z

Zhao, T., Shi, Q., Zhang, X., & Zhang, T. (2024). Decoding green food safety information dependency in the digital era: An intelligent validation using SEM-ANN framework. *Journal of Retailing and Consumer Services*, *79*, 103886. https://doi.org/10.1016/j.jretconser.2024.103886

Zheng, L., & Zheng, Y. (2014). Online sexual activity in Mainland China: Relationship to sexual sensation seeking and sociosexuality. *Computers in Human Behavior*, *36*, 323-329. https://doi.org/10.1016/j.chb.2014.03.062

Zhong, Y., & Moon, H. C. (2022). Investigating customer behavior of using contactless payment in China: A comparative study of facial recognition payment and mobile QR-code payment. *Sustainability*, *14*(12), 7150. https://doi.org/10.3390/su14127150

Zhu, X., Huang, I. Y., & Manning, L. (2019). The role of media reporting in food safety governance in China: A dairy case study. *Food Control*, *96*, 165-179. https://doi.org/10.1016/j.foodcont.2018.08.027

Supplementary materials

Supplementary Text 4.1: Questionnaire in English and Chinese

Questionnaire (English version)

Thank you for participating in this questionnaire. The questionnaire will take approximately 10 minutes to complete, and you may stop at any time. All data collected will be used solely for academic research and stored anonymously and securely, following Wageningen University & Research's general information security guidelines. By proceeding with the questionnaire, you consent to the use of your responses for the academic study. Any questions about study participation may be directed to [Pengfei Li (pengfei.li@wur.nl)].

Q1 How old are you?

- 18-24 years
- 25-34 years
- 35-44 years
- 45-54 years
- 55-64 years
- More than 65 years

Q2 What is your gender?

- Male
- Female
- Other
- Prefer not to say

Q3 Which of the following best describes your household income level?

- Low income
- Middle income
- High income
- Prefer not to say

Q4 What is the highest level of education you have completed?

- Primary school
- Middle school
- High school
- Bachelor’s degree
- Master's degree
- Doctorate or professional degree
- Prefer not to say

Q5 What is the size of your current household?

- 1
- 2
- 3
- 4
- 5+
- Prefer not to say

Q6 How many children under 16 are in your household?

- 0
- 1
- 2
- 3+
- Prefer not to say



Example of a Quick Response (QR) code

Q7 Have you ever scanned a Quick Response (QR) code before?

- Yes
- No
- I do not remember

Q8 How often do you scan a QR code?

- Never
- Less than once a month
- Several times a month
- Every week
- Daily

Q9 Have you ever scanned a QR code on a food packaging before?

- Yes
- No
- I do not remember

Q9a is available to respondents who select 'Yes' in Q9.

Q9a In what location(s) do you scan the QR code on a food package? **Multiple options may be selected.**

- Home
- Grocery store
- Work or school
- Public space
- Other, please specify _____

QR codes on food packages have many different purposes, including verifying the authenticity of the food product. Food authentication is a procedure that confirms if a food product matches the information on the label of the product. Offenders try to deceive consumers by replicating genuine food products and their packaging, including QR codes.

An example of a QR code used on food packaging is shown in the picture below. Each food product has a unique authentication code that is linked to a QR code on the food packaging. When scanning the QR code on the food package, the authentication code is revealed to consumers on their scanning device. Consumers can compare the authentication code acquired by scanning the QR code to the authentication code present on the food packaging. If the codes are the same, the food is identified as authentic.



The next part of the questionnaire aims to explore the willingness and behaviors of consumers towards scanning QR codes on food packaging for authentication purposes.

Q10 Assuming I have access to the authentication QR codes on food packaging, I intend to use it.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q11 Assuming I have access to the authentication QR codes on food packaging, I predict I would use it.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q12 I think the use of QR codes for food authentication is a good idea.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q13 I am positive about QR codes for food authentication.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q14 I like the idea of a QR code for food authentication.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q15 I find using QR codes for food authentication to be advantageous.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q16 I find using QR codes for food authentication to be useful.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q17 I find the reward of using QR codes for food authentication to be high.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q18 I find the QR codes for food authentication to be easy to use.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q19 It is easy to learn how to authenticate food products by using authentication QR codes.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q20 Acquiring food authentication information by using authentication QR codes requires minimal effort.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q21 I often check the authenticity of food products I intend to buy.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q22 I often try to find information about food authenticity.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q23 I think it is necessary to authenticate food products before purchase.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q24 I have the device(s), e.g., smartphones, necessary to use the authentication QR codes.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q25 There is Internet connectivity available to the device(s) to use the authentication QR codes.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q26 I have the knowledge necessary to use an authentication QR code.

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

Q27 With what food category in mind have you filled out this questionnaire? **Multiple options can be selected.**

- Dairy products (milk, infant formula, cheese, etc.)
- Seafood products
- Meat and poultry products
- Herbs, spices, and seasonings
- Beverages (alcoholic)
- Beverages (non-alcoholic)
- Olive oil
- Fruit
- Vegetables
- Grain
- Coffee, tea, and cocoa
- I didn't consider the specific food
- Other, please specify_____

Questionnaire (Chinese version)

感谢您参与本问卷调查。完成问卷大约需要 10 分钟，您可以随时停止填写该问卷。本问卷收集的所有数据仅用于学术研究，并按照瓦格宁根大学及研究中心的一般信息安全指南匿名且安全的存储。如您继续填写该问卷，则认定您同意将您的回答用于学术研究。有关参与研究的任何问题，请联系[李鹏飞(邮箱：pengfei.li@wur.nl)]。

Q1 你多少岁了？

- 18-24 岁
- 25-34 岁
- 35-44 岁
- 45-54 岁
- 55-64 岁
- 65 岁以上

Q2 你的性别是什么？

- 男性
- 女性
- 其他
- 不愿透露

Q3 以下哪一项最能描述你的家庭收入水平？

- 低收入
- 中等收入
- 高收入
- 不愿透露

Q4 你的最高学历是什么？

- 小学
- 初中
- 高中
- 本科
- 硕士
- 博士
- 不愿透露

Q5 你目前的家庭规模是多少?

- 1 人
- 2 人
- 3 人
- 4 人
- 5 人及以上
- 不愿透露

Q6 你家里有多少个 16 岁以下的孩子?

- 0 个
- 1 个
- 2 个
- 3 及 3 以上
- 不愿透露



快速响应码（二维码）示例

后称快速响应码为二维码

Q7 你以前扫描过二维码吗?

- 是的
- 没有
- 我不记得了

Q8 你多久扫描一次二维码?

- 从不
- 每月少于一次
- 一个月几次
- 每周
- 每日

Q9 你以前扫描过食品包装上的二维码吗？

- 是的
- 没有
- 我不记得了

Q9a 仅提供给在 Q9 中选择“是的”的受访者。

Q9a 您在哪里扫描食品包装上的二维码？可以选择多个选项。

- 家里
- 商店
- 工作单位或学校
- 公共区域
- 其他，请具体说明_____

食品包装上的二维码有许多不同的用途，包括认证食品的真实性。食品认证是一种确认食品是否与产品标签上的信息相匹配的程序。违法者试图通过复制真正的食品及其包装（包括二维码）来欺骗消费者。

下图显示了食品包装上使用的二维码示例。每种食品都有一个唯一的验证码，该验证码与食品包装上的二维码相关联。扫描食品包装上的二维码时，消费者的扫描设备上会显示身份验证码。消费者可以将扫描二维码获得的验证码与食品包装上的验证码进行比较。如果代码相同，则食品被认定为正品。



问卷的下一部分旨在探讨消费者扫描食品包装上的二维码进行食品真实性认证的意愿和行为。

Q10 假设我可以接触食品包装上的真实性认证二维码，我打算使用它。

- 非常同意
- 同意
- 既不同意也不反对
- 不同意
- 强烈反对

Q11 假设我可以接触食品包装上的真实性认证二维码，我预测我会使用它。

- ○ 非常同意
- ○ 同意
- ○ 既不同意也不反对
- ○ 不同意
- ○ 强烈反对

Q12 我认为使用二维码进行食品真实性认证是一个好主意。

- ○ 非常同意
- ○ 同意
- ○ 既不同意也不反对
- ○ 不同意
- ○ 强烈反对

Q13 我对用于食品真实性认证的二维码持肯定态度。

- ○ 非常同意
- ○ 同意
- ○ 既不同意也不反对
- ○ 不同意
- ○ 强烈反对

Q14 我喜欢用二维码进行食品真实性认证的方法。

- ○ 非常同意
- ○ 同意
- ○ 既不同意也不反对
- ○ 不同意
- ○ 强烈反对

Q15 我发现使用二维码进行食品真实性认证是有益的。

- ○ 非常同意
- ○ 同意
- ○ 既不同意也不反对
- ○ 不同意
- ○ 强烈反对

Q16 我发现使用二维码进行食品真实性认证很有用。

- ○ 非常同意
- ○ 同意
- ○ 既不同意也不反对
- ○ 不同意
- ○ 强烈反对

Q17 我发现使用二维码进行食品真实性认证的回报很高。

- 非常同意
- 同意
- 既不同意也不反对
- 不同意
- 强烈反对

Q18 我发现食品认证二维码真实性是很容易使用的。

- 非常同意
- 同意
- 既不同意也不反对
- 不同意
- 强烈反对

Q19 学习使用二维码认证食品真实性是非常简单的。

- 非常同意
- 同意
- 既不同意也不反对
- 不同意
- 强烈反对

Q20 使用认证二维码获取食品真实性信息只需付出很少的努力。

- 非常同意
- 同意
- 既不同意也不反对
- 不同意
- 强烈反对

Q21 我经常检查我打算购买的食品的真实性。

- 非常同意
- 同意
- 既不同意也不反对
- 不同意
- 强烈反对

Q22 我经常尝试查找有关食品真实性的信息。

- 非常同意
- 同意
- 既不同意也不反对
- 不同意
- 强烈反对

Q23 我认为在购买食品之前有必要对其真实性进行认证。

- 非常同意
- 同意
- 既不同意也不反对
- 不同意
- 强烈反对

Q24 我有使用食品真实性认证二维码所需的设备，例如智能手机。

- 非常同意
- 同意
- 既不同意也不反对
- 不同意
- 强烈反对

Q25 我的移动设备有互联网连接，可以使用食品真实性认证二维码。

- 非常同意
- 同意
- 既不同意也不反对
- 不同意
- 强烈反对

Q26 我具备使用食品真实性认证二维码所需的知识。

- 非常同意
- 同意
- 既不同意也不反对
- 不同意
- 强烈反对

Q27 你填写这份问卷时考虑了什么食物类别？可以选择多个选项。

- 乳制品（牛奶，奶粉、奶酪等）
- 海鲜产品
- 肉类和家禽产品
- 草本植物、香料和调味品
- 饮料（含酒精饮料）
- 饮料（不含酒精）
- 橄榄油
- 水果
- 蔬菜
- 谷物
- 咖啡、茶和可可
- 我没有考虑具体的食品
- 其他，请具体说明_____

Supplementary Text 4.2: The criteria for incomplete and invalid questionnaires

1 The built-in Screening-out Criteria set by Questionnaire Star and Dynata.

2 Answers with multicollinearity problems (Kim & Hwang, 2020).

3 Inconsistent and incomplete answers (Sun et al., 2022).

References

Kim, J. J., & Hwang, J. (2020). Merging the norm activation model and the theory of planned behavior in the context of drone food delivery services: Does the level of product knowledge really matter?. *Journal of Hospitality and Tourism Management*, *42*, 1-11. https://doi.org/10.1016/j.jhtm.2019.11.002

Sun, H., Zhang, Q., Guo, W., & Lin, K. (2022). Hikers' pro-environmental behavior in national park: Integrating theory of planned behavior and norm activation theory. *Frontiers in Forests and Global Change*, *5*, 1068960. https://doi.org/10.3389/ffgc.2022.1068960

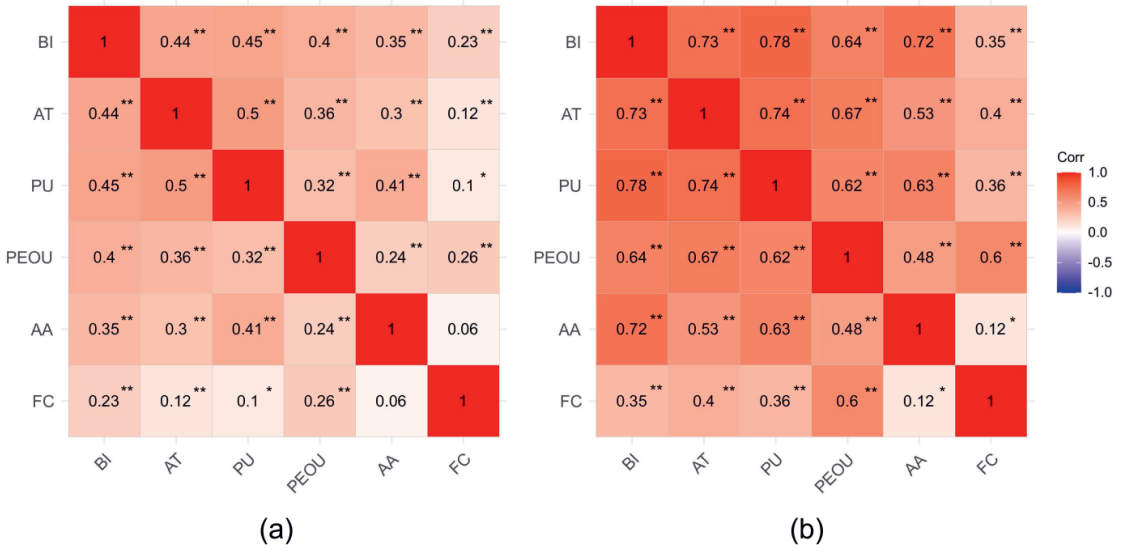


Fig. S4.1. The Pearson correlations among the variables for a) Chinese responses and b) British responses. * $p < .05$, ** $p < .01$. BI: behavioral intention, AT: attitude, PU: perceived usefulness, PEOU: perceived ease of use, AA: authenticity awareness, FC: facilitating conditions. The average scores of each variable are calculated by the scores of its corresponding scale items.

Table S4.1. RMSE values of ANN models for Chinese and British responses.

Network	RMSE (Chinese responses)				RMSE (British responses)			
	Model 1		Model 2		Model 1		Model 2	
	Training	Testing	Training	Testing	Training	Testing	Training	Testing
1	0.0746	0.0805	0.0760	0.0839	0.0924	0.0837	0.0823	0.0873
2	0.0787	0.0842	0.0759	0.0930	0.0893	0.0824	0.0849	0.0552
3	0.0795	0.0722	0.0808	0.0718	0.0868	0.0802	0.0817	0.0950
4	0.0776	0.0674	0.0812	0.0720	0.0849	0.0921	0.0993	0.0567
5	0.0831	0.0697	0.0840	0.0731	0.0886	0.0647	0.0859	0.0736
6	0.0748	0.0765	0.0869	0.0675	0.1004	0.1191	0.0810	0.1047
7	0.0765	0.0703	0.0812	0.0634	0.1003	0.1339	0.0859	0.0936
8	0.0752	0.0763	0.0775	0.0690	0.0902	0.0630	0.0839	0.0608
9	0.0768	0.0709	0.0812	0.0672	0.0887	0.0775	0.0861	0.0531
10	0.0746	0.0809	0.0758	0.0803	0.0924	0.1008	0.0835	0.0802
Mean	0.0771	0.0749	0.0801	0.0741	0.0914	0.0897	0.0855	0.0760
SD	0.0027	0.0056	0.0037	0.0090	0.0052	0.0226	0.0052	0.0189

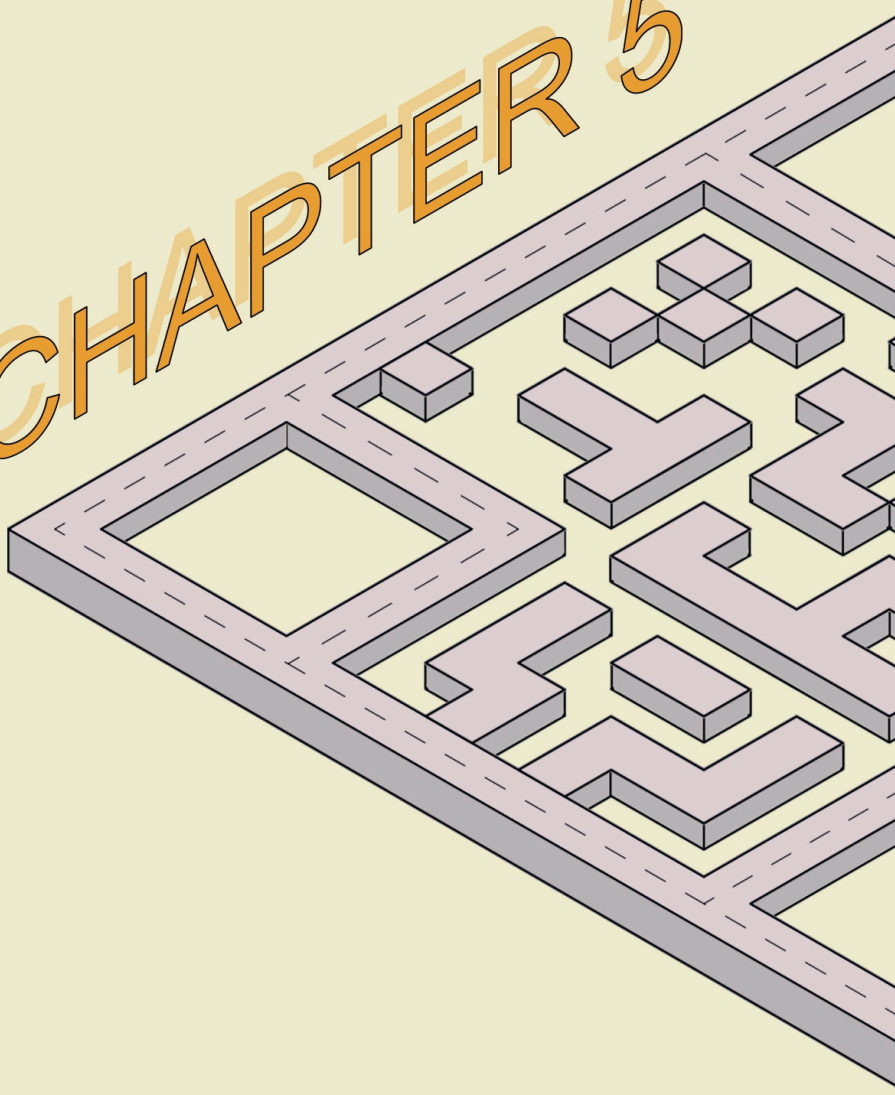
RMSE: Root mean square of error, SD: Standard deviation.

Table S4.2. The results of the sensitivity analysis.

Network	Relative importance (Chinese responses)					Relative importance (British responses)				
	Model 1			Model 2		Model 1			Model 2	
	PU	PEOU	AT	AA	FC	PU	PEOU	AT	AA	FC
1	0.738	0.262	0.479	0.397	0.124	0.541	0.459	0.497	0.426	0.077
2	0.574	0.426	0.467	0.424	0.109	0.579	0.421	0.466	0.418	0.116
3	0.552	0.448	0.415	0.375	0.211	0.571	0.429	0.492	0.407	0.101
4	0.692	0.308	0.423	0.398	0.179	0.624	0.376	0.338	0.429	0.232
5	0.557	0.443	0.436	0.426	0.138	0.636	0.364	0.439	0.472	0.090
6	0.776	0.224	0.557	0.324	0.118	0.566	0.434	0.460	0.443	0.096
7	0.626	0.374	0.418	0.355	0.226	0.546	0.454	0.498	0.348	0.154
8	0.740	0.260	0.557	0.287	0.156	0.596	0.404	0.448	0.409	0.143
9	0.669	0.331	0.470	0.335	0.195	0.579	0.421	0.456	0.437	0.108
10	0.756	0.244	0.671	0.132	0.197	0.533	0.467	0.462	0.420	0.118
Average Importance	0.668	0.332	0.489	0.345	0.165	0.577	0.423	0.456	0.421	0.124
Normalized Importance (%)	100	49.70	100	70.55	33.74	100	73.31	100	92.32	27.19

BI: behavioral intention, AT: attitude, PU: perceived usefulness, PEOU: perceived ease of use, AA: authenticity awareness, FC: facilitating conditions.

CHAPTER 5



Chapter 5

A meta-analysis of consumers' willingness to pay for the special food attributes

This chapter is prepared for submission as:

Pengfei Li, Maitri Prasrtyo, Tongzhe Li, Gangchao Chen, Shujuan Xing, Xiyu Li, Jingjie Yang, Shuangrun Li, Giorgiana Catunescu, Klaus G. Grunert, Kasper Hettinga, Sara Erasmus. A meta-analysis of consumers' willingness to pay for the special food attributes.

Abstract

Special food attributes can enhance product appeal and increase purchasing intent. However, the premium consumers are willing to pay does not rise indefinitely, as their perceived value for these attributes must stay aligned with the price within a reasonable range. We evaluated consumers' willingness to pay (WTP) for special food attributes by synthesizing the findings from 377 consumer studies published between 2000-2024. Among all the studies included, consumers are willing to pay 28% more for the special food attribute, and in 87% cases, the presence of special attributes is associated with an increase in food final prices. Subgroup meta-analysis revealed that statistically significant differences were found between the subgroups. Consumers' WTP for special attributes varied significantly by income level, with the highest WTP (49%) observed in upper-middle-income countries and the lowest (21%) in high-income countries. WTP was also higher in the periods 2007-2012 and 2013-2018 than in the periods before 2006 and 2019-2024, and differed by method for measuring WTP, with the multiple price list generating the highest estimates with considerable statistical uncertainty. Consumers showed a stronger preference for plant-based foods and attributes related to 'quality and safety' and 'sustainability', while the logo was found to be the most effective information carrier, associated with a higher WTP (34%). The findings of this study provide quantitative evidence of the market value of specific food attributes and offer valuable insights for food producers, marketers, and policymakers in developing effective strategies to promote food products possessing such attributes.

Keywords

Food attribute; Meta-analysis; Premium; Willingness to pay

5.1 Introduction

In the last 20 years, food consumption patterns have undergone a profound transformation. Consumers' purchasing decisions, in addition to traditional factors such as price, taste, and convenience, increasingly reflect a greater concern for the intangible attributes of food (Messer et al., 2017). This shift has led to a growing demand for products characterized by special food attributes, such as quality, safety, sustainability, health, and nutrition (Aluthge et al., 2025; Hu et al., 2024). These attributes are not only perceived as indicators of food quality but also reflect consumers' diverse values related to health and sustainability. The special food attributes are proven to shape consumers' perceptions and attitudes toward particular food products (Kolodinsky & Lusk, 2018). In this context, the effective transmission of special food attributes has become particularly critical, as it can lead to higher product prices and increased sales (Cohen & Vandenbergh, 2012).

Willingness to pay (WTP) is defined as the highest price a consumer is willing to pay for a specified quantity of goods or services (Le Gall-Ely, 2009). In the context of this study, WTP represents the premium being the maximum monetary difference a consumer is willing to pay for food products possessing a special attribute compared to those without it. The WTP has been employed as a proxy for consumer attitudes (Ryan & Spash, 2011) and as an indicator of public preferences (Harvey & Hubbard, 2013).

The distinctive attributes of food products lead to higher costs during production and processing stages, which are typically transferred to consumers through price premiums on the final products (Tran et al., 2024). A low premium paid for food special attributes may reduce enterprises' motivation to integrate these attributes into food products, thereby weakening consumers' right to access diverse and reliable information about food attributes. Conversely, a high premium may increase the overall cost of food products, potentially diminishing consumer purchase intentions and undermining the market sales. Therefore, it is essential to assess consumers' WTP for special food attributes. Such an evaluation not only enhances the understanding of consumers' perceived value of special food attributes but also provides a reference for food enterprises to develop more reasonable and targeted pricing strategies.

There are numerous studies on the WTP for labeled products (Yang & Fang, 2021). However, existing research remains fragmented, typically focusing on one type of specific attribute, resulting in findings that lack broader generalizability. Consequently, there is limited understanding of how different food attributes, geographical regions, food types, temporal factors, and information carriers systematically influence consumer valuation on a global scale. Our study addressed these shortcomings by

conducting a meta-analysis of the WTP for special food attributes and exploring the heterogeneity within the data.

5.2 Methods

This study was conducted and reported according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). The full review protocol and the explanations of exclusion criteria are provided in **Supplementary Text 5.1**.

5.2.1 Literature search and study eligibility criteria

Search strings for the databases were reported in **Supplementary Text 5.2**. The literature search was conducted on October 21, 2024, using the Scopus, Web of Science, and EconLit databases. All the included studies must be published in a peer-reviewed journal. Books, theses, dissertations, conference proceedings, grey literature, news articles, and articles from non-confirmed websites were not included. The date of publication needed to be after January 1st, 2000. There were no limits on geographical locations, food attributes, food types, research methods, and information carriers of the studies.

5.2.2 Study screening, data extraction, and risk of bias assessment

Study screening, data extraction, and risk of bias assessments were independently performed by two review authors. Before the formal screening process, two review authors independently assessed the same set of 100 articles, achieving an 84% agreement rate on inclusion/exclusion decisions. Discrepancies between reviewers' decisions were resolved through joint discussion, during which the inclusion/exclusion criteria were further clarified and standardized. During the screening process, for articles for which a review author could not make confident decisions, disagreements were resolved through group consensus after the participation of another author. Data extracted from prior studies were subsequently cross-checked through an independent validation process to ensure accuracy.

The duplicate records were screened in EndNote by comparing similarities in title, author, publication year, DOI, publisher, and other relevant details, and study screening was conducted in Rayyan. There were three phases of screening. The first phase was to screen the titles and abstracts of all the searched papers. The second phase aimed to extract the data of WTP through screening the full text of papers. The data on the experimental conditions and the premium of consumers' willingness to pay were extracted and recorded using a customized spreadsheet. During the third phase of screening, studies that did not report the base price or the variability measures were

excluded. The process of screening duplicate literature, as well as the inclusion and exclusion criteria for the three screening phases, is detailed in the **Supplementary Text 5.1**. The data extraction content and method are shown in the **Supplementary Text 5.3**. Information on variables related to experimental conditions was also extracted and recorded in this form, including geographical distribution, research year, food attribute type, related food type, research method, and information carrier.

In order to eliminate the influence of inflation and currency exchange fluctuations on the final results, the percentage of WTP for special food attributes is used as a parameter to reflect consumers' WTP for special food attributes. The calculation process of the percentage of WTP and its standard error is shown in **Supplementary Text 5.4**.

5.2.3 Meta-analyses

Effects were weighted by the standard error of the studies, thereby giving more weight to studies with lower standard errors. Given the broad scope of key characteristics in the studies, such as time (year), country, food type, attribute type, and information carriers, a high degree of heterogeneity in the observed effects was expected (Sedgwick, 2013). Therefore, a random-effects meta-analysis was employed (Borenstein et al., 2007). The DerSimonian-Laird (DL) method was used to perform a random-effects model analysis.

Differences between subgroups were examined using between-group significance testing. Heterogeneity was assessed by the I^2 statistic (Borenstein, 2024). I^2 was interpreted as low (I^2: <25%), low to moderate (I^2: 25-50%), moderate to substantial (I^2: 50-75%), or substantial (I^2: >75%) (Prasad et al., 2022).

5.2.4 Bias assessments

The asymmetry of funnel plots was used to visualize the bias and assessed by the Egger’s test (Egger et al., 1997; Hindes et al., 2025).

Given that the included studies are all single-arm studies (non-randomized studies), risk of bias was evaluated by using the Cochrane Risk of Bias Tool for Randomized Trials (Higgins et al., 2011), which is revised correspondingly for the current review (Clark et al., 2017) (**Supplementary Text 5.5**). Risk of bias was categorized as low risk, some concern, or high risk, and studies were not excluded based on risk-of-bias results (Quinn et al., 2025).

5.2.5 Subgroup analyses

Subgroup analysis is one of the most commonly used methods for exploring sources of heterogeneity in meta-analyses (Spineli & Pandis, 2020). In this approach, the included estimates are divided into several subgroups based on specific study characteristics, and subgroup analysis was employed to identify potential sources of heterogeneity in the results. Statistical tests were performed to test whether the pooled effect sizes differ significantly between these subgroups (Cuijpers et al., 2021).

All the effects were divided into groups by income level (at the national level), time period, method, food type, attribute type, and information carrier. Separate subgroup analyses were conducted for each group. The analysis accounted for study location at the national level, and all the countries were also classified into four income groups: low, lower-middle, upper-middle, and high (The World Bank, 2025). The income uses gross national income (GNI) per capita data in US dollars. The classification was assigned according to the publication year of each study to maintain consistency with the contextual conditions at the time of the research. The research years were grouped at six-year intervals. The included studies are divided into four time periods: before 2006, 2007-2012, 2013-2018, and 2019-2024. Methods used for measuring WTP included revealed preference methods, such as auctions and market data, and stated preference methods, including the multiple price list, contingent valuation, choice experiment, and conjoint analysis (Breidert et al., 2006). Food types were classified into three groups by the source of origin: animal-based, plant-based, and processed (Monteiro et al., 2023). The types of special food attributes the studies aimed at were classified as three groups: quality and safety, sustainability, health and nutrition (Barreiro Hurle et al., 2010; Grunert, 2005; Piracci et al., 2024). The special attributes were presented as three carriers: text, logo, and barcode (Bradu et al., 2014; Hall et al., 2025).

The guide and claim for the subgroup, as well as the detailed subgroup classification instructions, are shown in **Supplementary Text 5.6**.

5.2.6 Statistics

All data processing, statistical analyses, and data visualizations were performed using Stata (Version 18 BE).

5.3 Results

5.3.1 Flow of screening studies and report characteristics

An overview of the study identification, screening, and final selection is shown in **Fig. 5.1**. By using predefined search strings, the first database search yielded 3,848 records.

After removing 1,371 duplicates, 2,477 records remained for title and abstract screening. Based on predefined inclusion and exclusion criteria, 1,342 records were excluded at this stage. This left 1,135 full-text articles assessed for eligibility. Of these, 525 articles were excluded due to failure to meet the predefined inclusion and exclusion criteria (**Supplementary Text 5.1**). A total of 610 studies were included for full-text screening. The data was extracted and recorded in an Excel file, where further screening was conducted. This study excluded articles that did not report the base price (n = 48 articles) and standard error (n = 185 articles), resulting in 377 included articles (**Supplementary Text 5.7**).

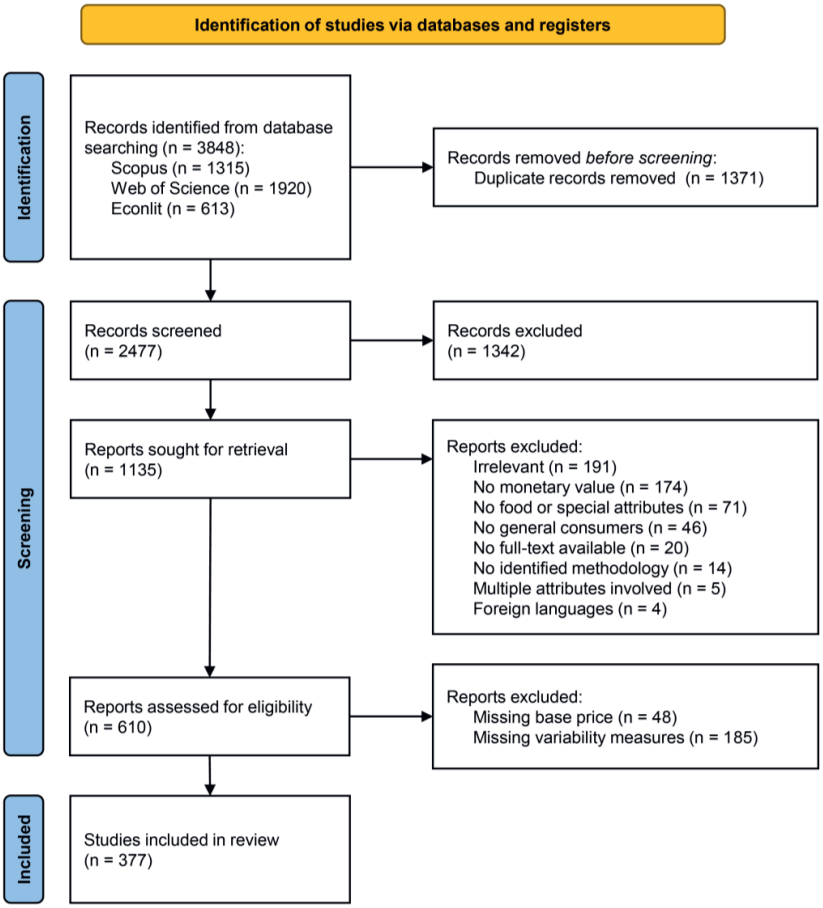


Fig. 5.1. Flow of studies through the review according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart (Page et al., 2021). This illustrates the systematic procedure employed to include studies identified through the search strategy.

Characteristics of the 377 reports included in the meta-analysis are summarized in **Fig. 5.2**. The included studies contributed a total of 1,587 effect estimates of consumers' WTP for the special attributes, involving around 340,000 participants in total (214 consumers on average for each estimate). This meta-analysis includes publications from fifty-one countries across six continents, covering almost all types of food and their attributes. The included studies encompass all widely used methods for measuring WTP and all carriers used to present special food attributes in the studies.

5.3.2 Meta-analysis result

A meta-analysis was conducted on 1,587 estimates from 377 studies, of which the results are presented in **Fig. 5.3a**. Based on the pooled estimate size, consumers are generally willing to pay a 28% (d=27.825 [26.779-28.871], I^2:100%, z=52.142, p<0.01) premium for food products with special attributes. However, the estimates of WTP vary substantially, with the minimum willingness to pay indicating a price discount of 143%, and the maximum reaching a premium of 416%. Notably, 87% of the estimates have positive values, indicating that in most cases the presence of special food attributes leads to an increase in food price (**Fig. 5.3b**). A positive value of WTP indicates that the consumer values the food attribute and is willing to pay a premium for it. A WTP of zero implies that consumers have no payment preference for the associated special food attributes. A negative WTP value means that the food attribute is considered undesirable among consumers, and this attribute reduces the price consumers are willing to pay for food products with it. The negative WTP for certain food attributes suggests that, holding other factors constant, consumers require compensation—either through a lower price or more favorable attributes—to choose food products with these attributes over those without.

In the funnel plot, each study is represented by a circle, indicating its corresponding effect size and standard error. When both publication bias and heterogeneity are small, data points are expected to form a symmetrical inverted funnel in the plot, with the majority falling within the pseudo-confidence region centered around the pooled effect size (denoted by the solid vertical line), and bounded by contours representing the 95% confidence interval. In our study, however, numerous data points exist outside the funnel boundaries (**Fig. 5.3c**), and an asymmetrical distribution implies potential publication bias. This inference is further supported by the results of Egger's test (p<0.01) and I^2 (I^2 =100%), confirming the presence of publication bias but also high heterogeneity.

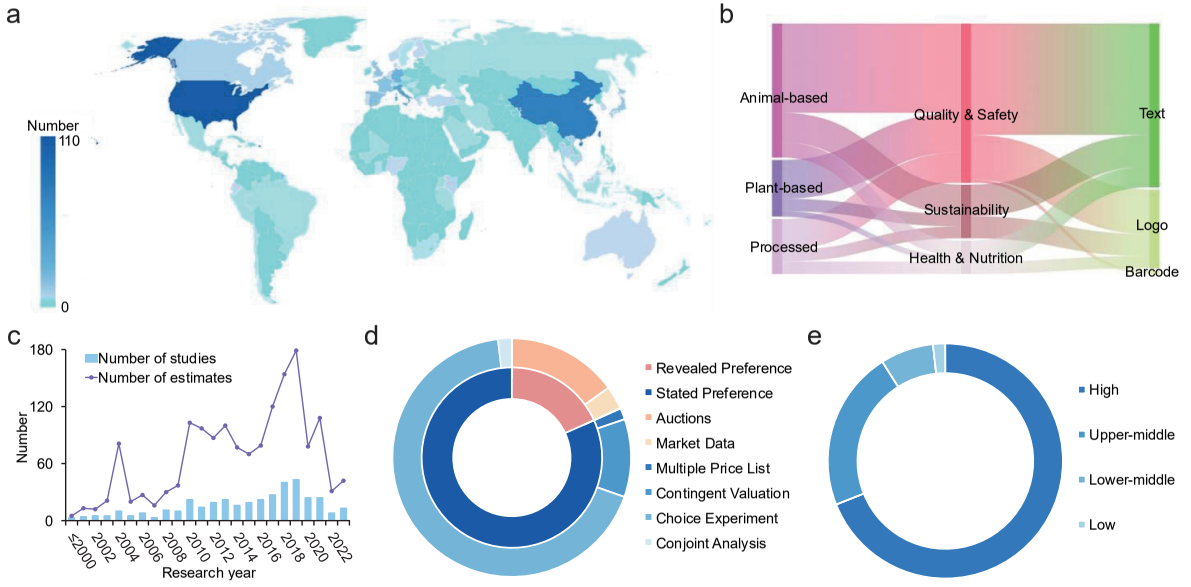


Fig. 5.2. Descriptive statistics of the included studies (n = 377) and their estimates (n = 1587). **a.** Geographical distribution of all included studies. The global map was created using Datawrapper (datawrapper.de). Countries are colored according to the number of studies reported, with darker blue shades indicating a higher number. For studies conducted in multiple countries, each participating country was recorded and counted individually in the analysis. **b.** Relationships between food types, food attributes, and information carriers across all estimates in the included studies. **c.** Trends in the number of included studies and extracted estimates. **d.** Classification and distribution of methods for measuring WTP. The inner ring distinguishes between two main categories: revealed preference and stated preference. The outer ring further details specific methods within each category. Each method is recorded and counted separately in studies employing two or more methods to ensure accurate and comprehensive analysis. **e.** Proportions of included studies conducted in countries with different income levels during the study year. For studies conducted in multiple countries, each participating country was recorded and counted individually in the analysis.

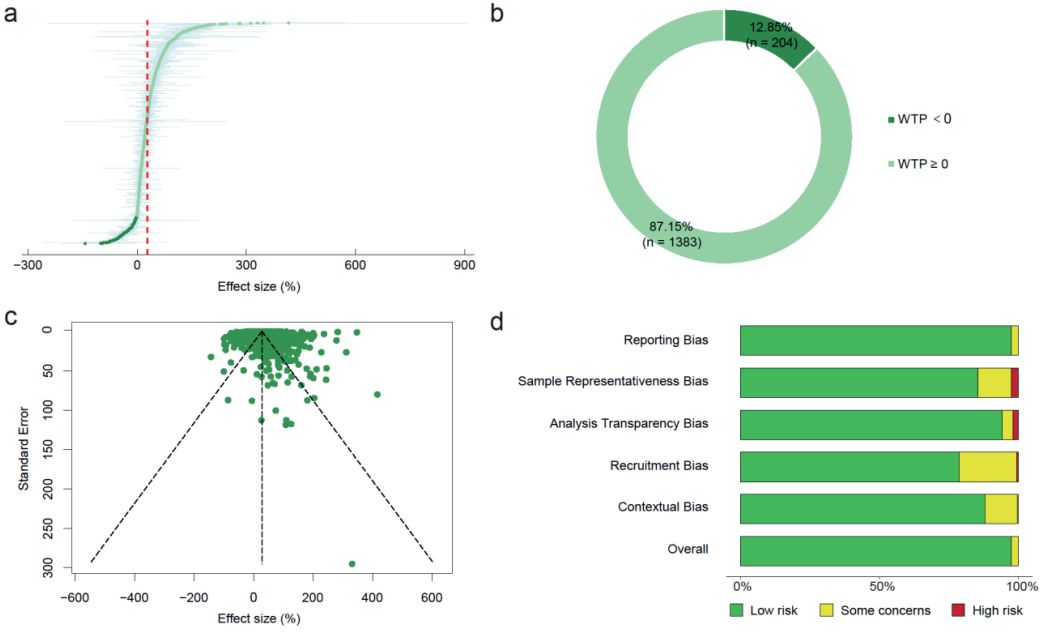


Fig. 5.3. The results and bias of meta-analysis. **a.** Forest plot of all 1,587 effect size estimates extracted from 377 included studies, sorted in ascending order of effect sizes (WTP value). Each dot represents an effect size: dark green dots indicate negative effect sizes (WTP < 0), and light green dots indicate non-negative effect sizes (WTP ≥ 0). Horizontal lines represent the 95% confidence intervals of the effect sizes, while longer lines reflect greater uncertainty in the estimates. The vertical red dashed line indicates the overall pooled effect size estimate (27.825%). **b.** The number and proportion of estimates with negative vs. non-negative effect sizes. **c.** The funnel plot assesses potential publication bias among 1,587 estimates extracted from 377 studies. The vertical dashed line indicates the pooled effect size, and the two diagonal lines represent the expected 95% confidence interval. **d.** Risk of bias assessments across included studies. Each bar represents the proportion of studies rated as having low risk (green), some concerns (yellow), or high risk (red) for each domain of the customized Risk of Bias tool.

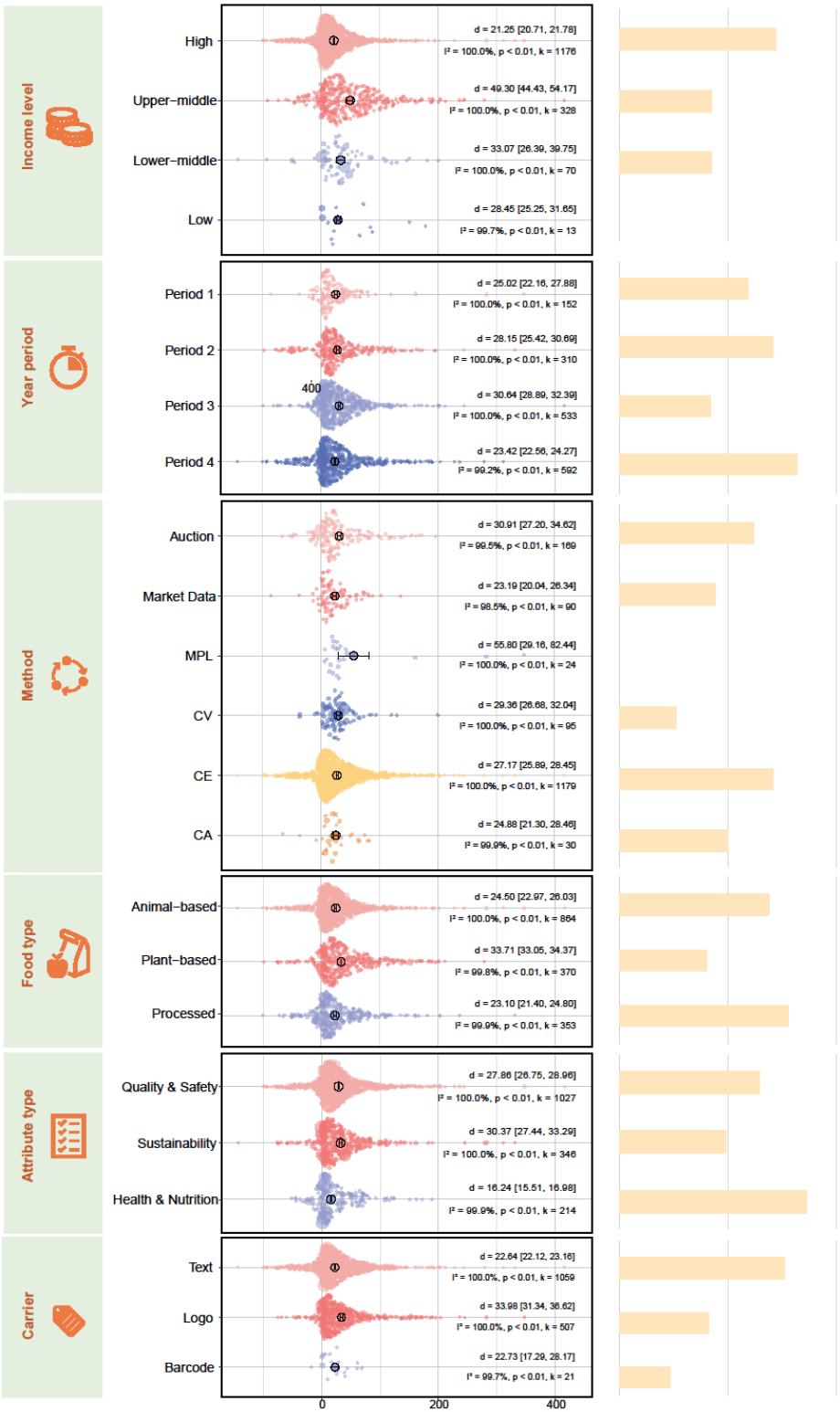

Income level
High
d = 21.25 [20.71, 21.78]
I² = 100.0%, p < 0.01, k = 1176
Upper−middle
d = 49.30 [44.43, 54.17]
I² = 100.0%, p < 0.01, k = 328
Lower−middle
d = 33.07 [26.39, 39.75]
I² = 100.0%, p < 0.01, k = 70
Low
d = 28.45 [25.25, 31.65]
I² = 99.7%, p < 0.01, k = 13
Year period
Period 1
d = 25.02 [22.16, 27.88]
I² = 100.0%, p < 0.01, k = 152
Period 2
d = 28.15 [25.42, 30.69]
I² = 100.0%, p < 0.01, k = 310
400
Period 3
d = 30.64 [28.89, 32.39]
I² = 100.0%, p < 0.01, k = 533
Period 4
d = 23.42 [22.56, 24.27]
I² = 99.2%, p < 0.01, k = 592
Method
Auction
d = 30.91 [27.20, 34.62]
I² = 99.5%, p < 0.01, k = 169
Market Data
d = 23.19 [20.04, 26.34]
I² = 98.5%, p < 0.01, k = 90
MPL
d = 55.80 [29.16, 82.44]
I² = 100.0%, p < 0.01, k = 24
CV
d = 29.36 [26.68, 32.04]
I² = 100.0%, p < 0.01, k = 95
CE
d = 27.17 [25.89, 28.45]
I² = 100.0%, p < 0.01, k = 1179
CA
d = 24.88 [21.30, 28.46]
I² = 99.9%, p < 0.01, k = 30
Food type
Animal−based
d = 24.50 [22.97, 26.03]
I² = 100.0%, p < 0.01, k = 864
Plant−based
d = 33.71 [33.05, 34.37]
I² = 99.8%, p < 0.01, k = 370
Processed
d = 23.10 [21.40, 24.80]
I² = 99.9%, p < 0.01, k = 353
Attribute type
Quality & Safety
d = 27.86 [26.75, 28.96]
I² = 100.0%, p < 0.01, k = 1027
Sustainability
d = 30.37 [27.44, 33.29]
I² = 100.0%, p < 0.01, k = 346
Health & Nutrition
d = 16.24 [15.51, 16.98]
I² = 99.9%, p < 0.01, k = 214
Carrier
Text
d = 22.64 [22.12, 23.16]
I² = 100.0%, p < 0.01, k = 1059
Logo
d = 33.98 [31.34, 36.62]
I² = 100.0%, p < 0.01, k = 507
Barcode
d = 22.73 [17.29, 28.17]
I² = 99.7%, p < 0.01, k = 21
0
200
400

Fig. 5.4. The results of subgroup analysis and the proportion of estimates with negative effect sizes across different subgroups. MPL, multiple price list; CV, contingent valuation; CE, choice experiment; CA, conjoint analysis. In the orchard plots, Circles represent the effect sizes of individual estimates across different subgroups, including income level, time period (before 2006, 2007-2012, 2013-2018, and 2019-2024), method, food type, attribute type, and information carrier. The size of each circle is the reciprocal of the standard error (1/SE). Circles with black borders indicate the pooled effect sizes for each subgroup, accompanied by 95% confidence intervals (black horizontal lines). The x-axis represents the effect size (%). To the right of each plot, the pooled effect size (d) with 95% confidence interval, heterogeneity index I^2, within-subgroup difference significance (p-value), and the total number of effect size estimates (k) for each subgroup are provided. The bar chart on the right shows the proportion of estimates with negative effect sizes across different subgroups. Classification criteria for each study characteristic are described in the **Supplementary Text 5.8**.

According to the quality assessment results (**Fig. 5.3d**), high-risk bias was rarely observed and was limited to a few domains, including sample representativeness bias, analysis transparency bias, and recruitment bias. The overall risk of bias among the included studies was low, reflecting their high quality. Only 2.65% of the studies were assessed as having some concerns, while the remaining studies were rated as low risk.

5.3.3 Subgroup analyses

The meta-analysis results of all subgroups are shown in **Fig. 5.4**. The differences between subgroups within all study characteristics are significant (p<0.01), and heterogeneity (I^2) was high across almost all subgroups, indicating substantial variability among studies.

In terms of income level, consumers from upper-middle-income countries showed the highest WTP for special food attributes, followed by those from lower-middle-income and low-income countries. Consumers in high-income countries reported the lowest WTP (21%).

Regarding the time period, consumer WTP was higher during 2007-2012 (28%) and 2013-2018 (31%) compared to the other periods (before 2006 and 2019-2024). In the subgroup analysis by methods, the multiple price list method yielded the highest WTP (56%), but it has a wide confidence interval (95%CI: 29.16%-82.44%), showing the high uncertainty of results, which may be attributable to the relatively small number of estimates (k=24) in this subgroup. The second and third highest estimates were

observed for the auction and contingent valuation, respectively. The method market data produced the lowest WTP estimate. For food type, the results show that consumers were willing to pay a 34% premium for plant-based foods which was higher than for animal-based (25%) or processed food (23%). In terms of attribute types, WTP for ‘quality and safety’ and ‘sustainability’ was nearly twice as high as for ‘health and nutrition’. Finally, logos emerged as the most favored information carrier, associated with a 34% premium, suggesting they are the most effective means of communicating value to consumers.

The estimates with negative effect sizes were classified across different subgroups to reveal potential reasons for consumers' negative WTP for specific food attributes. The WTP estimates with negative effect sizes appear to be more prevalent in certain subgroups. For instance, a higher proportion of negative estimates is observed in studies conducted in high-income countries (14%). In terms of information carriers, negative estimates are more frequently associated with texts (15%) compared to logos (8%) and barcodes (5%). Similarly, certain food types, such as processed products, and attribute categories, such as health and nutrition, also exhibit a relatively higher proportion of negative WTP estimates than their counterparts. Notably, no estimates with a negative effect size were observed in studies conducted in low-income countries or those employing the multiple price list method. However, this may be due to the limited number of estimates in these categories—only 13 and 24, respectively—thus warranting cautious interpretation.

5.4 Discussion

5.4.1 Main findings on WTP and their implications

We synthesized the findings of 377 studies to compare the consumers' WTP for the special attributes across different subgroups, including income level, time period, method, attribute type, food type, and information carriers. Our study found that 13% of the estimates have a negative WTP. The phenomenon of negative price premiums was attributed to several factors. First, the concept of information avoidance challenges the conventional belief that more information is inherently beneficial (Golman et al., 2017; Reisch et al., 2021). We observed that some negative WTP values were associated with origin information. Such information is sometimes perceived as unimportant or irrelevant, so it offers no added value and may even reduce consumers’ WTP (Sunstein, 2021). In some instances, food choices are driven primarily by personal taste or brand preference (Helfer et al., 2014). The information provided on labels may be entirely disregarded, rendering it irrelevant to the consumer's decision-making process (Viviana Viola et al., 2016). Second, emerging food technologies, such as genetically modification (GM), are not always perceived

positively by consumers, although they are scientifically supported (Rousu et al., 2007). This perceived risk may lead to food neophobia, disgust sensitivity, and cultural values, ultimately resulting in negative evaluations of the associated products (Siegrist & Hartmann, 2020). Finally, certain labels or attributes, such as a 'Nutrition Score D', may convey negative health implications (Stiletto et al., 2024). These signals can shape consumers' perceptions and preferences in unfavorable ways, contributing to the undervaluation of products.

The analysis result of subgroups by income level reveals that consumers in the countries at the upper-middle and lower-middle income levels exhibit a high willingness to pay for specific food attributes. This finding is consistent with previous research (Tran et al., 2024), suggesting that consumers in developing countries place greater emphasis on special food attributes compared to those in developed nations. Over the past several decades, high-income countries have seen steady improvements in food safety and corresponding consumer awareness, leading to widespread trust in national food safety systems, largely due to strict regulations and consistent enforcement (Meixner & Katt, 2020). Consumers often no longer heavily rely on additional information to assess food quality and nutrition, which in turn reduces their willingness to pay a premium for specific food attributes. In contrast, while consumers in low-income countries may value special food attributes, economic constraints often limit their ability to act on these preferences, due to a large share of their household budgets being dedicated to basic food needs (MacLachlan et al., 2025).

This study further reveals that consumers' WTP for specific food attributes has a fluctuating trend over time. During the initial three phases of the study period (2000-2018), WTP consistently increased, possibly driven by heightened public awareness of food quality and health and the widespread dissemination of sustainability-oriented values (Hu et al., 2024). Food safety incidents—such as the 2008 melamine contamination in China (Soon-Sinclair et al., 2024) and the 2013 horsemeat scandal in Europe (Yiannaka, 2023)—further intensified consumers' concerns about food quality and safety, which may have increased demand for food information and led to a higher willingness to pay for value-added food attributes (Liu et al., 2022). However, in the past six years, a noticeable decline in WTP has been observed, which has been empirically linked to broader socio-economic disruptions (Mustapa & Kallas, 2025). Global events such as the COVID-19 pandemic, recurring avian influenza outbreaks, and the Russia-Ukraine war have led to rising food prices and reductions in household disposable income (MacLachlan et al., 2025; Midões & Seré, 2022), thereby constraining consumers' ability and willingness to pay premiums for enhanced food features. These findings suggest that, although consumer interest in food special

attributes remains, WTP appears to be sensitive to shifts in economic and social conditions.

The results of the meta-analysis also indicate that there is a significant difference in WTP measured by various methods. The multiple price list approach was the exception among stated preference methods, as the auction elicited a higher WTP than the other three methods. This may be attributed to potential measurement biases or overbidding behavior often observed in auction settings (Gupta, 2021). Our study also found that WTP effect sizes derived from market data are generally lower than those obtained through other methods. Kang et al. (2011) proposed that analyses based on market data may more accurately reflect true market demand, whereas stated preference methods such as choice experiments and contingent valuation are more likely to overestimate WTP under hypothetical conditions. The choice experiment was widely applied among the various methods, reflecting its popularity in WTP estimation. This is possibly because of the methodological advantages, including the ability to provide richer value information, reduce implementation costs, and achieve statistical efficiency with small sample sizes (Holmes et al., 2017). In conclusion, the results highlight the importance of selecting appropriate methods for measuring WTP, as they can substantially influence the results and reliability of WTP estimates.

Our study observed that consumers tend to be willing to pay higher premiums for plant-based foods compared to animal-based food and processed products. This finding is consistent with prior studies, such as those of Li and Kallas (2021), who highlighted that consumers often pay more for plant-based foods than others. Similarly, van Doorn and Verhoef (2011) found that consumers exhibit greater WTP for organic labels on “virtue” foods—such as fruits and vegetables—than on “vice” processed food. A partial explanation for this trend lies in basic economic reasoning: plant-based foods generally have lower base prices than animal-based or processed alternatives. Thus, even when the absolute premium paid is the same (e.g., an additional dollar), the relative increase appears more substantial for lower-priced plant-based items, potentially inflating percentage-based WTP. Additionally, consumers may view special attributes on plant-based foods as more directly tied to health outcomes, given that these items are often consumed raw or with minimal processing (Pollard et al., 2002). In contrast, the thorough cooking of animal-based products and processed food is seen as a safeguard that mitigates many potential safety risks, such as pathogens, reducing reliance on production-related claims.

The result of the subgroup meta-analysis showed that consumers’ WTP varies significantly across different types of food attributes. Specifically, consumers are willing to pay more for attributes like ‘quality and safety’ and ‘sustainability’ than for ‘health

and nutrition'. While there has been a steady improvement in population health literacy in recent years, leading to a higher awareness of the role of healthy eating in disease prevention and physical well-being, this is still insufficient to drive sustained changes in consumers' WTP for such a food attribute (Bi et al., 2025). As a typical credence attribute (Darby & Karni, 1973), the benefits of health and nutrition are not easily observable or verifiable after consumption, and this information asymmetry may weaken consumer confidence and further reduce their WTP for such attributes.

The results of our study indicate that logos (as opposed to text and barcode) significantly enhance consumers' WTP for special attributes. This may be because many consumers struggle to understand the traditional food labels, which are only effective when it is transmitted in a clear and accessible way (Camilleri et al., 2019; Hartikainen et al., 2014). Logos improve the efficiency of information transmission through more intuitive visual signals. For example, Reeck et al (2023) found that traffic-light nutrition indicators on packaging were more effective in conveying health-related information than complex textual descriptions. Similarly, Hu et al. (2022) showed that presenting information in the form of a logo can increase consumers' WTP. In addition, our study found that consumers' WTP is almost the same whether the information is delivered through text or through barcodes, although the number of studies on barcodes was much less (**Fig. 5.4**). Barcodes, particularly QR codes, require users to access information via smartphones, but this marginal effort does not appear to diminish their willingness to pay. **Fig. 5.2b** shows that barcodes are consistently associated with the attribute 'quality and safety', likely because they have advantages in effectively transmitting large amounts of traceability and product-specific information (Li et al., 2024).

5.4.2 Advantages, limitations, and implications

This study has two prominent advantages over previous meta-analyses on measuring WTP. First, whereas previous studies only focused on one type of food attribute, the present analysis includes WTP estimates for a comprehensive range of food attribute types. Second, this is the first meta-analysis to examine variations in WTP across different national income levels, time periods, and carriers. These contributions not only provide multidimensional insights into consumers' WTP but also support the development of tailored strategies for presenting distinctive food attributes to specific consumer groups.

In terms of the modeling approach, it is possible that subgroup analyses, despite the application of rigorous statistical methods, do not comprehensively address all potential sources of heterogeneity and bias due to the heterogeneity existing in many subgroups.

One of the limitations is that our study did not take demographics into account because of the incomplete relevant information in many included studies. Evidence from previous studies (Katt & Meixner, 2020) suggests that the demographic variables that frequently influence consumers' WTP are age, gender, income, and education level.

Another potential reason for high heterogeneity is different values and attitudes. There exists a positive relationship among consumer awareness, value orientation, and willingness to pay (Hu et al., 2024). In other words, when a specific attribute of food products aligns with a consumer's strongly held awareness or concern (e.g., environmental or health-related), the consumer is more likely to perceive the attribute favorably and demonstrate a higher willingness to pay.

A second limitation is the high study heterogeneity, which suggests that the included estimates tended to differ from each other on several dimensions (Quinn et al., 2025). This can be explained by the complexity of the consumers' decision on payment (Stavins, 2017). Heterogeneity might have arisen from the relatively broad subgroup classification adopted in our study. Findings of a previous study conducted by Jin et al (2017) indicate that when all other variables are held constant, consumers may exhibit different WTP based solely on the level of detail in traceability information. Their results show that a high degree of heterogeneity still exists within each subgroup. This suggests that the current subgrouping approach contributes to the explanation of the heterogeneity sources to some extent, but is not sufficient to fully disclose the underlying differences. Therefore, in the future, it is necessary to refine the subgroup classification further to reduce the heterogeneity of subgroups and enhance the accuracy of their results. Achieving this will depend on more comprehensive and detailed reporting of study designs and contextual factors across studies. In addition to the six subgroups explored, factors such as the econometric model (van Loo et al., 2011; Wang et al., 2022), product pricing (Piracci et al., 2024), product amount (Elbakidze & Nayga Jr, 2012), and the attribute verification (Indrawan et al., 2021) can also lead to variations in WTP measurements.

Previous studies that focus on consumers' WTP for multiple food attributes were excluded. The evidence from relevant studies shows that consumers' WTP for multiple attributes is not simply the sum of their WTP for each attribute. Instead, when multiple attributes are present simultaneously, the overall WTP may be influenced by the number of attributes and their complex interactions, resulting in unknown integration effects (Tran et al., 2024). At present, the number of studies examining consumers' WTP for multiple food attributes remains limited. As more research becomes available over time, future meta-analyses may be able to explore how multiple food attributes

together influence WTP, offering deeper insights into the interaction effects among attributes in consumer payment.

Our research supports the influence of food attributes on the premium consumers are willing to pay for food, and provides insights highlighting consumers' sensitivity to special food attributes, indicating the importance of considering product attributes in food design and marketing processes. By integrating findings from multiple studies, the analysis also contributes to the overall validity of WTP estimations.

References

Aluthge, S., Gunathilake, S., Farahnaky, A., Brennan, C. S., Urban, S., Golneshin, A., & Majzoobi, M. (2025). Green wheat Freekeh: evolution from traditional cereal to sustainable future food. *Critical Reviews in Food Science and Nutrition*, 1-15. https://doi.org/10.1080/10408398.2025.2528741

Barreiro-Hurle, J., Gracia, A., & De-Magistris, T. (2010). The effects of multiple health and nutrition labels on consumer food choices. *Journal of Agricultural Economics*, *61*(2), 426-443. https://doi.org/10.1111/j.1477-9552.2010.00247.

Bi, C., Cui, X., Sun, Z., & Jin, Y. (2025). Thinking AI or feeling AI? The effect of AI on consumers' willingness to purchase healthy food from the perspective of nudge. *Humanities and Social Sciences Communications*, *12*(1), 1-15. https://doi.org/10.1057/s41599-025-05391-w

Borenstein, M. (2024). Avoiding common mistakes in meta-analysis: Understanding the distinct roles of Q, I-squared, tau-squared, and the prediction interval in reporting heterogeneity. *Research Synthesis Methods*, *15*(2), 354-368. https://doi.org/10.1002/jrsm.1678

Borenstein, M., Hedges, L. & Rothstein, H. (2007). Meta-analysis: Fixed Effect vs. Random Effects (Meta-Analysis). Retrieved from *https://www.meta-analysis.com/downloads/Meta-analysis%20fixed%20effect%20vs%20random%20effects%20072607.pdf*. Accessed November 11, 2024

Bradu, C., Orquin, J. L., & Thøgersen, J. (2014). The mediated influence of a traceability label on consumer's willingness to buy the labelled product. *Journal of Business Ethics*, *124*(2), 283-295. https://doi.org/10.1007/s10551-013-1872-2

Breidert, C., Hahsler, M., & Reutterer, T. (2006). A review of methods for measuring willingness-to-pay. *Innovative Marketing*, *2*(4).

Camilleri, A. R., Larrick, R. P., Hossain, S., & Patino-Echeverri, D. (2019). Consumers underestimate the emissions associated with food but are aided by labels. *Nature Climate Change, 9*(1), 53-58. https://doi.org/10.1038/s41558-018-0354-z

Clark, B., Stewart, G. B., Panzone, L. A., Kyriazakis, I., & Frewer, L. J. (2017). Citizens, consumers and farm animal welfare: A meta-analysis of willingness-to-pay studies. *Food Policy*, *68*, 112-127. https://doi.org/10.1016/j.foodpol.2017.01.006

Cohen, M. A., & Vandenbergh, M. P. (2012). The potential role of carbon labeling in a green economy. *Energy Economics*, *34*, S53-S63. https://doi.org/10.1016/j.eneco.2012.08.032

Cuijpers, P., Griffin, J. W., & Furukawa, T. A. (2021). The lack of statistical power of subgroup analyses in meta-analyses: a cautionary note. *Epidemiology and Psychiatric Sciences*, *30*, e78. https://doi.org/10.1017/S2045796021000664

Darby, M. R., & Karni, E. (1973). Free competition and the optimal amount of fraud. *The Journal of Law and Economics, 16*(1), 67-88. https://doi.org/10.1086/466756

Egger, M., Smith, G. D., Schneider, M., & Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. *bmj*, *315*(7109), 629-634. https://doi.org/10.1136/bmj.315.7109.629

Elbakidze, L., & Nayga Jr, R. M. (2012). The effects of information on willingness to pay for animal welfare in dairy production: Application of nonhypothetical valuation mechanisms. *Journal of Dairy Science*, *95*(3), 1099-1107. https://doi.org/10.3168/jds.2011-4730

Golman, R., Hagmann, D., & Loewenstein, G. (2017). Information avoidance. *Journal of Economic Literature*, *55*(1), 96-135. https://doi.org/10.1257/jel.20151245

Grunert, K. G. (2005). Food quality and safety: consumer perception and demand. *European Review of Agricultural Economics*, *32*(3), 369-391. https://doi.org/10.1093/eurrag/jbi011

Gupta, S. (2021). Strategic overbidding in dynamic auctions: Structural estimation of value of synergy. *Production and Operations Management*, *30*(2), 584-605. https://doi.org/10.1111/poms.13282

Hall, M. G., Grummon, A. H., Whitesell, C., Lee, C. J., Errico, Q., Portacio, T., Avendano-Galdamez, M. I., Byron, M. J., & Goldstein, A. O. (2025). Evaluating text, icon, and graphic nutrition labels: An eye tracking experiment with Latino adults in the US. *Appetite*, *204*, 107745. https://doi.org/10.1016/j.appet.2024.107745

Hartikainen, H., Roininen, T., Katajajuuri, J. M., & Pulkkinen, H. (2014). Finnish consumer perceptions of carbon footprints and carbon labelling of food products. *Journal of Cleaner Production*, *73*, 285-293. https://doi.org/10.1016/j.jclepro.2013.09.018

Harvey, D., & Hubbard, C. (2013). Reconsidering the political economy of farm animal welfare: An anatomy of market failure. *Food Policy*, *38*, 105-114. https://doi.org/10.1016/j.foodpol.2012.11.006

Helfer, P., & Shultz, T. R. (2014). The effects of nutrition labeling on consumer food choice: a psychological experiment and computational model. *Annals of the New York Academy of Sciences*, *1331*(1), 174-185. https://doi.org/10.1111/nyas.12461

Higgins, J. P., Altman, D. G., Gøtzsche, P. C., Jüni, P., Moher, D., Oxman, A. D., Savović, J., Schulz, K. F., Weeks, L., & Sterne, J. A. (2011). The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ*, *343*. https://doi.org/10.1136/bmj.d5928

Hindes, I., Sarwar, H. N., Gravesteijn, B. Y., Jardine, J., Burgos-Ochoa, L., Been, J. V., Zenner, D., & Iliodromiti, S. (2025). The association of COVID-19 lockdowns with adverse birth and pregnancy outcomes in 28 high-income countries: a systematic review and meta-analysis. *Nature Human Behaviour*, 1-11. https://doi.org/10.1038/s41562-025-02139-z

Holmes, T. P., Adamowicz, W. L., & Carlsson, F. (2017). Choice experiments. In *A primer on nonmarket valuation* (pp. 133-186). Dordrecht: Springer Netherlands.

Hu, T., Al Mamun, A., Reza, M. N. H., Wu, M., & Yang, Q. (2024). Examining consumers' willingness to pay premium price for organic food. *Humanities and Social Sciences Communications*, *11*(1), 1-15. https://doi.org/10.1057/s41599-024-03789-6

Hu, Y., House, L. A., & Gao, Z. (2022). How do consumers respond to labels for crispr (gene-editing)?. *Food Policy*, *112*, 102366. https://doi.org/10.1016/j.foodpol.2022.102366

Indrawan, D., Christy, A., & Hogeveen, H. (2021). Improving poultry meat and sales channels to address food safety concerns: consumers' preferences on poultry meat attributes. *British Food Journal*, *123*(13), 529-546. https://doi.org/10.1108/BFJ-04-2021-0362

Jin, S., Zhang, Y., & Xu, Y. (2017). Amount of information and the willingness of consumers to pay for food traceability in China. *Food Control*, *77*, 163-170. https://doi.org/10.1016/j.foodcont.2017.02.012

Kang, M. J., Rangel, A., Camus, M., & Camerer, C. F. (2011). Hypothetical and real choice differentially activate common valuation areas. *Journal of Neuroscience*, *31*(2), 461-468. https://doi.org/10.1523/JNEUROSCI.1583-10.2011

Katt, F., & Meixner, O. (2020). A systematic review of drivers influencing consumer willingness to pay for organic food. *Trends in Food Science & Technology*, *100*, 374-388. https://doi.org/10.1016/j.tifs.2020.04.029

Kolodinsky, J., & Lusk, J. L. (2018). Mandatory labels can improve attitudes toward genetically engineered food. *Science Advances*, *4*(6), eaaq1413. https://doi.org/10.1126/sciadv.aaq1413

Le Gall-Ely, M. (2009). Definition, measurement and determinants of the consumer's willingness to pay: a critical synthesis and avenues for further research. *Recherche et Applications en Marketing (English Edition)*, *24*(2), 91-112. https://doi.org/10.1177/205157070902400205

Li, P., Yang, J., Jiménez-Carvelo, A. M., & Erasmus, S. W. (2024). Applications of food packaging quick response codes in information transmission toward food supply chain integrity. *Trends in Food Science & Technology*, *146*, 104384. https://doi.org/10.1016/j.tifs.2024.104384

Li, S., & Kallas, Z. (2021). Meta-analysis of consumers' willingness to pay for sustainable food products. *Appetite*, 163, 105239. https://doi.org/10.1016/j.appet.2021.105239

Liu, R., Gao, Z., Snell, H. A., & Ma, H. (2020). Food safety concerns and consumer preferences for food safety attributes: Evidence from China. *Food Control*, *112*, 107157. https://doi.org/10.1016/j.foodcont.2020.107157

MacLachlan, M. J., Adjemian, M. K., Etienne, X., Sweitzer, M., Volpe III, R., & Zeng, W. (2025). Adaptive food price forecasting improves public information in times of rapid economic change. *Nature Communications*, *16*(1), 6282. https://doi.org/10.1038/s41467-025-61660-x

Meixner, O., & Katt, F. (2020). Assessing the impact of COVID-19 on consumer food safety perceptions—A choice-based willingness to pay study. *Sustainability*, *12*(18), 7270. https://doi.org/10.3390/su12187270

Messer, K. D., Costanigro, M., & Kaiser, H. M. (2017). Labeling food processes: the good, the bad and the ugly. *Applied Economic Perspectives and Policy*, *39*(3), 407-427. https://doi.org/10.1093/aepp/ppx028

Midões, C., & Seré, M. (2022). Living with reduced income: an analysis of household financial vulnerability under COVID-19. *Social Indicators Research*, *161*(1), 125-149. https://doi.org/10.1007/s11205-021-02811-7

Monteiro, J. S., Botelho, R. B. A., Zandonadi, R. P., & Araujo, W. M. C. (2023). Is there a convergence between the food classification adopted by food-based dietary guidelines and food science and technology?. *Foods*, *12*(20), 3824. https://doi.org/10.3390/foods12203824

Mustapa, M. A. C., & Kallas, Z. (2025). Meta-analysis of consumer willingness to pay for short food supply chain products. *Global Challenges*, *9*(3), 2400154. https://doi.org/10.1002/gch2.202400154

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., & Chou, R. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*, *372*. https://doi.org/10.1136/bmj.n71

Piracci, G., Lamonaca, E., Santeramo, F. G., Boncinelli, F., & Casini, L. (2024). On the willingness to pay for food sustainability labelling: A meta-analysis. *Agricultural Economics*, *55*(2), 329-345. https://doi.org/10.1111/agec.12826

Pollard, J., Kirk, S. L., & Cade, J. E. (2002). Factors affecting food choice in relation to fruit and vegetable intake: a review. *Nutrition Research Reviews, 15*(2), 373-387. https://doi.org/10.1079/NRR200244

Prasad, S., Kalafat, E., Blakeway, H., Townsend, R., O'Brien, P., Morris, E., Draycott, T., Thangaratinam, S., Le Doare, K., Ladhani, S., von Dadelszen, P., Magee, L. A., Heath, P., & Khalil, A. (2022). Systematic review and meta-analysis of the effectiveness and perinatal outcomes of COVID-19 vaccination in pregnancy. *Nature Communications*, *13*(1), 2414. https://doi.org/10.1038/s41467-022-30052-w

Quinn, E. A., Millard, E., & Jones, J. M. (2025). Group arts interventions for depression and anxiety among older adults: a systematic review and meta-analysis. *Nature Mental Health*, 1-13. https://doi.org/10.1038/s44220-024-00368-1

Reeck, C., Posner, N. A., Mrkva, K., & Johnson, E. J. (2023). Nudging app adoption: Choice architecture facilitates consumer uptake of mobile apps. *Journal of Marketing*, *87*(4), 510-527. https://doi.org/10.1177/00222429221141066

Reisch, L. A., Sunstein, C. R., & Kaiser, M. (2021). What do people want to know? Information avoidance and food policy implications. *Food Policy*, 102, 102076. https://doi.org/10.1016/j.foodpol.2021.102076

Rousu, M., Huffman, W. E., Shogren, J. F., & Tegene, A. (2007). Effects and value of verifiable information in a controversial market: evidence from lab auctions of genetically modified food. *Economic Inquiry*, *45*(3), 409-432. https://doi.org/10.1111/j.1465-7295.2007.00017.x

Ryan, A. M., & Spash, C. L. (2011). Is WTP an attitudinal measure? Empirical analysis of the psychological explanation for contingent values. *Journal of Economic Psychology*, *32*(5), 674-687. https://doi.org/10.1016/j.joep.2011.07.004

Sedgwick, P. (2013). Meta-analyses: heterogeneity and subgroup analysis. *BMJ*, *346*. https://doi.org/10.1136/bmj.f4040

Siegrist, M., & Hartmann, C. (2020). Consumer acceptance of novel food technologies. *Nature Food*, *1*(6), 343-350. https://doi.org/10.1038/s43016-020-0094-x

Soon-Sinclair, J. M., Nayak, R., & Manning, L. (2024). An AcciMap approach to analyse the Chinese melamine milk scandal. *British Food Journal*, *126*(6), 2604-2618. https://doi.org/10.1108/BFJ-02-2023-0161

Spineli, L. M., & Pandis, N. (2020). Exploring heterogeneity in meta-analysis: Subgroup analysis. Part 1. *American Journal of Orthodontics and Dentofacial Orthopedics*, *158*(2), 302-304. https://doi.org/10.1016/j.ajodo.2020.04.002

Stavins, J. (2017). How do consumers make their payment choices?. *Research Data Reports Paper*, (17-1).

Stiletto, A., Vecchio, R., Cembalo, L., & Trestini, S. (2024). The impact of nutri-score on consumers' preferences for geographical indications. Evidence from a non-hypothetical experiment. *Appetite*, *199*, 107400. https://doi.org/10.1016/j.appet.2024.107400

Sunstein, C. R. (2021). Are food labels good?. *Food Policy*, *99*, 101984. https://doi.org/10.1016/j.foodpol.2020.101984

The World Bank. (2025). World Bank Country and Lending Groups. Retrieved from *https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups*. Accessed February 21, 2025

Tran, D., Schouteten, J. J., Gellynck, X., & De Steur, H. (2024). How do consumers value food traceability?-A meta-analysis. *Food Control*, 110453. https://doi.org/10.1016/j.foodcont.2024.110453

van Doorn, J., & Verhoef, P. C. (2011). Willingness to pay for organic products: Differences between virtue and vice foods. *International Journal of Research in Marketing*, *28*(3), 167-180. https://doi.org/10.1016/j.ijresmar.2011.02.005

van Loo, E. J., Caputo, V., Nayga Jr, R. M., Meullenet, J. F., & Ricke, S. C. (2011). Consumers' willingness to pay for organic chicken breast: Evidence from choice experiment. *Food Quality and Preference*, *22*(7), 603-613. https://doi.org/10.1016/j.foodqual.2011.02.003

Viviana Viola, G. C., Bianchi, F., Croce, E., & Ceretti, E. (2016). Are food labels effective as a means of health prevention?. *Journal of Public Health Research*, *5*(3), jphr-2016. https://doi.org/10.4081/jphr.2016.768

Wang, H. H., Yang, J., & Hao, N. (2022). Consumers' willingness to pay for rice from remediated soil: potential from the public in sustainable soil pollution treatment. *International Journal of Environmental Research and Public Health*, *19*(15), 8946. https://doi.org/10.3390/ijerph19158946

Yiannaka, A. (2023). Food fraud: a persistent problem that demands a comprehensive approach. *Journal of Consumer Protection and Food Safety*, *18*(4), 359-360. https://doi.org/10.1007/s00003-023-01465-6

Supplementary Materials: Protocol and supporting results

Supplementary Text 5.1: Inclusion and exclusion criteria for the three phases

The inclusion criteria for the first phase of screening

- Relevant. The research topic of a paper should match that of our study. In other words, the keyword 'WTP' or its synonyms should appear in the titles or abstracts.
- Involving food products. The research object should be at least one of the specific food types or a general food concept. 'Food products' here is a broad concept, specifically referring to all the products edible for humans. Thus, the papers focusing on WTP for plants, seeds, cigars, food for pets, pesticides, and so on, will be excluded.
- Involving specific special food attributes. The included papers should involve at least one of the special food attributes. Some standard food attributes, including the observable attributes (appearance, price, convenience), new food products without any additional nutrition attributes, food storage ways, innovative packages, brand logos, hometown information related to food, and general ingredient information, are not considered as one of the special attributes.
- English version. The title and abstract should be in English.
- Abstract available. The abstract should be available for screening.

The exclusion criteria for the second phase of screening

- Irrelevant. The research topic was not sufficiently aligned with the scope of this study. Specifically, excluded papers met at least one of the following criteria: (1) no WTP or price premiums was mentioned in the study; (2) purely qualitative methods rather than quantitative analysis were employed; (3) only policy-related issues concerning WTP rather than consumer behavior were involved; (4) whether consumers had WTP for specific food information attributes using only binary (yes/no) responses was explored; (5) actors other than consumers within the supply chain were participated in the studies. (6) The consumer sample was not representative. Studies involved participants who received specialized training prior to the research or those belonging to groups with heightened awareness (such as experts). (7) There is no empirical data (reviews, meta-analyses) in the study.
- No monetary WTP value. Only studies that quantify consumers' willingness to pay (WTP) as a specific monetary value were included. Studies that merely reported the number of consumers within different ranges of WTP —without

converting them into monetary terms—were excluded. Studies measuring WTP by dummy or Likert scales are excluded.

- No food or special attributes. No food refers to the items not intended for human consumption, such as plants, seeds, chewing gum, cigars, pet food, pesticides, and similar products. No special attributes means that the exclusive papers do not involve any special food attributes in their research. In these cases, the papers may just focus on consumers' WTP for observable attributes (appearance, price, convenience), new food products without any additional nutrition attributes, food storage ways, innovative packages, and so on. Brand logo, hometown food, plant-based food, ingredient information, innovation business practice information, mainstream food, ready-to-cook, and recycled glass are not considered as one of the special attributes.
- No general consumers. General consumers refer to members of the general public who make food purchasing decisions primarily for consumption. Studies were excluded if they only focused on specific populations (e.g., students or businessmen), on consumers with specific awareness (e.g., environmentally conscious or health-focused individuals), or on participants who received training or educational interventions before the experiment.
- No full-text available. Studies whose full text could not be accessed were excluded, as the absence of complete information prevented a thorough assessment of the research results. The full texts of the articles were retrieved through platforms and databases, such as Sci-Hub, ResearchGate, and Google Scholar.
- No identified methodology. Studies in which the research methodology was unclear, insufficiently described, or entirely missing were excluded, as the research results may be unreliable.
- Multiple attributes involved. Studies that explored consumers' WTP for two or more hybrid attributes were excluded, as their principles and effects are complex (Tran et al., 2024).
- Foreign languages. Studies published in languages other than English were excluded

The exclusion criteria for the last phase of screening

- Missing the base price of food. The base price is one of the key variables used to calculate the percentage of willingness to pay as an essential parameter in our study.
- Missing variability measures. Variability measures, including standard error (SE), standard deviation (SD), and confidence intervals (CI), are essential for

determining the weight of each estimate in a meta-analysis. The absence of such variability measures is a serious issue in meta-analysis (Idris & Robertson, 2009).

Therefore, studies lacking information on base price or variability measures were excluded from this study. Given the substantial variation in food prices across regions and time periods (D'Souza & Jolliffe, 2012), as well as the large differences observed in the reported variability measures of included studies, no imputation was performed for missing base prices or variability data. As a result, this study followed a complete case analysis approach (Clark et al., 2017).

Supplementary Text 5.2: Search strings

To identify all relevant studies regarding consumers' willingness to pay (WTP) for special food attributes, a systematic search strategy was developed by combining key terms using Boolean operators.

((“WTP” OR “willingness to pay” OR “willingness-to-pay” OR premium) AND (food* OR “agrifood” OR “agri-food” OR agricultur* OR “food system”) AND (label* OR certificat* OR attribute*) AND (consumer))

The Scopus searches yielded 1920, the Web of Science searches 1315, and the Econlit yielded 613 results.

Supplementary Text 5.3: Data extraction content and method

- Willingness to pay (WTP). This indicates how much consumers are willing to pay extra for specific food attributes. The data represent a quantitative variable, extracted as a monetary value, with the corresponding currency unit documented accordingly.
- Publication year. The publication year of an article refers to the year in which the work was officially published by a journal. The publication year is determined based on the relevant information provided by the journal.
- Research year. It refers to the year in which a study was conducted. If a study spans two or more years, the year in which the study began is recorded as the research year. Of the 377 studies ultimately included in this study, 13 did not report the specific research year. Based on the remaining 364 studies with available data, the gap between the research year and the publication year is calculated (see **Fig. S5.1**). The majority of studies showed a gap of 2 to 3 years between these two time points. As a result, for 13 studies without a reported research year, the research year is imputed by subtracting three years from the publication year.
- Method. The methodological details of each included study were carefully reviewed to identify the specific method used for measuring willingness to pay (WTP). In cases where the method was not explicitly stated, the method was identified based on the definition and characteristics of diverse WTP measurement proposed by Breidert et al. (2006).
- Information carriers. It denotes the medium or carrier through which information on special food attributes is communicated to consumers. If the food attributes in the experiments are conveyed through a barcode or logo, the information transmission carrier is recorded as ‘barcode’ or 'logo', respectively. When the attributes are presented to the participants through textual descriptions, verbal explanations, or similar means, the transmission channel is classified as 'text'. In studies where the mode of information transmission is not specified, 'text' is considered to be the information transmission carrier. It is worth noting that some logos may incorporate textual elements, such as the name of a food attribute. Such cases are still categorized as 'logo' because logo, as a prominently visual element, is likely to attract consumers' attention first (Bhatt et al., 2021). One-dimensional code, two-dimensional codes, and Quick Response (QR) codes are all categorized as barcodes.
- Number of participants. This refers to the total number of individuals who take part in a study. Participants must be consumers, the final users in the food supply chain who purchase and utilize food products or services (Luning &

Marcelis, 2020). Only valid samples are included in the count, as invalid data are excluded from the model by the researchers. For panel data, each observation is counted as one instance of consumer participation. In some studies, households are used as the unit of analysis and are thus considered as a single instance of consumer participation.

- Food. The type of food targeted by the included study is directly recorded.
- Country. The methodology section of each included study was reviewed to identify the country in which the research was conducted.
- Food attribute. The type of food targeted by the included study is directly recorded.
- Base price. This refers to the selling price of food in the market. In some studies, it is equivalent to consumers' willingness to pay for the food without special attributes. In choice experiments, consumers are typically offered several price alternatives for food products, allowing researchers to assess their preferences and willingness to pay under different pricing scenarios. When there are two price options, the average of the two is taken as the base price. When there are three options, the median price is used as the base price. For four or more price options, the base price is defined as the average of the highest and lowest prices.
- Variability measures. It includes standard error (SE), standard deviation (SD), and confidence intervals (CI). In some studies, variability measures for WTP were not directly reported and can be calculated based on the variability measures of the coefficients using the formulas provided in the study.

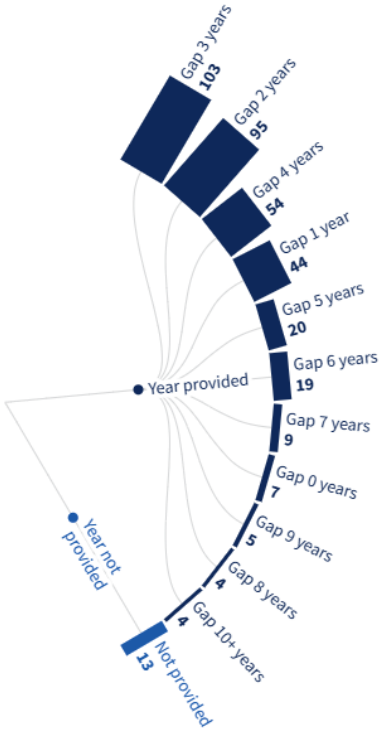


Fig. S5.1 Distribution of studies with a reported research year (N = 364) and without a reported research year (N = 13), along with a visualization of the time gap between research year and publication year. Bold numbers represent the number of studies in each gap category. The majority of studies reported a 2- or 3-year gap between research and publication.

Supplementary Text 5.4: Calculation process of the percentage of WTP and its standard error

Calculation process of the percentage of WTP

i. If the values of WTP for special food attributes are presented in the form of a percentage, they are extracted directly.
ii. If the values of WTP for special food attributes are reported in monetary form, they are converted into percentages using the following formula.

$$WTP(\%) = \frac{WTP_{special\ attribute}}{Price_{conventional\ food}} \times 100\%$$

$WTP_{special\ attribute}$ refers to consumers' willingness to pay for a special food attribute, and can be calculated by consumers' willingness to pay for the food with a special attribute minus the selling price of conventional food.

$Price_{conventional\ food}$ denotes the selling price of food products in the market.

Calculation process of the standard error

i. If the values of the standard errors of WTP for special food attributes are presented in the form of a percentage, they are extracted directly.
ii. If the standard errors are associated with consumers' willingness to pay for a special food attribute, they are converted into percentages using the following formula (Altman & Bland, 2005).

$$SE(\%) = \frac{SE_{special\ attribute}}{Price_{conventional\ food}} \times 100\%$$

$SE_{special\ attribute}$ represents the standard error of the consumers' willingness to pay for a special food attribute, and can be diverted by the standard deviation (SD) or confidence interval (CI) using the following conversion formula.

$$SE = \frac{SD}{\sqrt{n}}$$

$$SE = \frac{(Upper\ Bound - Lower\ Bound)}{2 \times Z}$$

n denotes the sample size, typically referring to the number of consumers who participated in the study.

Upper Bound and *Lower Bound* refer to the upper and lower limits of the confidence interval, respectively.

Z represents the critical value from the standard normal distribution corresponding to the selected confidence level.

- For a 95% confidence level, $Z = 1.96$
- For a 90% confidence level, $Z = 1.645$
- For a 99% confidence level, $Z = 2.576$

Supplementary Text 5.5: Customized tool for the analysis of bias

The studies used to measure consumers' willingness to pay (WTP) are not a typical Randomized Controlled Trial (RCT). Thus, the items for Risk of Bias in Cochrane are revised to adapt to the characteristics of this study and are shown in **Table S5.1**.

- **Reporting bias:** The results, including WTP values and their SE, are reported selectively or not.
- **Sample Representativeness Bias**: The participants are representative or not.
- **Analysis Transparency Bias**: The data process is stated or not.
- **Recruitment Bias:** The recruitment approach is stated/reliable or not.
- **Contextual Bias:** Some information, including search year and food unit, is missing.

Table S5.1. The assessment criteria for each domain of risk of bias.

Type of bias	Criteria	Risk level
Reporting bias	All the data are reported completely	Low risk of bias
	One of the WTP values and its SEs is missing	Unclear risk of bias/Some concerns
	More than two of the WTP values and their SEs are missing	High risk of bias
Sample representativeness bias	All respondents are randomly recruited. Or the panel data is used.	Low risk of bias
	The randomness of respondent recruitment is a bit low. E.g., all the respondents are citizens or recruited in one city.	Unclear risk of bias/Some concerns
	The randomness of respondent recruitment is very low. E.g., all respondents are recruited from a school or a supermarket, meaning that they are all students or businessmen.	High risk of bias
Analysis transparency bias	The principles and the process of calculation and analysis are transparent. E.g., Models and equations are clearly elaborated.	Low risk of bias
	The principles and the process of calculation and analysis are not transparent enough. E.g., Models and equations are shown roughly.	Unclear risk of bias/Some concerns
	The principles and the process of calculation and analysis are not transparent. E.g., just to describe the data without the calculation process.	High risk of bias
Recruitment bias	The recruitment approach is clearly stated. E.g., while collaborating with a company in questionnaire distribution, the company's name, time, and the number of effective and ineffective samples are shown clearly; While recruiting respondents in shops, locations, time, the number of interviewers and respondents, and the process are shown clearly.	Low risk of bias
	The recruitment approach is roughly stated as some relevant information is not shown.	Unclear risk of bias/Some concerns
	No information is shown.	High risk of bias
Contextual bias	The contextual information is completely shown.	Low risk of bias
	One type of information, including the research year, the demographics of respondents, currency, and the food unit, is missing.	Unclear risk of bias/Some concerns
	Two or more types of information, including the research year, the demographics of respondents, currency, and the food unit, are missing.	High risk of bias

Supplementary Text 5.6: Guide and claims for subgroup effects

The guide and claim for conducting subgroup meta-analyses were designed through modifications informed by prior literature (Dijkman et al., 2009).

- **Subgroup design.** The subgroup analyses in this study were designed to test hypotheses proposed prior to the initiation of the research, rather than post hoc hypotheses developed after statistical analysis. The definition and scope of each subgroup have a theoretical basis and logical significance. The subgroup categories were mutually exclusive and uncorrelated, ensuring both independence and methodological rigor. Furthermore, to avoid the risk of unreliable results due to the narrow subgroup divisions (Dijkman et al., 2009), the number of subgroups within each category ranges from three to six.
- **Low selective publishing of reports.** In conducting the subgroup analyses for each subgroup category, all willingness-to-pay (WTP) estimates from the included studies were systematically allocated to the predefined subgroups. This approach minimizes the risk of selective reporting bias, ensuring that any bias in the subgroup analyses does not attribute to incomplete or selective reporting across studies
- **Unbalanced estimates in subgroups.** The reliability of subgroup analyses largely depends on the number of estimates across subgroups. Small subgroup sizes or insufficient estimates may lead to low statistical power, undermining the validity of the research findings. A minimum of 350 estimates is required to achieve sufficient statistical power for meaningful subgroup analysis (Cuijpers et al., 2021). In this study, 1,587 effect estimates were extracted from 377 individual studies, surpassing the recommended threshold. As a result, the subgroup analyses conducted in this study are considered statistically robust and reliable.
- **Observational results.** The results of the subgroup analysis in this study are observational in nature, and there is no causal relationship between WTP and subgroup category (Higgins & Thompson, 2002; Borenstein & Higgins, 2013). The subgroup categories are based on the characteristics of the estimates rather than randomly selected variables. The findings of subgroup analyses reveal variations in effect sizes across different subgroups

Representativeness and robustness. Subgroup interaction effects become more credible when they are consistently observed across many independent studies. Such consistency enhances the representativeness and robustness of the result of subgroup analyses. The Discussion section addresses the consistency of our subgroup analysis results with findings from prior research.

Supplementary Text 5.7: Studies included in the meta-analysis

1. Tran, D., Broeckhoven, I., Hung, Y., Diem My, N. H., De Steur, H., & Verbeke, W. (2022). Willingness to pay for food labelling schemes in vietnam: a choice experiment on water spinach. *Foods*, *11*(5), 722. https://doi.org/10.3390/foods11050722
2. Enneking, U. (2004). Willingness-to-pay for safety improvements in the German meat sector: the case of the Q&S label. *European Review of Agricultural Economics*, *31*(2), 205-223. https://doi.org/10.1093/erae/31.2.205
3. Petrontino, A., Frem, M., Fucilli, V., Tria, E., Campobasso, A. A., & Bozzo, F. (2024). Consumers' purchase propensity for pasta tracked with blockchain technology and labelled with sustainable credence attributes. *Frontiers in Sustainable Food Systems*, *8*. https://doi.org/10.3389/fsufs.2024.1367362
4. Alphonce, R., & Alfnes, F. (2012). Consumer willingness to pay for food safety in Tanzania: An incentive-aligned conjoint analysis. *International Journal of Consumer Studies*, *36*(4), 394-400. https://doi.org/10.1111/j.1470-6431.2011.01067.x
5. van Loo, E. J., Caputo, V., Nayga, R. M., Meullenet, J. F., & Ricke, S. C. (2011). Consumers' willingness to pay for organic chicken breast: Evidence from choice experiment. *Food Quality and Preference*, *22*(7), 603-613. https://doi.org/10.1016/j.foodqual.2011.02.003
6. Chen, X., Zhen, S., Li, S., Yang, J., & Ren, Y. (2024). Consumers' willingness to pay for carbon-labeled agricultural products and its effect on greenhouse gas emissions: Evidence from beef products in urban China. *Environmental Impact Assessment Review*, *106*, 107528. https://doi.org/10.1016/j.eiar.2024.107528
7. Loureiro, M. L., McCluskey, J. J., & Mittelhammer, R. C. (2002). Will consumers pay a premium for eco-labeled apples?. *Journal of Consumer Affairs*, *36*(2), 203-219. https://doi.org/10.1111/j.1745-6606.2002.tb00430.x
8. Curtis, K. R., Drugova, T., Knudsen, T., Reeve, J., & Ward, R. (2020). Is organic certification important to farmers' market shoppers or is eco-friendly enough? *HortScience*, *55*(11), 1822-1831. https://doi.org/10.21273/HORTSCI15291-20
9. Zhang, M., Fan, Y., Cao, J., Chen, L., & Chen, C. (2021). Willingness to pay for enhanced mandatory labelling of genetically modified soybean oil: Evidence from a choice experiment in China. *Foods*, *10*(4), 736. https://doi.org/10.3390/foods10040736
10. Ishaq, M., Kolady, D., & Grebitus, C. (2023). Analyzing behavioral factors of willingness to pay for sustainability. *Journal of the Agricultural and Applied Economics Association*, *2*(4), 703-717. https://doi.org/10.1002/jaa2.86
11. Otieno, D. J. (2020). Consumer willingness to pay for fair-trade attributes of goat meat in Kenya: A choice experiment analysis. *African Journal of Agricultural and Resource Economics*, *15*(4), 372-386.
12. Alagsam, F. A., Alhashim, J. I., Alamri, Y. A., & Alnafissa, M. A. (2023). Demand for dates free of pesticide residue in Saudi Arabia. *Applied Ecology and Environmental Research*, *21*(3), 2441-2456. https://doi.org/10.15666/aeer/2103_24412456
13. Harkness, C., & Areal, F. (2018). Consumer willingness to pay for low acrylamide content. *British Food Journal*, *120*(8), 1888-1900. https://doi.org/10.1108/BFJ-01-2018-0043

14. Akinwehinmi, J. O., Amos, T. T., & Ogundari, K. (2021). Consumer preferences for organic vegetables in southwestern Nigeria: A choice experiment approach. *African Journal of Agricultural and Resource Economics*, *16*(1), 1-13. https://doi.org/10.53936/afjare.2021.16(2).01
15. Gracia, A. (2014). Consumers' preferences for a local food product: a real choice experiment. *Empirical Economics*, *47*(1), 111-128. https://doi.org/10.1007/s00181-013-0738-x
16. Jin, S., Zhang, Y., & Xu, Y. (2017). Amount of information and the willingness of consumers to pay for food traceability in China. *Food Control*, *77*, 163-170. https://doi.org/10.1016/j.foodcont.2017.02.012
17. Vecchio, R., & Annunziata, A. (2015). Willingness-to-pay for sustainability-labelled chocolate: an experimental auction approach. *Journal of Cleaner Production*, *86*, 335-342. https://doi.org/10.1016/j.jclepro.2014.08.006
18. Tempesta, T., Vecchiato, D., Nassivera, F., Bugatti, M., & Torquati, B. (2019). Consumers demand for social farming products: An analysis with discrete choice experiments. *Sustainability*, *11*(23), 6742. https://doi.org/10.3390/su11236742
19. Zanoli, R., Scarpa, R., Napolitano, F., Piasentier, E., Naspetti, S., & Bruschi, V. (2013). Organic label as an identifier of environmentally related quality: A consumer choice experiment on beef in Italy. *Renewable Agriculture and Food Systems*, *28*(1), 70-79. https://doi.org/10.1017/S1742170512000026
20. Kang, Q., Carpio, C. E., Garcia, M., Wang, C., Boonsaeng, T., & Hudson, D. (2024). Chinese consumers' preferences for imported beef products. *Agribusiness*. https://doi.org/10.1002/agr.21968
21. Staffolani, G., Rahmani, D., Bentivoglio, D., Finco, A., & Gil, J. M. (2023). The mountain product label: Choice drivers and price premium. *Future Foods*, *8*, 100270. https://doi.org/10.1016/j.fufo.2023.100270
22. Bozoglu, M., Bilgic, A., Huang, C. L., Florkowski, W. J., & Topuz, B. K. (2019). Urban households' willingness to pay for milk safety in Samsun and Trabzon provinces of Turkey. *British Food Journal*, *121*(10), 2379-2395. https://doi.org/10.1108/BFJ-03-2018-0174
23. Yormirzoev, M., Li, T., & Teuber, R. (2021). Consumers' willingness to pay for organic versus all-natural milk-Does certification make a difference?. *International Journal of Consumer Studies*, *45*(5), 1020-1029. https://doi.org/10.1111/ijcs.12622
24. Cagalj, M., Haas, R., & Morawetz, U. B. (2016). Effects of quality claims on willingness to pay for organic food: Evidence from experimental auctions in Croatia. *British food journal*, *118*(9), 2218-2233. https://doi.org/10.1108/BFJ-11-2015-0453
25. Ha, T. M., Shakur, S., & Do, K. H. P. (2019). Rural-urban differences in willingness to pay for organic vegetables: Evidence from Vietnam. *Appetite*, *141*, 104273. https://doi.org/10.1016/j.appet.2019.05.004
26. Hossain, K. Z., Xue, J., & Rabbany, M. G. (2023). Consumers' willingness to pay (WTP) for HACCP certified frozen farmed fish: A consumer survey from wet markets in Dhaka, Bangladesh. *Aquaculture Economics & Management*, *27*(1), 143-158. https://doi.org/10.1080/13657305.2022.2046204
27. Huffman, W. E., Shogren, J. F., Rousu, M., & Tegene, A. (2003). Consumer willingness to pay for genetically modified food labels in a market with diverse information: evidence from experimental auctions. *Journal of Agricultural and Resource Economics*, 481-502.

28. Macdiarmid, J. I., Cerroni, S., Kalentakis, D., & Reynolds, C. (2021). How important is healthiness, carbon footprint and meat content when purchasing a ready meal? Evidence from a non-hypothetical discrete choice experiment. *Journal of Cleaner Production*, *282*, 124510. https://doi.org/10.1016/j.jclepro.2020.124510
29. Liang, Y., Xu, Y., Lai, D., Hua, G., Huang, D., Wang, H., Li, H., & Han, L. (2023). Emerging market for pork with animal welfare attribute in China: An ethical perspective. *Meat Science*, *195*, 108994. https://doi.org/10.1016/j.meatsci.2022.108994
30. Wang, J., Zhou, L., Ni, Z., Wu, W., Liu, G., Fu, W., Zhang, X., & Tian, J. (2022). Consumer preference and willingness to pay for low-residue vegetables: Evidence from discrete choice experiments in China. *Frontiers in Sustainable Food Systems*, *6*, 1019372. https://doi.org/10.3389/fsufs.2022.1019372
31. Chen, X., Shang, J., Zada, M., Zada, S., Ji, X., Han, H., Ariza-Montes, A., & Ramírez-Sobrino, J. (2021). Health is wealth: Study on consumer preferences and the willingness to pay for ecological agricultural product traceability technology: Evidence from Jiangxi province China. *International Journal of Environmental Research and Public Health*, *18*(22), 11761. https://doi.org/10.3390/ijerph182211761
32. Vecchio, R., Toccaceli, D., Pacciani, A., Cavallo, C., & Caso, G. (2023). Shrinking the market space: consumer (overlapping) preferences for organic wines and three alternative competitors. *International Journal of Wine Business Research*, *35*(3), 467-486. https://doi.org/10.1108/IJWBR-10-2022-0034
33. Rambonilaza, T., & Neang, M. (2018). Exploring the potential of local market in remunerating water ecosystem services in Cambodia: An application for endogenous attribute non-attendance modelling. *Water Resources and Economics*, *25*, 14-26. https://doi.org/10.1016/j.wre.2018.07.001
34. Yue, F., Arbiol, J., Nomura, H., & Yabe, M. (2015). Preferences and willingness to pay for organic milk among urban consumers in Dalian, China. *Journal of the Faculty of Agriculture, Kyushu University*, *60*(2), 501-509. https://doi.org/10.5109/1543415
35. Marette, S., Nabec, L., & Durieux, F. (2019). Improving nutritional quality of consumers' food purchases with traffic-lights labels: An experimental analysis. *Journal of Consumer Policy*, *42*(3), 377--395. https://doi.org/10.1007/s10603-019-09420-5
36. Shahabi Ahangarkolaee, S., & Gorton, M. (2021). The effects of perceived regulatory efficacy, ethnocentrism and food safety concern on the demand for organic food. *International Journal of Consumer Studies*, *45*(2), 273-286. https://doi.org/10.1111/ijcs.12619
37. Gerrard, C., Janssen, M., Smith, L., Hamm, U., & Padel, S. (2013). UK consumer reactions to organic certification logos. *British Food Journal*, *115*(5), 727-742. https://doi.org/10.1108/00070701311331517
38. Schott, L., Britwum, K., & Bernard, J. C. (2022). Can region labeling alter taste impressions and willingness to pay? A field experiment with chocolate bars. *Food Quality and Preference*, *100*, 104606. https://doi.org/10.1016/j.foodqual.2022.104606
39. Wang, Z., Mao, Y., & Gale, F. (2008). Chinese consumer demand for food safety attributes in milk products. *Food Policy*, *33*(1), 27-36. https://doi.org/10.1016/j.foodpol.2007.05.006

40. Marette, S. (2021). Sustainability and consumer willingness to pay for legumes: A laboratory study with lentils. *Sustainability*, *13*(6), 3408. https://doi.org/10.3390/su13063408
41. Mamani Escobar, B., Sandoval, L., Palma, M. A., Carpio, C., & Garcia, M. D. (2023). Coffee sustainability attributes in developing countries: the Honduran domestic coffee market. *International Food and Agribusiness Management Review*, *26*(4), 673-689. https://doi.org/10.22434/ifamr2022.0126
42. Andersen, L. M. (2011). Animal welfare and eggs - Cheap talk or money on the counter? *Journal of Agricultural Economics*, *62*(3), 565-584. https://doi.org/10.1111/j.1477-9552.2011.00310.x
43. Chen, M., Wang, Y., Yin, S., Hu, W., & Han, F. (2019). Chinese consumer trust and preferences for organic labels from different regions: Evidence from real choice experiment. *British Food Journal*, *121*(7), 1521-1535. https://doi.org/10.1108/BFJ-02-2018-0128
44. Wang, C., Zhu, J., Zhang, X., Li, L., & Wang, M. (2024). Chinese consumers' preference and willingness to pay for carbon-labeled forest fruit products. *Polish Journal of Environmental Studies*, *33*(3), 3407-3419. https://doi.org/10.15244/pjoes/176556
45. Yang, Y., Hobbs, J. E., & Natcher, D. C. (2020). Assessing consumer willingness to pay for Arctic food products. *Food Policy*, *92*, 101846. https://doi.org/10.1016/j.foodpol.2020.101846
46. Boncinelli, F., Dominici, A., Bondioni, F., & Marone, E. (2024). Consumers behavior towards the country of origin labeling policy: The case of the pasta market in Italy. *Agribusiness*, *40*(1), 46-69. https://doi.org/10.1002/agr.21831
47. Aoki, K., Akai, K., Ujiie, K., Shimmura, T., & Nishino, N. (2019). The impact of information on taste ranking and cultivation method on rice types that protect endangered birds in Japan: Non-hypothetical choice experiment with tasting. *Food Quality and Preference, 75*, 28-38. https://doi.org/10.1016/j.foodqual.2018.11.021
48. Fang, P., Zhou, Z., Wang, H., & Zhang, L. (2024). Consumer preference and willingness to pay for rice attributes in China: Results of a choice experiment. *Foods*, *13*(17), 2774. https://doi.org/10.3390/foods13172774
49. Boehm, R., Kitchel, H., Ahmed, S., Hall, A., Orians, C. M., Stepp, J. R., Robbat, A., Griffin, T. S., & Cash, S. B. (2019). Is agricultural emissions mitigation on the menu for tea drinkers? *Sustainability*, *11*(18), 4883. https://doi.org/10.3390/su11184883
50. Aoki, K., Akai, K., & Ujiie, K. (2017). A choice experiment to compare preferences for rice in Thailand and Japan: The impact of origin, sustainability, and taste. *Food Quality and Preference*, *56,* 274-284. https://doi.org/10.1016/j.foodqual.2016.03.001
51. Hu, W., Batte, M. T., Woods, T., & Ernst, S. (2012). Consumer preferences for local production and other value-added label claims for a processed food product. *European Review of Agricultural Economics*, *39*(3), 489-510. https://doi.org/10.1093/erae/jbr039
52. Shonkwiler, V. P. (2024). Exploring co-labeling strategies in local food markets: Insights from a choice experiment on southern buyers' preferences for cherry tomatoes. *HortScience*, *59*(6), 736-742. https://doi.org/10.21273/HORTSCI17769-24

53. Endara, P., Wiedmann, M., & Adalja, A. (2023). Consumer willingness to pay for shelf life of high-temperature, short-time-pasteurized fluid milk: Implications for smart labeling and food waste reduction. *Journal of Dairy Science*, *106*(9), 5940-5957. https://doi.org/10.3168/jds.2022-22968
54. Ruggeri, G., Corsi, S., & Nayga, R. M. (2021). Eliciting willingness to pay for fairtrade products with information. *Food Quality and Preference*, *87*, 104066. https://doi.org/10.1016/j.foodqual.2020.104066
55. Connor, M., Cuong, O. Q., Demont, M., Sander, B. O., & Nelson, K. (2022). The influence of climate change knowledge on consumer valuation of sustainably produced rice in Vietnam. *Sustainable Production and Consumption*, *31*, 1-12. https://doi.org/10.1016/j.spc.2022.01.034
56. Bazzani, C., Caputo, V., Nayga Jr, R. M., & Canavari, M. (2017). Revisiting consumers' valuation for local versus organic food using a non-hypothetical choice experiment: Does personality matter?. *Food Quality and Preference*, *62*, 144-154. https://doi.org/10.1016/j.foodqual.2017.06.019
57. Džever, S., Tatić, M., Matkovski, B., & Đokić, D. (2024). Generation Z's willingness to pay for domestic and organic milk: A discrete choice experiment in Serbia. *Applied Ecology and Environmental Research*, *22*(5), 3919-3939. https://doi.org/10.15666/aeer/2205_39193939
58. Bello, M., & Abdulai, A. (2015). Measuring heterogeneity, survey engagement and response quality in preferences for organic products in Nigeria. *Applied Economics*, *48*(13), 1159-1171. https://doi.org/10.1080/00036846.2015.1093089
59. Isabel Sonntag, W., Lemken, D., Spiller, A., & Schulze, M. (2023). Welcome to the (label) jungle? Analyzing how consumers deal with intra-sustainability label trade-offs on food. *Food Quality and Preference*, *104*, 104746. https://doi.org/10.1016/j.foodqual.2022.104746
60. Moreno, F., & Malone, T. (2021). The role of collective food identity in local food demand. *Agricultural and Resource Economics Review*, *50*(1), 22-42. https://doi.org/10.1017/age.2020.9
61. Stiletto, A., Vecchio, R., Cembalo, L., & Trestini, S. (2024). The impact of nutri-score on consumers' preferences for geographical indications. Evidence from a non-hypothetical experiment. *Appetite*, *199*, 107400. https://doi.org/10.1016/j.appet.2024.107400
62. Onozaka, Y., & McFadden, D. T. (2011). Does local labeling complement or compete with other sustainable labels? A conjoint analysis of direct and joint values for fresh produce claim. *American Journal of Agricultural Economics*, *93*(3), 689-702. https://doi.org/10.1093/ajae/aar005
63. Tran, L., McCann, L., & Su, Y. (2023). Consumer preferences for produce grown with reduced pesticides: a choice experiment in Missouri. *Renewable Agriculture and Food Systems*, *38*, e49. https://doi.org/10.1017/S1742170523000418
64. Wuepper, D., Wree, P., & Ardali, G. (2019). Does information change German consumers' attitudes about genetically modified food?. *European Review of Agricultural Economics*, *46*(1), 53-78. https://doi.org/10.3929/ethz-b-000275765
65. Capitello, R., Agnoli, L., Charters, S., & Begalli, D. (2021). Labelling environmental and terroir attributes: Young Italian consumers' wine preferences. *Journal of Cleaner Production*, *304*, 126991. https://doi.org/10.1016/j.jclepro.2021.126991

66. Risius, A., & Hamm, U. (2017). The effect of information on beef husbandry systems on consumers' preferences and willingness to pay. *Meat science*, *124*, 9-14. https://doi.org/10.1016/j.meatsci.2016.10.008
67. Grant, K. R., Gallardo, R. K., & McCluskey, J. J. (2021). Consumer preferences for foods with clean labels and new food technologies. *Agribusiness*, *37*(4), 764-781. https://doi.org/10.1002/agr.21705
68. Farina, G., Casati, M., & Sckokai, P. (2024). The country-of-origin dilemma: domestic bias or need for transparency? Assessing consumer's value of information for country-of-origin labelling in Italy. *British Food Journal*, *126*(13), 521-541. https://doi.org/10.1108/BFJ-03-2024-0235
69. Traoré, O. Z., Tamini, L. D., & Korai, B. (2023). Willingness to pay for credence attributes associated with agri-food products—Evidence from Canada. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, *71*(3-4), 303-327. https://doi.org/10.1111/cjag.12336
70. Ruggeri, G., Mazzocchi, C., & Corsi, S. (2020). Drinking biodiversity: A choice experiment on Franciacorta sparkling wines. *British Food Journal*, *122*(8), 2531-2549. https://doi.org/10.1108/BFJ-06-2019-0451
71. Caso, G., Blasi, E., Cembalo, L., & Vecchio, R. (2023). This cookie will save the planet! The effect of a private sustainability claim on consumers' expectations. *Heliyon*, *9*(3), e14206. https://doi.org/10.1016/j.heliyon.2023.e14206
72. Yin, S., Hu, W., Chen, Y., Han, F., Wang, Y., & Chen, M. (2019). Chinese consumer preferences for fresh produce: Interaction between food safety labels and brands. *Agribusiness*, *35*(1), 53-68. https://doi.org/10.1002/agr.21585
73. Liu, J., Kassas, B., & Lai, J. (2024). Investigating the role of political messaging on preferences for local food products in the United States. *Journal of Agricultural and Applied Economics*, *56*(3), 405-428. https://doi.org/10.1017/aae.2024.22
74. Colantuoni, F., Cicia, G., Del Giudice, T., Lass, D., Caracciolo, F., & Lombardi, P. (2016). Heterogeneous preferences for domestic fresh produce: evidence from German and Italian early potato markets. *Agribusiness*, *32*(4), 512-530. https://doi.org/10.1002/agr.21460
75. Jensen, K. L., DeLong, K. L., Gill, M. B., & Hughes, D. W. (2021). Consumer willingness to pay for locally produced hard cider in the USA. *International Journal of Wine Business Research*, *33*(3), 411-431. https://doi.org/10.1108/IJWBR-06-2020-0029
76. Stanco, M., & Lerro, M. (2020). Consumers' preferences for and perception of CSR initiatives in the wine sector. *Sustainability*, *12*(13), 5230. https://doi.org/10.3390/su12135230
77. Raun Mørkbak, M., Christensen, T., & Gyrd-Hansen, D. (2010). Consumer preferences for safety characteristics in pork. *British Food Journal*, *112*(7), 775-791. https://doi.org/10.1108/00070701011058299
78. Lerro, M., Yeh, C. H., Klink-Lehmann, J., Vecchio, R., Hartmann, M., & Cembalo, L. (2021). The effect of moderating variables on consumer preferences for sustainable wines. *Food Quality and Preference*, *94*, 104336. https://doi.org/10.1016/j.foodqual.2021.104336
79. Liu, X., Zhou, X., Wang, Q., Zheng, H., & MacMillan, D. C. (2023). Modeling heterogeneity in preferences for organic rice in China: evidence from a choice experiment. *Journal of Environmental Planning and Management*, *66*(13), 2794-2809. https://doi.org/10.1080/09640568.2022.2086855

80. Ribeiro, J. E., Gschwandtner, A., & Revoredo-Giha, C. (2024). Valuing the organic attribute in chicken meat: Correcting for endogeneity. *International Journal of the Economics of Business*, *31*(3), 181-213. https://doi.org/10.1080/13571516.2024.2362986
81. Thunström, L., & Nordström, J. (2015). Determinants of food demand and the experienced taste effect of healthy labels-An experiment on potato chips and bread. *Journal of Behavioral and Experimental Economics*, *56*, 13-20. https://doi.org/10.1016/j.socec.2015.02.004
82. Rousseau, S. (2015). The role of organic and fair trade labels when choosing chocolate. *Food Quality and Preference*, *44*, 92-100. https://doi.org/10.1016/j.foodqual.2015.04.002
83. Schouteten, J. J., Gellynck, X., & Slabbinck, H. (2019). Influence of organic labels on consumer's flavor perception and emotional profiling: Comparison between a central location test and home-use-test. *Food Research International*, *116*, 1000-1009. https://doi.org/10.1016/j.foodres.2018.09.038
84. Lim, K. H., Hu, W., Maynard, L. J., & Goddard, E. (2013). US consumers' preference and willingness to pay for country-of-origin-labeled beef steak and food safety enhancements. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, *61*(1), 93-118. https://doi.org/10.1111/j.1744-7976.2012.01260.x
85. Wu, L., Liu, X., Zhu, D., Wang, H., Wang, S., & Xu, L. (2015). Simulation of market demand for traceable pork with different levels of safety information: a case study in Chinese consumers. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, *63*(4), 513-537. https://doi.org/10.1111/cjag.12083
86. Wang, J., Shen, M., & Gao, Z. (2018). Research on the irrational behavior of consumers' safe consumption and its influencing factors. *International Journal of Environmental Research and Public Health*, *15*(12), 2764. https://doi.org/10.3390/ijerph15122764
87. Lin, W., Ortega, D. L., Ufer, D., Caputo, V., & Awokuse, T. (2022). Blockchain-based traceability and demand for US beef in China. *Applied Economic Perspectives and Policy*, *44*(1), 253-272. https://doi.org/10.1002/aepp.13135
88. Brayden, W. C., Noblet, C. L., Evans, K. S., & Rickard, L. (2018). Consumer preferences for seafood attributes of wild-harvested and farm-raised products. *Aquaculture Economics & Management*, *22*(3), 362-382. https://doi.org/10.1080/13657305.2018.1449270
89. Owusu-Sekyere, E., Abdulai, A., Jordaan, H., & Hansson, H. (2020). Heterogeneous demand for ecologically sustainable products on ensuring environmental sustainability in South Africa. *Environmental Economics and Policy Studies*, *22*(1), 39-64. https://doi.org/10.1007/s10018-019-00246-6
90. Eldesouky, A., Mesias, F. J., & Escribano, M. (2020). Consumer assessment of sustainability traits in meat production. A choice experiment study in Spain. *Sustainability*, *12*(10), 4093. https://doi.org/10.3390/su12104093
91. Cubero Dudinskaya, E., Naspetti, S., Arsenos, G., Caramelle-Holtz, E., Latvala, T., Martin-Collado, D., Orsini, S.., Ozturk, E., & Zanoli, R. (2021). European consumers' willingness to pay for red meat labelling attributes. *Animals*, *11*(2), 556. https://doi.org/10.3390/ani11020556
92. Hoque, M. Z., & Myrland, Ø. (2022). Consumer preference for fish safety inspection in Bangladesh. *Aquaculture*, *551*, 737911. https://doi.org/10.1016/j.aquaculture.2022.737911

93. Lin, B. H., Smith, T. A., & Huang, C. L. (2008). Organic premiums of US fresh produce. *Renewable Agriculture and Food Systems*, *23*(3), 208-216. https://doi.org/10.1017/S1742170508002238
94. Khai, H. V., & Yabe, M. (2015). Consumer preferences for agricultural products considering the value of biodiversity conservation in the Mekong Delta, Vietnam. *Journal for Nature Conservation*, *25*, 62-71. https://doi.org/10.1016/j.jnc.2015.02.004
95. Goldberg, I., Roosen, J., & Nayga Jr, R. M. (2009). Parental response to health risk information: experimental results on willingness-to-pay for safer infant milk formula. *Health Economics*, *18*(5), 503-518. https://doi.org/10.1002/hec.1381
96. Bernard, J. C., Zhang, C., & Gifford, K. (2006). An experimental investigation of consumer willingness to pay for non-GM foods when an organic option is present. *Agricultural and Resource Economics Review*, *35*(2), 374-385. https://doi.org/10.1017/S1068280500006808
97. Bernard, J. C., & Bernard, D. J. (2009). What is it about organic milk? An experimental analysis. *American journal of agricultural economics*, *91*(3), 826-836. https://doi.org/10.1111/j.1467-8276.2009.01258.x
98. Zhou, J., Liu, Q., Mao, R., & Yu, X. (2017). Habit spillovers or induced awareness: Willingness to pay for eco-labels of rice in China. *Food Policy*, *71*, 62-73. https://doi.org/10.1016/j.foodpol.2017.07.006
99. Yin, S., Lv, S., Chen, Y., Wu, L., Chen, M., & Yan, J. (2018). Consumer preference for infant milk-based formula with select food safety information attributes: Evidence from a choice experiment in China. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, *66*(4), 557-569. https://doi.org/10.1111/cjag.12183
100. Wu, L., Wang, S., Zhu, D., Hu, W., & Wang, H. (2015). Chinese consumers' preferences and willingness to pay for traceable food quality and safety attributes: The case of pork. *China Economic Review*, *35*, 121-136. https://doi.org/10.1016/j.chieco.2015.07.001
101. Widmar, N. J. O., & Ortega, D. L. (2014). Comparing consumer preferences for livestock production process attributes across products, species, and modeling methods. *Journal of Agricultural and Applied Economics*, *46*(3), 375-391. https://doi.org/10.1017/S1074070800030121
102. Rossi, E. S., Cacchiarelli, L., Severini, S., & Sorrentino, A. (2024). Consumers preferences and social sustainability: a discrete choice experiment on 'Quality Agricultural Work' ethical label in the Italian fruit sector. *Agricultural and Food Economics*, *12*(1), 14. https://doi.org/10.1186/s40100-024-00307-9
103. Lee, J. Y., Pavasopon, N., Napasintuwong, O., & Nayga Jr, R. M. (2020). Consumers' Valuation of Geographical Indication-Labeled Food: The Case of Hom Mali Rice in Bangkok. *Asian Economic Journal*, *34*(1), 79-96. https://doi.org/10.1111/asej.12196
104. Fuller, K., & Grebitus, C. (2023). Consumers' preferences and willingness to pay for coffee sustainability labels. *Agribusiness*, *39*(4), 1007-1025. https://doi.org/10.1002/agr.21810
105. Bronnmann, J., & Asche, F. (2016). The value of product attributes, brands and private labels: an analysis of frozen seafood in Germany. *Journal of Agricultural Economics*, *67*(1), 231-244. https://doi.org/10.1111/1477-9552.12138
106. Loureiro, M. L., & Lotade, J. (2005). Do fair trade and eco-labels in coffee wake up the consumer conscience?. *Ecological Economics*, *53*(1), 129-138. https://doi.org/10.1016/j.ecolecon.2004.11.002

107. Tran, L., & Su, Y. (2023). Are state branded products local? A case in Missouri. *Journal of Food Distribution Research*, *54*(1), 33-44. https://doi.org/10.22004/ag.econ.339700
108. Asioli, D., Zhou, X., Halmemies-Beauchet-Filleau, A., Vanhatalo, A., Givens, D. I., Rondoni, A., & Turpeinen, A. M. (2023). Consumers' valuation for low-carbon emission and low-saturated fat butter. *Food Quality and Preference*, *108*, 104859. https://doi.org/10.1016/j.foodqual.2023.104859
109. Ramli, N. N., Joya, K., Shamsudin, M. N., & Kamarulzaman, N. H. (2023). Consumers' valuation on food safety attributes. *Journal Ekonomi Malaysia*, *57*(1), 9-20. https://doi.org/10.17576/JEM-2023-5701-02
110. Piracci, G., Boncinelli, F., & Casini, L. (2022). Wine consumers' demand for social sustainability labeling: Evidence for the fair labor claim. *Applied Economic Perspectives and Policy*, *44*(4), 1742-1761. https://doi.org/10.1002/aepp.13260
111. Suhandoko, A. A., Chen, D. C. B., & Yang, S. H. (2021). Meat traceability: Traditional market shoppers' preferences and willingness-to-pay for additional information in Taiwan. *Foods*, *10*(8), 1819. https://doi.org/10.3390/foods10081819
112. Hossain, K. Z., Xue, J., & Rabbany, M. G. (2021). Consumers' willingness to pay for GLOBALG. AP certified chicken: Empirical evidence from a consumer survey in Bangladesh. *Food Control*, *130*, 108397. https://doi.org/10.1016/j.foodcont.2021.108397
113. Yang, X., Chen, Q., Lin, N., Han, M., Chen, Q., Zheng, Q., Gao, B., Liu, F., & Xu, Z. (2021). Chinese consumer preferences for organic labels on Oolong tea: Evidence from a choice experiment. *International Food and Agribusiness Management Review*, *24*(3), 545-562. https://doi.org/10.22434/IFAMR2020.0113
114. Dunne, C., & Siettou, C. (2020). UK consumers' willingness to pay for laying hen welfare. *British Food Journal*, *122*(9), 2867-2880. https://doi.org/10.1108/BFJ-12-2019-0914
115. Hori, J., Wakamatsu, H., Miyata, T., & Oozeki, Y. (2020). Has the consumers awareness of sustainable seafood been growing in Japan? Implications for promoting sustainable consumerism at the Tokyo 2020 Olympics and Paralympics. *Marine Policy*, *115*, 103851. https://doi.org/10.1016/j.marpol.2020.103851
116. Chakrabarti, A., Campbell, B. L., & Shonkwiler, V. (2019). Eliciting consumer preference and willingness to pay for mushrooms: a latent class approach. *Journal of Food Distribution Research*, *50*(1), 46-62. https://doi.org/10.22004/ag.econ.292182
117. Wu, L., Gong, X., Qin, S., Chen, X., Zhu, D., Hu, W., & Li, Q. (2017). Consumer preferences for pork attributes related to traceability, information certification, and origin labeling: Based on China's Jiangsu Province. *Agribusiness*, *33*(3), 424-442. https://doi.org/10.1002/agr.21509
118. Butler, J. M., & Vossler, C. A. (2018). What is an unregulated and potentially misleading label worth? The case of "natural"-labelled groceries. *Environmental and Resource Economics*, *70*(2), 545-564. https://doi.org/10.1007/s10640-017-0132-9
119. My, N. H., Demont, M., van Loo, E. J., de Guia, A., Rutsaert, P., Tuan, T. H., & Verbeke, W. (2018). What is the value of sustainably-produced rice? Consumer evidence from experimental auctions in Vietnam. *Food Policy*, *79*, 283-296. https://doi.org/10.1016/j.foodpol.2018.08.004

120. Kubota, S., Sawano, H., & Kono, H. (2017). Japanese consumer preferences for additive-free wine labeling. *Agricultural and Food Economics*, *5*(1), 4. https://doi.org/10.1186/s40100-017-0073-1
121. Lai, J., Wang, H. H., Ortega, D. L., & Widmar, N. J. O. (2018). Factoring Chinese consumers' risk perceptions into their willingness to pay for pork safety, environmental stewardship, and animal welfare. *Food Control*, *85*, 423-431. https://doi.org/10.1016/j.foodcont.2017.09.032
122. Schjøll, A. (2017). Country-of-origin preferences for organic food. *Organic Agriculture*, *7*(3), 315-327. https://doi.org/10.1007/s13165-016-0159-1
123. Silva, A. G., Canavari, M., & Wander, A. E. (2018). Consumer preferences and willingness-to-pay for integrated production label on common beans. *Economia agro-alimentare*, (2018/1). https://doi.org/10.3280/ECAG2018-001002
124. Wu, L., Wang, H., Zhu, D., Hu, W., & Wang, S. (2016). Chinese consumers' willingness to pay for pork traceability information—The case of Wuxi. *Agricultural Economics*, *47*(1), 71-79. https://doi.org/10.1111/agec.12210
125. Lee, J. Y., Han, D. B., Nayga Jr, R. M., & Yoon, J. M. (2014). Assessing Korean consumers' valuation for domestic, Chinese, and US rice: Importance of country of origin and food miles information. *China Agricultural Economic Review*, *6*(1), 125-138. https://doi.org/10.1108/CAER-07-2012-0071
126. Chen, X., Alfnes, F., & Rickertsen, K. (2015). Consumer preferences, ecolabels, and the effects of negative environmental information. *AgBioForum, 18*(3), 327-336.
127. De-Magistris, T., & Lopéz-Galán, B. (2016). Consumers' willingness to pay for nutritional claims fighting the obesity epidemic: the case of reduced-fat and low salt cheese in Spain. *Public Health*, *135*, 83-90. https://doi.org/10.1016/j.puhe.2016.02.004
128. Hasselbach, J. L., & Roosen, J. (2015). Consumer heterogeneity in the willingness to pay for local and organic food. *Journal of Food Products Marketing*, *21*(6), 608-625. https://doi.org/10.1080/10454446.2014.885866
129. Viegas, I., Nunes, L. C., Madureira, L., Fontes, M. A., & Santos, J. L. (2014). Beef credence attributes: Implications of substitution effects on consumers' WTP. *Journal of Agricultural Economics*, *65*(3), 600-615. https://doi.org/10.1111/1477-9552.12067
130. Sogn-Grundvåg, G., Larsen, T. A., & Young, J. A. (2014). Product differentiation with credence attributes and private labels: The case of whitefish in UK supermarkets. *Journal of Agricultural Economics*, *65*(2), 368-382. https://doi.org/10.1111/1477-9552.12047
131. Zheng, Y., Li, X., & Peterson, H. H. (2013). In pursuit of safe foods: Chinese preferences for soybean attributes in soymilk. *Agribusiness*, *29*(3), 377-391. https://doi.org/10.1002/agr.21342
132. Uchida, H., Onozaka, Y., Morita, T., & Managi, S. (2014). Demand for ecolabeled seafood in the Japanese market: A conjoint analysis of the impact of information and interaction with other labels. *Food Policy*, *44*, 68-76. https://doi.org/10.1016/j.foodpol.2013.10.002
133. Ahmad Hanis, I. A. H., Jinap, S., Mad Nasir, S., Alias, R., & Muhammad Shahrim, A. K. (2012). Consumers' demand and willingness to pay for rice attributes in Malaysia. *International Food Research Journal*, *19*(1), 363.
134. Chung, C., Boyer, T., & Han, S. (2009). Valuing quality attributes and country of origin in the Korean beef market. *Journal of Agricultural Economics*, *60*(3), 682-698. https://doi.org/10.1111/j.1477-9552.2009.00218.x

135. Loureiro, M. L., Gracia, A., & Nayga Jr, R. M. (2006). Do consumers value nutritional labels?. *European Review of Agricultural Economics*, *33*(2), 249-268. https://doi.org/10.1093/erae/jbl005
136. Elbakidze, L., & Nayga Jr, R. M. (2012). The effects of information on willingness to pay for animal welfare in dairy production: Application of nonhypothetical valuation mechanisms. *Journal of Dairy Science*, *95*(3), 1099-1107. https://doi.org/10.3168/jds.2011-4730
137. Gracia, A., Loureiro, M. L., & Nayga, Jr, R. M. (2011). Valuing an EU animal welfare label using experimental auctions. *Agricultural Economics*, *42*(6), 669-677. https://doi.org/10.1111/j.1574-0862.2011.00543.x
138. Kanter, C., Messer, K. D., & Kaiser, H. M. (2009). Does production labeling stigmatize conventional milk?. *American Journal of Agricultural Economics*, *91*(4), 1097-1109. https://doi.org/10.1111/j.1467-8276.2009.01317.x
139. Ortega, D. L., Wang, H. H., Wu, L., & Olynk, N. J. (2011). Modeling heterogeneity in consumer preferences for select food safety attributes in China. *Food Policy*, *36*(2), 318-324. https://doi.org/10.1016/j.foodpol.2010.11.030
140. Zhang, Y., & Jin, S. (2020). Hedonic valuation of country of origin in the Chinese dairy market. *International Food and Agribusiness Management Review*, *23*(3), 487-500. https://doi.org/10.22434/IFAMR2019.0212
141. Merritt, M. G., Delong, K. L., Griffith, A. P., & Jensen, K. L. (2018). Consumer willingness to pay for Tennessee certified beef. *Journal of Agricultural and Applied Economics*, *50*(2), 233-254. https://doi.org/10.1017/aae.2017.35
142. van Loo, E. J., Caputo, V., Nayga Jr, R. M., Seo, H. S., Zhang, B., & Verbeke, W. (2015). Sustainability labels on coffee: Consumer preferences, willingness-to-pay and visual attention to attributes. *Ecological Economics*, *118*, 215-225. https://doi.org/10.1016/j.ecolecon.2015.07.011
143. Salladarré, F., Brécard, D., Lucas, S., & Ollivier, P. (2016). Are French consumers ready to pay a premium for eco-labeled seafood products? A contingent valuation estimation with heterogeneous anchoring. *Agricultural Economics*, *47*(2), 247-258. https://doi.org/10.1111/agec.12226
144. Magnier, A., Kalaitzandonakes, N., & Lusk, J. (2022). Changes in consumer preferences toward non-GM foods within an information-rich environment: the case of the Washington State ballot initiative. *Applied Economic Perspectives and Policy*, *44*(1), 489-510. https://doi.org/10.1002/aepp.13129
145. Huang, Y. K., Palma, M. A., & Rangel, J. (2024). Can a local food label nudge consumer behavior? Implications of an eye-tracking study of honey products. *Journal of Agricultural and Applied Economics*, *56*(1), 101-119. https://doi.org/10.1017/aae.2024.2
146. Hu, W., Woods, T., & Bastin, S. (2009). Consumer acceptance and willingness to pay for blueberry products with nonconventional attributes. *Journal of Agricultural and Applied Economics*, *41*(1), 47-60. https://doi.org/10.1017/S1074070800002546
147. Hong, X., Li, C., Bai, J., Gao, Z., & Wang, L. (2021). Chinese consumers' willingness-to-pay for nutrition claims on processed meat products, using functional sausages as a food medium. *China Agricultural Economic Review*, *13*(2), 495-518. https://doi.org/10.1108/CAER-06-2020-0160
148. Heng, Y., Peterson, H. H., & Li, X. (2013). Consumer attitudes toward farm-animal welfare: the case of laying hens. *Journal of Agricultural and Resource Economics*, 418-434.

149. Grebitus, C., & van Loo, E. J. (2022). Relationship between cognitive and affective processes, and willingness to pay for pesticide-free and GMO-free labeling. *Agricultural Economics*, *53*(3), 407-421. https://doi.org/10.1111/agec.12701
150. Caputo, V., van Loo, E. J., Scarpa, R., Nayga Jr, R. M., & Verbeke, W. (2018). Comparing serial, and choice task stated and inferred attribute non-attendance methods in food choice experiments. *Journal of Agricultural Economics*, *69*(1), 35-57.https://doi.org/10.1111/1477-9552.12246
151. Caputo, V., Lagoudakis, A., Shupp, R., & Bazzani, C. (2023). Comparing experimental auctions and real choice experiments in food choice: a homegrown and induced value analysis. *European Review of Agricultural Economics*, *50*(5), 1796-1823. https://doi.org/10.1093/erae/jbad033
152. Brooks, K., & Lusk, J. L. (2010). Stated and revealed preferences for organic and cloned milk: combining choice experiment and scanner data. *American Journal of Agricultural Economics*, *92*(4), 1229-1241. https://doi.org/10.1093/ajae/aaq054
153. Britwum, K., & Yiannaka, A. (2019). Labeling food safety attributes: to inform or not to inform?. *Agricultural and Food Economics*, *7*(1), 4. https://doi.org/10.1186/s40100-019-0123-y
154. Bi, X., House, L., & Gao, Z. (2016). Impacts of nutrition information on choices of fresh seafood among parents. *Marine Resource Economics*, *31*(3), 355-372. https://doi.org/10.1086/686714
155. Bazoche, P., Combris, P., Giraud-Héraud, E., Seabra Pinto, A., Bunte, F., & Tsakiridou, E. (2014). Willingness to pay for pesticide reduction in the EU: nothing but organic?. *European Review of Agricultural Economics*, *41*(1), 87-109. https://doi.org/10.1093/erae/jbt011
156. Asante-Addo, C., & Weible, D. (2020). Is there hope for domestically produced poultry meat? A choice experiment of consumers in Ghana. *Agribusiness*, *36*(2), 281-298. https://doi.org/10.1002/agr.21626
157. Abidoye, B. O., Bulut, H., Lawrence, J. D., Mennecke, B., & Townsend, A. M. (2011). US consumers' valuation of quality attributes in beef products. *Journal of Agricultural and Applied Economics*, *43*(1), 1-12. https://doi.org/10.1017/S1074070800004016
158. Yue, C., Lai, Y., Wang, J., & Mitchell, P. (2020). Consumer preferences for sustainable product attributes and farm program features. *Sustainability*, *12*(18), 7388. https://doi.org/10.3390/SU12187388
159. Liu, C., Liu, X., Yao, L., & Liu, J. (2023). Consumer preferences and willingness to pay for eco-labelled eggs: A discrete choice experiment from Chongqing in China. *British Food Journal*, *125*(5), 1683-1697. https://doi.org/10.1108/BFJ-12-2021-1305
160. Bernard, J. C., & Bernard, D. J. (2010). Comparing parts with the whole: Willingness to pay for pesticide-free, non-GM, and organic potatoes and sweet corn. *Journal of Agricultural and Resource Economics*, 457-475.
161. Heinola, K., Latvala, T., & Niemi, J. K. (2023). Consumer trust and willingness to pay for establishing a market-based animal welfare assurance scheme for broiler chickens. *Poultry Science*, *102*(7), 102765. https://doi.org/10.1016/j.psj.2023.102765

162. Wang, H. H., Yang, J., & Hao, N. (2022). Consumers' willingness to pay for rice from remediated soil: potential from the public in sustainable soil pollution treatment. *International Journal of Environmental Research and Public Health*, *19*(15), 8946. https://doi.org/10.3390/ijerph19158946
163. Akaichi, F., de Grauw, S., Darmon, P., & Revoredo-Giha, C. (2016). Does fair trade compete with carbon footprint and organic attributes in the eyes of consumers? Results from a pilot study in Scotland, the Netherlands and France. *Journal of Agricultural and Environmental Ethics*, *29*(6), 969-984. https://doi.org/10.1007/s10806-016-9642-7
164. van Zyl, K., Vermeulen, H., & Kirsten, J. F. (2013). Determining South African consumers' willingness to pay for certified Karoo lamb: An application of an experimental auction. *Agrekon*, *52*(4), 1-20. https://doi.org/10.1080/03031853.2013.847030
165. Dinc-Cavlak, O., & Ozdemir, O. (2021). Comparing the willingness to pay through three elicitation mechanisms: An experimental evidence for organic egg product. *Agribusiness*, *37*(4), 782-803. https://doi.org/10.1002/agr.21702
166. Alphonce, R., Temu, A., & Almli, V. L. (2015). European consumer preference for African dried fruits. *British Food Journal*, *117*(7), 1886-1902. https://doi.org/10.1108/BFJ-10-2014-0342
167. Hossain, K. Z., Xue, J., & Rabbany, M. G. (2023). Consumers' Preferences and Willingness to Pay (WTP) for Traceable Liquid Milk: A Survey in Dhaka, Bangladesh. *Journal of Food Products Marketing*, *29*(7), 219-231. https://doi.org/10.1080/10454446.2023.2228731
168. Fuller, K., Grebitus, C., & Schmitz, T. G. (2022). The effects of values and information on the willingness to pay for sustainability credence attributes for coffee. *Agricultural Economics*, *53*(5), 775-791. https://doi.org/10.1111/agec.12706
169. Boonkong, A., Jiang, B., Kassoh, F. S., & Srisukwatanachai, T. (2023). Chinese and Thai consumers' willingness to pay for quality rice attributes: A discrete choice experiment method. *Frontiers in Sustainable Food Systems*, *7*, 1270331. https://doi.org/10.3389/fsufs.2023.1270331
170. Chen, M., Yin, S., Xu, Y., & Wang, Z. (2015). Consumers' willingness to pay for tomatoes carrying different organic labels: Evidence from auction experiments. *British Food Journal*, *117*(11), 2814-2830. https://doi.org/10.1108/BFJ-12-2014-0415
171. Chen, N., Zhang, Z. H., Huang, S., & Zheng, L. (2018). Chinese consumer responses to carbon labeling: evidence from experimental auctions. *Journal of Environmental Planning and Management*, *61*(13), 2319-2337. https://doi.org/10.1080/09640568.2017.1394276
172. Hou, B., Wu, L., Chen, X., Zhu, D., Ying, R., & Tsai, F. S. (2019). Consumers' willingness to pay for foods with traceability information: ex-ante quality assurance or ex-post traceability?. *Sustainability*, *11*(5), 1464. https://doi.org/10.3390/su11051464
173. Argemí-Armengol, I., Villalba, D., Ripoll, G., Teixeira, A., & Álvarez-Rodríguez, J. (2019). Credence cues of pork are more important than consumers' culinary skills to boost their purchasing intention. *Meat Science*, *154*, 11-21. https://doi.org/10.1016/j.meatsci.2019.04.001

174. Habiyaremye, N., Mtimet, N., Ouma, E. A., & Obare, G. A. (2023). Consumers' willingness to pay for safe and quality milk: Evidence from experimental auctions in Rwanda. *Agribusiness*, *39*(4), 1049-1074. https://doi.org/10.1002/agr.21817
175. Wang, J., Ge, J., & Ma, Y. (2018). Urban Chinese consumers' willingness to pay for pork with certified labels: A discrete choice experiment. *Sustainability*, *10*(3), 603. https://doi.org/10.3390/su10030603
176. Rizzo, G., Borrello, M., Dara Guccione, G., Schifani, G., & Cembalo, L. (2020). Organic food consumption: The relevance of the health attribute. *Sustainability*, *12*(2), 595. https://doi.org/10.3390/su12020595
177. Oh, C. O., Herrnstadt, Z., & Howard, P. H. (2015). Consumer willingness to pay for bird management practices in fruit crops. *Agroecology and Sustainable Food Systems*, *39*(7), 782-797. https://doi.org/10.1080/21683565.2015.1017896
178. Zhu, Z., Ma, X., Tian, X., & Zhang, T. (2022). The value of food products from mixed crop-livestock systems: Environmental benefits and regional environmental carrying capacity. *Applied Economics*, *55*(16), 1859-1875. https://doi.org/10.1080/00036846.2022.2099804
179. Li, F., Zhang, K., Yang, P., Jiao, J., Yin, Y., Zhang, Y., & Yin, C. (2022). Information exposure incentivizes consumers to pay a premium for emerging pro-environmental food: Evidence from China. *Journal of Cleaner Production*, *363*, 132412. https://doi.org/10.1016/j.jclepro.2022.132412
180. Nam, K., Qiao, Y., & Ahn, B. -i. (2022). Analysis of consumer preference for green tea with eco-friendly certification in China. *Sustainability*, *14*(1), 211. https://doi.org/10.3390/su14010211
181. Zanchini, R., Di Vita, G., Panzone, L., & Brun, F. (2023). What is the value of a "mountain product" claim? A ranking conjoint experiment on goat's milk yoghurt. *Foods*, *12*(10), 2059. https://doi.org/10.3390/foods12102059
182. Waldrop, M. E., & McCluskey, J. J. (2018). Does information about organic status affect consumer sensory liking and willingness to pay for beer? *Agribusiness*, *35*(2), 149-167. https://doi.org/10.1002/agr.21567
183. Maaya, L., Meulders, M., Surmont, N., & Vandebroek, M. (2018). Effect of environmental and altruistic attitudes on willingness-to-pay for organic and fair trade coffee in Flanders. *Sustainability*, *10*(12), 4496. https://doi.org/10.3390/su10124496
184. Aprile, M. C., Caputo, V., & Nayga, R. M., Jr. (2012). Consumers' valuation of food quality labels: The case of the European geographic indication and organic farming labels. *International Journal of Consumer Studies*, *36*(2), 158-165. https://doi.org/10.1111/j.1470-6431.2011.01092.x
185. Nugraha, W. S., Yang, S.-H., & Ujiie, K. (2021). The heterogeneity of consumer preferences for meat safety attributes in traditional markets. *Foods*, *10*(3), 624. https://doi.org/10.3390/foods10030624
186. Scozzafava, G., Gerini, F., Boncinelli, F., Contini, C., & Casini, L. (2021). How much is a bottle of conventional, organic or biodynamic wine worth? Results of an experimental auction. *Food Quality and Preference*, *93*, 104259. https://doi.org/10.1016/j.foodqual.2021.104259
187. Olesen, I., Alfnes, F., Røra, M. B., & Kolstad, K. (2010). Eliciting consumers' willingness to pay for organic and welfare-labelled salmon in a non-hypothetical choice experiment. *Livestock Science*, *127*(2-3), 218-226. https://doi.org/10.1016/j.livsci.2009.10.001

188. Britwum, K., Bernard, J. C., & Albrecht, S. E. (2021). Does importance influence confidence in organic food attributes? *Food Quality and Preference*, *87*, 104056.https://doi.org/10.1016/j.foodqual.2020.104056
189. Herring, M. W., Garnett, S. T., & Zander, K. K. (2022). From boutique to mainstream: Upscaling wildlife-friendly farming through consumer premiums. *Conservation Science and Practice*, *4*(7), e12730. https://doi.org/10.1111/csp2.12730
190. Nazzaro, C., Stanco, M., Uliano, A., & Marotta, G. (2024). Consumers' acceptance and willingness to pay for enriched foods: Evidence from a choice experiment in Italy. *Future Foods*, *10*, 100405. https://doi.org/10.1016/j.fufo.2024.100405
191. Drugova, T., Curtis, K. R., & Akhundjanov, S. B. (2020). Are multiple labels on food products beneficial or simply ignored? *Canadian Journal of Agricultural Economics*, *68*(4), 411-427. https://doi.org/10.1111/cjag.12259
192. Li, C., Bai, J., Gao, Z., & Fu, J. (2017). Willingness to pay for "taste of Europe": geographical origin labeling controversy in China. *British Food Journal*, *119*(8), 1897-1914. https://doi.org/10.1108/BFJ-11-2016-0580
193. Janssen, M., & Hamm, U. (2012). Product labelling in the market for organic food: Consumer preferences and willingness-to-pay for different organic certification logos. *Food Quality and Preference*, *25*(1), 9-22. https://doi.org/10.1016/j.foodqual.2011.12.004
194. Indrawan, D., Christy, A., & Hogeveen, H. (2021). Improving poultry meat and sales channels to address food safety concerns: Consumers' preferences on poultry meat attributes. *British Food Journal*, *123*(13), 529-546. https://doi.org/10.1108/BFJ-04-2021-0362
195. Ubilava, D., Foster, K. A., Lusk, J. L., & Nilsson, T. (2010). Effects of income and social awareness on consumer WTP for social product attributes. *Technological Forecasting and Social Change*, *77*(4), 587-593. https://doi.org/10.1016/j.techfore.2009.02.002
196. Liu, R., Wang, J., Liang, J., Ma, H., & Liang, F. (2023). Perceived value of information attributes: Accounting for consumer heterogeneous preference and valuation for traceable agri-food. *Foods*, *12*(4), 711. https://doi.org/10.3390/foods12040711
197. Sans, P., & Sanjuán-López, A. I. (2015). Beef animal welfare, attitudes and willingness to pay: A regional comparison across the Pyrenees. *Spanish Journal of Agricultural Research*, *13*(3), e0105. https://doi.org/10.5424/sjar/2015133-7273
198. Gao, Z., Li, C., Bai, J., & Fu, J. (2020). Chinese consumer quality perception and preference of sustainable milk. *China Economic Review*, *59,* 100939. https://doi.org/10.1016/j.chieco.2016.05.004
199. Wu, L., Yin, S., Xu, Y., & Zhu, D. (2014). Effectiveness of China's organic food certification policy: Consumer preferences for infant milk formula with different organic certification labels. *Canadian Journal of Agricultural Economics*, *62*(4), 545-568. https://doi.org/10.1111/cjag.12050
200. Macht, J., Klink-Lehmann, J., Piqueras-Fiszman, B., & Hartmann, M. (2022). Insights into the organic labelling effect: The special case of wine. *British Food Journal*, *124*(11), 3974-3992. https://doi.org/10.1108/BFJ-04-2021-0378

201. Liu, R., Wang, J., Liang, F., Nian, Y., & Ma, H. (2022). What we can learn from the interactions of food traceable attributes? A case study of fuji apple products in China. *Applied Economics*, *54*(59), 6829-6849. https://doi.org/10.1080/00036846.2022.2084017
202. Smith, M., Lal, P., Oluoch, S., Vedwan, N., & Smith, A. (2021). Valuation of sustainable attributes of hard apple cider: A best-worst choice approach. *Journal of Cleaner Production*, *318*, 128478. https://doi.org/10.1016/j.jclepro.2021.128478
203. Solgaard, H. S., & Yang, Y. (2011). Consumers' perception of farmed fish and willingness to pay for fish welfare. *British Food Journal*, *113*(8), 997-1010. https://doi.org/10.1108/00070701111153751
204. Costanigro, M., Appleby, C., & Menke, S. D. (2014). The wine headache: Consumer perceptions of sulfites and willingness to pay for non-sulfited wines. *Food Quality and Preference*, *31*, 81-89. https://doi.org/10.1016/j.foodqual.2013.08.002
205. Olynk, N. J., & Ortega, D. L. (2013). Consumer preferences for verified dairy cattle management practices in processed dairy products. *Food Control*, *30*(1), 298-305. https://doi.org/10.1016/j.foodcont.2012.07.030
206. Nam, K., Lim, H., & Ahn, B.-i. (2020). Information values on the consumer's valuation of non-GM material: The case of cooking oil in Korea. *Sustainability*, *12*(19), 7876. https://doi.org/10.3390/SU12197876
207. Torquati, B., Tempesta, T., Vecchiato, D., & Venanzi, S. (2018). Tasty or sustainable? The effect of product sensory experience on a sustainable new food product: An application of discrete choice experiments on Chianina tinned beef. *Sustainability*, *10*(8), 2795. https://doi.org/10.3390/su10082795
208. Dey, M. M., Rahman, Md. S., Dewan, Md. F., Sudhakaran, P. O., Deb, U., & Khan, Md. A. (2024). Consumers' willingness to pay for safer fish: Evidence from experimental auctions in Bangladesh. *Aquaculture Economics & Management*, *28*(3), 460-490. https://doi.org/10.1080/13657305.2024.2353212
209. Enneking, U. (2004). Willingness-to-pay for safety improvements in the German meat sector: The case of the Q&S label. *European Review of Agricultural Economics*, *31*(2), 205-223. https://doi.org/10.1093/erae/31.2.205
210. Batte, M. T., Hooker, N. H., Haab, T. C., & Beaverson, J. (2007). Putting their money where their mouths are: Consumer willingness to pay for multi-ingredient, processed organic food products. *Food Policy*, *32*(2), 145-159. https://doi.org/10.1016/j.foodpol.2006.05.003
211. Petrontino, A., Frem, M., Fucilli, V., Tria, E., Campobasso, A. A., & Bozzo, F. (2024). Consumers' purchase propensity for pasta tracked with blockchain technology and labelled with sustainable credence attributes. *Frontiers in Sustainable Food Systems*, *8*, 1367362. https://doi.org/10.3389/fsufs.2024.1367362
212. Papoutsi, G. S. (2023). Consumer valuation of European certification labels on extra virgin olive oil: Assessing the impact of multiple labels and consumer heterogeneity. *Journal of Food Products Marketing*, *29*(8-9), 291-307. https://doi.org/10.1080/10454446.2023.2276182
213. Vecchio, R., van Loo, E. J., & Annunziata, A. (2016). Consumers' willingness to pay for conventional, organic and functional yogurt: Evidence from experimental auctions. *International Journal of Consumer Studies*, *40*(3), 368-378. https://doi.org/10.1111/ijcs.12264

214. Güney, O. I., & Giraldo, L. (2020). Consumers' attitudes and willingness to pay for organic eggs: A discrete choice experiment study in Turkey. *British Food Journal*, *122*(2), 678-692. https://doi.org/10.1108/BFJ-04-2019-0297
215. Bir, C. L., Widmar, N. J. O., Davis, M. K., Erasmus, M. A., & Zuelly, S. (2020). Willingness to pay for whole turkey attributes during Thanksgiving holiday shopping in the United States. *Poultry Science*, *99*(5), 2798-2810. https://doi.org/10.1016/j.psj.2019.12.047
216. Ortega, D. L., Hong, S. J., Wang, H. H., & Wu, L. (2016). Emerging markets for imported beef in China: Results from a consumer choice experiment in Beijing. *Meat Science*, *121*, 317-323. https://doi.org/10.1016/j.meatsci.2016.06.032
217. Paudel, B., & Zhou, M. (2024). Are consumers "green" enthusiasts or skeptics? Evidence from nontimber forest products. *Forest Policy and Economics*, *168*, 103302. https://doi.org/10.1016/j.forpol.2024.103302
218. Joya, K., Ramli, N. N., Shamsudin, M. N., & Kamarulzaman, N. H. (2022). Consumers' willingness to pay for food safety attributes of tomato. *British Food Journal*, *124*(3), 701-717. https://doi.org/10.1108/BFJ-02-2021-0164
219. Lemken, D., Knigge, M., Meyerding, S., & Spiller, A. (2017). The value of environmental and health claims on new legume products: A non-hypothetical online auction. *Sustainability*, *9*(8), 1340. https://doi.org/10.3390/su9081340
220. Ifft, J., Roland-Holst, D., & Zilberman, D. (2012). Consumer valuation of safety-labeled free-range chicken: Results of a field experiment in Hanoi. *Agricultural Economics*, *43*(6), 607-620. https://doi.org/10.1111/j.1574-0862.2012.00607.x
221. Mameno, K., & Kubo, T. (2023). Mainstreaming eating agrobiodiversity: Appealing with heron labels and boosting with loach labels. *Food Quality and Preference*, *109*, 104919. https://doi.org/10.1016/j.foodqual.2023.104919
222. Ortega, D. L., Chen, M., Wang, H. H., & Shimokawa, S. (2017). Emerging markets for U.S. pork in China: Experimental evidence from mainland and Hong Kong consumers. *Journal of Agricultural and Resource Economics*, *42*(2), 275-290.
223. Cao, S., Foth, M., Powell, W., & McQueenie, J. (2021). What are the effects of short video storytelling in delivering blockchain-credentialed Australian beef products to China? *Foods*, *10*(10), 2403. https://doi.org/10.3390/foods10102403
224. Liu, Q., Yan, Z., & Zhou, J. (2017). Consumer choices and motives for eco-labeled products in China: An empirical analysis based on the choice experiment. *Sustainability*, *9*(3), 331. https://doi.org/10.3390/su9030331
225. Yu, H., Jiang, Y., Sun, Y., Ding, Y., & Alita, L. (2024). Geographical indications and organic labels: Complements or substitutes? - The case of online rice consumption in China. *Applied Economics*, *57*(26), 3660-3674. https://doi.org/10.1080/00036846.2024.2337814
226. Yin, S., Li, Y., Xu, Y., Chen, M., & Wang, Y. (2017). Consumer preference and willingness to pay for the traceability information attribute of infant milk formula: Evidence from a choice experiment in China. *British Food Journal*, *119*(6), 1276-1288. https://doi.org/10.1108/BFJ-11-2016-0555
227. Tran, D., De Steur, H., Gellynck, X., Papadakis, A., & Schouteten, J. J. (2024). Consumers' valuation of blockchain-based food traceability: Role of consumer ethnocentrism and communication via QR codes. *British Food Journal*, *126*(13), 72-93. https://doi.org/10.1108/BFJ-09-2023-0812

228. Stiletto, A., & Trestini, S. (2022). When less isn't more and more isn't less: Is there an overlap between "protected designation of origin", "mountain product" and "organic" in Italy? *British Food Journal*, *125*(13), 45-60. https://doi.org/10.1108/BFJ-02-2022-0107
229. Rousu, M., Huffman, W. E., Shogren, J. F., & Tegene, A. (2007). Effects and value of verifiable information in a controversial market: Evidence from lab auctions of genetically modified food. *Economic Inquiry*, *45*(3), 409-432. https://doi.org/10.1111/j.1465-7295.2007.00017.x
230. Carroll, K. A., & Zepeda, L. (2024). Food miles and regional logos: Investigating consumer preferences in the Midwestern United States. *Sustainability*, *16*(7), 2735. https://doi.org/10.3390/su16072735
231. Tu, V. H., Kopp, S. W., Trang, N. T., Kontoleon, A., & Yabe, M. (2021). UK consumers' preferences for ethical attributes of floating rice: Implications for environmentally friendly agriculture in Vietnam. *Sustainability*, *13*(15), 8354. https://doi.org/10.3390/su13158354
232. Schell, R. C., Bulut, E., Padda, H., Safi, A. G., Moroni, P., & Ivanek, R. (2023). Responsible antibiotic use labeling and consumers' willingness to buy and pay for fluid milk. *Journal of Dairy Science*, *106*(1), 132-150. https://doi.org/10.3168/jds.2022-21791
233. Garcia-Yi, J. (2015). Willingness to pay for organic and fairtrade certified yellow chili peppers: Evidence from middle and high income districts in Lima, Peru. *British Food Journal, 117*(2), 929-942. https://doi.org/10.1108/BFJ-11-2013-0321
234. Areal, F. J., & Asioli, D. (2024). Heterogeneous preferences and consumer willingness to pay for vitamin D fortification of eggs. *Agribusiness*, *40*(3), 661-679. https://doi.org/10.1002/agr.21919
235. Xu, L., Yang, X., Wu, L., Chen, X., Chen, L., & Tsai, F.-S. (2019). Consumers' willingness to pay for food with information on animal welfare, lean meat essence detection, and traceability. *International Journal of Environmental Research and Public Health*, *16*(19), 3616. https://doi.org/10.3390/ijerph16193616
236. Wakamatsu, M., & Managi, S. (2022). Does spatially targeted information boost the value of ecolabeling seafood? A choice experiment in Japan. *Applied Economics*, *54*(52), 6008-6021. https://doi.org/10.1080/00036846.2022.2056127
237. Huang, S., & Uehara, T. (2023). Young consumers' perceptions of and preferences for alternative meats: an empirical study in Japan and China. *Frontiers in Sustainable Food Systems*, *7*, 1290131. https://doi.org/10.3389/fsufs.2023.1290131
238. Tanner, M. K., Olivares-Arenas, M., Puebla, L., & Jarrin, J. R. M. (2021). Shifting demand to sustainable fishing practices in Darwin's Archipelago: A discrete choice experiment application for Galapagos' certified yellow-fin tuna. *Marine Policy*, *132*, 104665. https://doi.org/10.1016/j.marpol.2021.104665
239. Bir, C., Widmar, N. O., Thompson, N. M., Townsend, J., & Wolf, C. A. (2020). US respondents' willingness to pay for cheddar cheese from dairy cattle with different pasture access, antibiotic use, and dehorning practices. *Journal of Dairy Science*, *103*(4), 3234-3249. https://doi.org/10.3168/jds.2019-17031
240. Hoque, M. Z. (2021). Sustainability indicators for sustainably-farmed fish in Bangladesh. *Sustainable Production and Consumption*, *27*, 115-127. https://doi.org/10.1016/j.spc.2020.10.020

241. Iwatani, S., Honda, H., Otaki, Y., & Ueda, K. (2023). Effect of asking questions and providing knowledge on attitudes toward organic foods among Japanese consumers. *Frontiers in Psychology*, *14*, 1274446. https://doi.org/10.3389/fpsyg.2023.1274446
242. Jürkenbeck, K. (2023). The effect of information among established and new sustainability labelling on consumers' preference and willingness to pay. *Cleaner and Responsible Consumption*, *10*, 100131. https://doi.org/10.1016/j.clrc.2023.100131
243. Zhen, S., Xia, X., Huang, L., Cao, Y., Fu, H., & Ren, Y. (2024). Does risk preference matter to consumers' willingness to pay for functional food: Evidence from lab experiments using the eye-tracking technology. *Food Quality and Preference*, *119*, 105197. https://doi.org/10.1016/j.foodqual.2024.105197
244. Bonnet, C., & Simioni, M. (2001). Assessing consumer response to protected designation of origin labelling: A mixed multinomial logit approach. *European Review of Agricultural Economics*, *28*(4), 433-449.
245. Dominici, A., Boncinelli, F., Gerini, F., & Marone, E. (2020). Consumer preference for wine from hand-harvested grapes. *British Food Journal*, *122*(8), 2551-2567. https://doi.org/10.1108/BFJ-04-2019-0301
246. Yang, Y., Hobbs, J. E., & Natcher, D. C. (2020). The Arctic as a food producing region: Consumer perceptions and market segments. *Canadian Journal of Agricultural Economics*, *68*(4), 387-410. https://doi.org/10.1111/cjag.12255
247. Török, Á., Gorton, M., Yeh, C.-H., Czine, P., & Balogh, P. (2022). Understanding consumers' preferences for protected geographical indications: A choice experiment with Hungarian sausage consumers. *Foods*, *11*(7), 997. https://doi.org/10.3390/foods11070997
248. Gao, Z., Yu, X., Li, C., & McFadden, B. R. (2019). The interaction between country of origin and genetically modified orange juice in urban China. *Food Quality and Preference, 71,* 475-484. https://doi.org/10.1016/j.foodqual.2018.03.016
249. Castillo, M. J., & Carpio, C. E. (2019). Demand for high-quality beef attributes in developing countries: The case of Ecuador. *Journal of Agricultural and Applied Economics*, *51*(4), 568-590. https://doi.org/10.1017/aae.2019.21
250. De Valck, J., Rolfe, J., Star, M., Rajapaksa, D., & Burton, M. (2023). Who cares about meat carbon footprint? Exploring preferences for credence factors among Australian consumers. *Journal of Cleaner Production*, *418*, 138157. https://doi.org/10.1016/j.jclepro.2023.138157
251. Wang, H., Chen, Q., & Katare, B. (2023). Nudging Chinese consumers to embrace sustainable milk consumption: How should information be provided? *Agribusiness*, *39*(S1), 1512-1534. https://doi.org/10.1002/agr.21853
252. Steiner, B. E., & Yang, J. (2010). How do U.S. and Canadian consumers value credence attributes associated with beef labels after the North American BSE crisis of 2003? *International Journal of Consumer Studies*, *34*(4), 449-463. https://doi.org/10.1111/j.1470-6431.2010.00889.x
253. Xu, L., Yang, X., & Wu, L. (2020). Consumers' willingness to pay for imported milk: Based on Shanghai, China. *International Journal of Environmental Research and Public Health*, *17*(1), 244. https://doi.org/10.3390/ijerph17010244
254. Dahlhausen, J. L., Rungie, C., & Roosen, J. (2018). Value of labeling credence attributes—common structures and individual preferences. *Agricultural Economics*, *49*(6), 741-751. https://doi.org/10.1111/agec.12456

255. Zheng, Q., Wen, X., Xiu, X., Yang, X., & Chen, Q. (2022). Can the part replace the whole? A choice experiment on organic and pesticide-free labels. *Foods, 11*(17), 2564. https://doi.org/10.3390/foods11172564
256. Sehra, K. K., & MacMillan, D. C. (2021). Wildlife-friendly food requires a multi-actor approach to deliver landscape-scale biodiversity conservation in the Satoyama landscape of Japan. *Journal of Environmental Management*, *297*, 113275. https://doi.org/10.1016/j.jenvman.2021.113275
257. Lim, K. H., Hu, W., & Nayga, R. M., Jr. (2021). Consumer preference for grass-fed beef: A case of food safety halo effect. *Journal of Agricultural and Resource Economics*, *46*(3), 447-463. https://doi.org/10.22004/ag.econ.307458
258. Chaiyesh, T. (2022). Consumers' willingness to pay for healthiness, quality and carbon footprint reduction of bagged rice. *Global Business Review*, 09721509221120775. https://doi.org/10.1177/09721509221120775
259. Bassi, I., Mian, G., Troiano, S., Gori, E., & Iseppi, L. (2023). Assessing consumer preferences for new red-pulp kiwifruit: Application of a choice experiment between different countries. *Foods*, *12*(15), 2865. https://doi.org/10.3390/foods12152865
260. Slade, P., Michler, J. D., & Josephson, A. (2019). Foreign geographical indications, consumer preferences, and the domestic market for cheese. *Applied Economic Perspectives and Policy*, *41*(3), 370-390. https://doi.org/10.1093/aepp/ppz010
261. Richartz, C., & Abdulai, A. (2022). The role of information in consumer preferences for sustainable certified palm oil products in Germany. *PLoS ONE*, *17*(7), e0271198. https://doi.org/10.1371/journal.pone.0271198
262. Gracia, A., Loureiro, M. L., & Nayga, R. M., Jr. (2009). Consumers' valuation of nutritional information: A choice experiment study. *Food Quality and Preference*, *20*(7), 463-471. https://doi.org/10.1016/j.foodqual.2009.03.010
263. Zhou, G., Hu, W., & Huang, W. (2016). Are consumers willing to pay more for sustainable products? A study of eco-labeled tuna steak. *Sustainability*, *8*(5), 494. https://doi.org/10.3390/su8050494
264. Xuan, B. B. (2021). Consumer preference for eco-labelled aquaculture products in Vietnam. *Aquaculture*, *532*, 736111. https://doi.org/10.1016/j.aquaculture.2020.736111
265. Vroegindewey, R., Richardson, R. B., Ortega, D. L., & Theriault, V. (2021). Consumer and retailer preferences for local ingredients in processed foods: Evidence from a stacked choice experiment in an African urban dairy market. *Food Policy*, *103*, 102106. https://doi.org/10.1016/j.foodpol.2021.102106
266. Zhang, X., Fang, Y., & Gao, Z. (2020). Accounting for attribute non-attendance (ANA) in Chinese consumers' away-from-home sustainable salmon consumption. *Marine Resource Economics*, *35*(3), 263-284. https://doi.org/10.1086/709458
267. Báez-Montenegro, A., Sepúlveda, E., & Echeverría, R. (2024). Is social sustainability relevant for food consumers? Evidence from Chile. *Spanish Journal of Agricultural Research*, *22*(2), e0102. https://doi.org/10.5424/sjar/2024222-20600
268. Lagerkvist, C. J., & Okello, J. (2016). Using the integrative model of behavioral prediction and censored quantile regression to explain consumers' revealed preferences for food safety: Evidence from a field experiment in Kenya. *Food Quality and Preference*, *49*, 75-86. https://doi.org/10.1016/j.foodqual.2015.11.012

269. van Loo, E. J., Grebitus, C., & Verbeke, W. (2021). Effects of nutrition and sustainability claims on attention and choice: An eye-tracking study in the context of a choice experiment using granola bar concepts. *Food Quality and Preference*, *90*, 104100. https://doi.org/10.1016/j.foodqual.2020.104100
270. Holt, D., Slade, P., & Hobbs, J. (2024). Do consumers care about clean labels? Willingness to pay for simple ingredient lists and front-of-package labels on beef and plant-based burgers. *Canadian Journal of Agricultural Economics*, *72*(1), 5-21. https://doi.org/10.1111/cjag.12346
271. Schwickert, H. (2023). Paying for animal welfare labelling no matter what? A discrete choice experiment. *European Review of Agricultural Economics*, *50*(5), 1754-1795. https://doi.org/10.1093/erae/jbad027
272. van der Stricht, H., Profeta, A., Hung, Y., & Verbeke, W. (2023). Consumers' willingness-to-buy pasta with microalgae proteins - Which label can promote sales? *Food Quality and Preference*, *110*, 104948. https://doi.org/10.1016/j.foodqual.2023.104948
273. Grashuis, J. (2023). Preferences for the farmer-owned label: Evidence from cheese consumers in the United States. *Journal of Agricultural and Food Industrial Organization*, *21*(2), 109-116. https://doi.org/10.1515/jafio-2022-0010
274. Liu, Y., & Sam, A. G. (2022). The organic premium of baby food based on market segments. *Agribusiness*, *38*(3), 533-556. https://doi.org/10.1002/agr.21745
275. Premashthira, A., Photchanaprasert, N., & Sanglestsawai, S. (2022). Consumer preferences for pork safety characteristics in Thailand. *Kasetsart Journal of Social Sciences*, *43*(3), 653-660. https://doi.org/10.34044/j.kjss.2022.43.3.16
276. Sarasty, O., Carpio, C., & Cabrera, T. (2023). Effect of the traffic-light system on nutrition labeling in processed food products in the Ecuadorian population. *Q Open*, *3*(2), qoad018. https://doi.org/10.1093/qopen/qoad018
277. Marescotti, M. E., Amato, M., Demartini, E., Barbera, F. La, Verneau, F., & Gaviglio, A. (2021). The effect of verbal and iconic messages in the promotion of high-quality mountain cheese: A non-hypothetical BDM approach. *Nutrients*, *13*(9), 3063. https://doi.org/10.3390/nu13093063
278. Iweala, S., Spiller, A., Nayga, R. M., Jr., & Lemken, D. (2022). Warm glow and consumers' valuation of ethically certified products. *Q Open*, *2*(2), qoac020. https://doi.org/10.1093/qopen/qoac020
279. Weir, M. J., Uchida, H., & Vadiveloo, M. (2021). Quantifying the effect of market information on demand for genetically modified salmon. *Aquaculture Economics and Management*, *25*(1), 1-26. https://doi.org/10.1080/13657305.2020.1803447
280. Menozzi, D., Nguyen, T. T., Sogari, G., Taskov, D., Lucas, S., Castro-Rial, J. L. S., & Mora, C. (2020). Consumers' preferences and willingness to pay for fish products with health and environmental labels: Evidence from five European countries. *Nutrients*, *12*(9), 2650. https://doi.org/10.3390/nu12092650
281. Lu, J., Wang, H., Wu, L., & Chen, X. (2020). Traceability information and willingness to pay: The case of pork. *The Singapore Economic Review*, *65*(3), 737-754. https://doi.org/10.1142/S0217590818500108
282. Ochs, D., Wolf, C. A., Widmar, N. O., Bir, C., & Lai, J. (2019). Hen housing system information effects on U.S. egg demand. *Food Policy*, *87*, 101743. https://doi.org/10.1016/j.foodpol.2019.101743
283. Vecchio, R., Annunziata, A., & Mariani, A. (2018). Is more better? Insights on consumers' preferences for nutritional information on wine labelling. *Nutrients*, *10*(11), 1667. https://doi.org/10.3390/nu10111667

284. Otieno, D. J., & Nyikal, R. A. (2016). Analysis of consumer preferences for quality and safety attributes in artisanal fruit juices in Kenya. *Journal of Food Products Marketing*, *23*(7), 817-834. https://doi.org/10.1080/10454446.2016.1164103
285. Pomarici, E., Asioli, D., Vecchio, R., & Næs, T. (2018). Young consumers' preferences for water-saving wines: An experimental study. *Wine Economics and Policy*, *7*(1), 65-76. https://doi.org/10.1016/j.wep.2018.02.002
286. Yin, S., Chen, M., Xu, Y., & Chen, Y. (2017). Chinese consumers' willingness-to-pay for safety label on tomato: Evidence from choice experiments. *China Agricultural Economic Review*, *9*(1), 141-155. https://doi.org/10.1108/CAER-11-2015-0147
287. Grebitus, C., Peschel, A. O., & Hughner, R. S. (2018). Voluntary food labeling: The additive effect of "free from" labels and region of origin. *Agribusiness*, *34*(4), 714-727. https://doi.org/10.1002/agr.21558
288. Byrd, E. S., Widmar, N. J. O., & Wilcox, M. D. (2017). Are consumers willing to pay for local chicken breasts and pork chops? *Journal of Food Products Marketing*, *24*(2), 235-248. https://doi.org/10.1080/10454446.2016.1266556
289. Yu, X., Gao, Z., & Zeng, Y. (2014). Willingness to pay for the "green food" in China. *Food Policy*, *45*, 80-87. https://doi.org/10.1016/j.foodpol.2014.01.003
290. Blomquist, J., Bartolino, V., & Waldo, S. (2015). Price premiums for providing eco-labelled seafood: Evidence from MSC-certified cod in Sweden. *Journal of Agricultural Economics*, *66*(3), 690-704. https://doi.org/10.1111/1477-9552.12106
291. Lim, K. H., Hu, W., Maynard, L. J., & Goddard, E. (2014). A taste for safer beef? How much does consumers' perceived risk influence willingness to pay for country-of-origin labeled beef. *Agribusiness*, *30*(1), 17-30. https://doi.org/10.1002/agr.21365
292. Meas, T., Hu, W., Batte, M. T., Woods, T. A., & Ernst, S. (2015). Substitutes or complements? Consumer preference for local and organic food attributes. *American Journal of Agricultural Economics*, *97*(4), 1044-1071. https://doi.org/10.1093/ajae/aau108
293. Shi, L., House, L. A., & Gao, Z. (2013). Impact of purchase intentions on full and partial bids in BDM auctions: Willingness-to-pay for organic and local blueberries. *Journal of Agricultural Economics*, *64*(3), 707-718. https://doi.org/10.1111/1477-9552.12022
294. Muth, M. K., Zhen, C., Taylor, J., Cates, S., Kosa, K., Zorn, D., & Choiniere, C. (2013). The value to consumers of health labeling statements on breakfast foods and cereals. *Journal of Food Products Marketing*, *19*(4), 279-298. https://doi.org/10.1080/10454446.2013.724372
295. Mauracher, C., Tempesta, T., & Vecchiato, D. (2013). Consumer preferences regarding the introduction of new organic products. The case of the Mediterranean sea bass (*Dicentrarchus labrax*) in Italy. *Appetite*, *63*, 84-91. https://doi.org/10.1016/j.appet.2012.12.009
296. Verbeke, W., Rutsaert, P., Bonne, K., & Vermeir, I. (2013). Credence quality coordination and consumers' willingness-to-pay for certified halal labelled meat. *Meat Science*, *95*(4), 790-797. https://doi.org/10.1016/j.meatsci.2013.04.042
297. McKendree, M. G. S., Widmar, N. O., Ortega, D. L., & Foster, K. A. (2013). Consumer preferences for verified pork-rearing practices in the production of ham products. *Journal of Agricultural and Resource Economics*, *38*(3), 397-417.

298. Ortega, D. L., Wang, H. H., & Olynk Widmar, N. J. (2014). Aquaculture imports from Asia: An analysis of U.S. consumer demand for select food quality attributes. *Agricultural Economics*, *45*(5), 625-634. https://doi.org/10.1111/agec.12111
299. Uchida, H., Roheim, C. A., Wakamatsu, H., & Anderson, C. M. (2013). Do Japanese consumers care about sustainable fisheries? Evidence from an auction of ecolabelled seafood. *Australian Journal of Agricultural and Resource Economics*, *58*(2), 263-280. https://doi.org/10.1111/1467-8489.12036
300. van Loo, E. J., Diem, M. N. H., Pieniak, Z., & Verbeke, W. (2013). Consumer attitudes, knowledge, and consumption of organic yogurt. *Journal of Dairy Science*, *96*(4), 2118-2129. https://doi.org/10.3168/jds.2012-6262
301. Durham, C. A., Roheim, C. A., & Pardoe, I. (2012). Picking apples: Can multi-attribute ecolabels compete? *Journal of Agricultural and Food Industrial Organization*, *10*(1), 1-28. https://doi.org/10.1515/1542-0485.1372
302. Chern, W. S., & Lin, H. C. (2012). Taiwanese consumer valuation of country of origin labeling using auction experiment with tasting. *Journal of Family and Economic Issues*, *33*(2), 184-198. https://doi.org/10.1007/s10834-012-9316-1
303. Loureiro, M. L. (2003). Rethinking new wines: Implications of local and environmentally friendly labels. *Food Policy*, *28*(5-6), 547-560. https://doi.org/10.1016/j.foodpol.2003.10.004
304. Onyango, B., Nayga, R. M., Jr., & Govindasamy, R. (2006). U.S. consumers' willingness to pay for food labeled "genetically modified." *Agricultural and Resource Economics Review*, *35*(2), 299-310. https://doi.org/10.1017/S1068280500006742
305. Zhu, Z., Zhang, T., & Hu, W. (2023). The accumulation and substitution effects of multi-nation certified organic and protected eco-origin food labels in China. *Ecological Economics*, *203*, 107625. https://doi.org/10.1016/j.ecolecon.2022.107625
306. Yang, S.-H., Hu, W., Mupandawana, M., & Liu, Y. (2012). Consumer willingness to pay for fair trade coffee: A Chinese case study. *Journal of Agricultural and Applied Economics*, *44*(1), 21-34. https://doi.org/10.1017/s1074070800000146
307. Wongprawmas, R., & Canavari, M. (2017). Consumers' willingness-to-pay for food safety labels in an emerging market: The case of fresh produce in Thailand. *Food Policy*, *69*, 25-34. https://doi.org/10.1016/j.foodpol.2017.03.004
308. Waldrop, M. E., McCluskey, J. J., & Mittelhammer, R. C. (2017). Products with multiple certifications: Insights from the US wine market. *European Review of Agricultural Economics*, *44*(4), 658-682. https://doi.org/10.1093/erae/jbx010
309. Umberger, W. J., Boxall, P. C., & Lacy, R. C. (2009). Role of credence and health information in determining us consumers' willingness-to-pay for grass-finished beef. *Australian Journal of Agricultural and Resource Economics*, *53*(4), 603-623. https://doi.org/10.1111/j.1467-8489.2009.00466.x
310. Uddin, A., & Gallardo, R. K. (2021). Consumers' willingness to pay for organic, clean label, and processed with a new food technology: An application to ready meals. *International Food and Agribusiness Management Review*, *24*(3), 563-579. https://doi.org/10.22434/IFAMR2020.0127
311. Ubilava, D., & Foster, K. (2009). Quality certification vs. product traceability: Consumer preferences for informational attributes of pork in Georgia. *Food Policy*, *34*(3), 305-310. https://doi.org/10.1016/j.foodpol.2009.02.002

312. Soley, G., Hu, W., & Vassalos, M. (2019). Willingness to pay for shrimp with Homegrown by Heroes, Community-Supported Fishery, Best Aquaculture Practices, or local attributes. *Journal of Agricultural and Applied Economics*, *51*(4), 606-621. https://doi.org/10.1017/aae.2019.19
313. Sanjuán, A. I., & Khliji, S. (2016). Urban consumers' response to the EU food mountain labelling: An empirical application in Southern Europe. *New Medit*, *15*(1), 72-80.
314. Sackett, H., Shupp, R., & Tonsor, G. (2016). Differentiating "sustainable" from "organic" and "local" food choices: Does information about certification criteria help consumers? *International Journal of Food and Agricultural Economics, 4*(3), 17-31. https://doi.org/10.22004/ag.econ.244284
315. Rousseau, S., & Vranken, L. (2013). Green market expansion by reducing information asymmetries: Evidence for labeled organic food products. *Food Policy*, *40*, 31-43. https://doi.org/10.1016/j.foodpol.2013.01.006
316. Phong, T. N., Tat Thang, V., & Nguyen Trong, H. (2022). The effect of sustainability labels on farmed-shrimp preferences: Insights from a discrete choice experiment in Vietnam. *Aquaculture Economics & Management*, *27*(3), 468-497. https://doi.org/10.1080/13657305.2022.2147248
317. Ortega, D. L., Wang, H. H., & Olynk Widmar, N. J. (2015). Effects of media headlines on consumer preferences for food safety, quality and environmental attributes. *Australian Journal of Agricultural and Resource Economics*, *59*(3), 433-445. https://doi.org/10.1111/1467-8489.12097
318. Nian, Y., Gao, Z., & Zhao, R. (2023). Are people's daily life habits consistent with their preference for food sustainability labels? *Agribusiness*, *39*(3), 589-622. https://doi.org/10.1002/agr.21803
319. Loureiro, M. L., & Umberger, W. J. (2005). Assessing consumer preferences for country-of-origin labeling. *Journal of Agricultural and Applied Economics*, *37*(1), 49-63. https://doi.org/10.1017/s1074070800007094
320. Loureiro, M. L., & Umberger, W. J. (2003). Estimating consumer willingness to pay for country-of-origin labeling. *Journal of Agricultural and Resource Economics*, *28*(2), 287-301. https://doi.org/10.22004/ag.econ.31091
321. Loureiro, M. L., & Hine, S. (2002). Discovering niche markets: A comparison of consumer willingness to pay for local (Colorado grown), organic, and GMO-free products. *Journal of Agricultural and Applied Economics*, *34*(3), 477-487. https://doi.org/10.1017/s1074070800009251
322. Lim, K. H., & Hu, W. (2016). How local is local? A reflection on Canadian local food labeling policy from consumer preference. *Canadian Journal of Agricultural Economics*, *64*(1), 71-88. https://doi.org/10.1111/cjag.12062
323. Froehlich, E. J., Carlberg, J. G., & Ward, C. E. (2009). Willingness-to-pay for fresh brand name beef. *Canadian Journal of Agricultural Economics*, *57*(1), 119-137. https://doi.org/10.1111/j.1744-7976.2008.01141.x
324. Drichoutis, A. C., Vassilopoulos, A., Lusk, J. L., & Nayga, R. M., Jr. (2017). Consumer preferences for fair labour certification. *European Review of Agricultural Economics*, *44*(3), 455-474. https://doi.org/10.1093/erae/jbx002
325. Costanigro, M., McFadden, D. T., Kroll, S., & Nurse, G. (2011). An in-store valuation of local and organic apples: The role of social desirability. *Agribusiness, 27*(4), 465-477. https://doi.org/10.1002/agr.20281

326. Chung, C., Briggeman, B. C., & Han, S. (2012). Willingness-to-pay for beef quality attributes: A latent segmentation analysis of Korean grocery shoppers. *Journal of Agricultural and Applied Economics*, *44*(4), 447-459. https://doi.org/10.1017/s1074070800024032
327. Chang, J. B., Moon, W., & Balasubramanian, S. K. (2012). Consumer valuation of health attributes for soy-based food: A choice modeling approach. *Food Policy*, *37*(3), 335-342. https://doi.org/10.1016/j.foodpol.2012.03.001
328. Bai, J., Zhang, C., & Jiang, J. (2013). The role of certificate issuer on consumers' willingness-to-pay for milk traceability in China. *Agricultural Economics*, *44*(4-5), 537-544. https://doi.org/10.1111/agec.12037
329. Thuannadee, A., & Noosuwan, C. (2025). Consumer meat preference and willingness to pay for local organic meat in Thailand: A case study of Taphao Thong-Kasetsart chicken. *Journal of Agribusiness in Developing and Emerging Economies*, *15*(1), 81-95. https://doi.org/10.1108/JADEE-12-2022-0279
330. Nishimura, T. (2021). The effect of greenhouse pollination methods on consumers' willingness to pay for tomatoes in Japan. *Journal of Agricultural and Applied Economics*, *53*(2), 186-208. https://doi.org/10.1017/aae.2020.33
331. Bir, C., Delgado, M. S., & Widmar, N. O. (2020). Presenting smaller 'component designs' in place of large discrete choice experiment. *Journal of Agriculture and Food Research*, *2*, 100083. https://doi.org/10.1016/j.jafr.2020.100083
332. Asioli, D., Banovic, M., Barone, A. M., Grasso, S., & Nayga, R. M., Jr. (2023). European consumers' valuation for hybrid meat: Does information matter? *Applied Economic Perspectives and Policy*, *45*(1), 44-62. https://doi.org/10.1002/aepp.13283
333. McFadden, J. R., & Huffman, W. E. (2017). Willingness-to-pay for natural, organic, and conventional foods: The effects of information and meaningful labels. *Food Policy*, *68*, 214-232. https://doi.org/10.1016/j.foodpol.2017.02.007
334. Mahé, T. (2010). Are stated preferences confirmed by purchasing behaviours? The case of fair trade-certified bananas in Switzerland. *Journal of Business Ethics*, *92*, 301-315. https://doi.org/10.1007/s10551-010-0585-z
335. Anastasiou, C. N., Keramitsoglou, K. M., Kalogeras, N., Tsagkaraki, M. I., Kalatzi, I., & Tsagarakis, K. P. (2017). Can the "Euro-leaf" logo affect consumers' willingness-to-buy and willingness-to-pay for organic food and attract consumers' preferences? An empirical study in Greece. *Sustainability*, *9*(8), 1450. https://doi.org/10.3390/su9081450
336. McFadden, J. R., & Huffman, W. E. (2017). Consumer valuation of information about food safety achieved using biotechnology: Evidence from new potato products. *Food Policy*, *69*, 82-96. https://doi.org/10.1016/j.foodpol.2017.03.002
337. He, C., Shi, L., Gao, Z., & House, L. (2020). The impact of customer ratings on consumer choice of fresh produce: A stated preference experiment approach. *Canadian Journal of Agricultural Economics*, *68*(3), 359-373. https://doi.org/10.1111/cjag.12222
338. Atallah, S. S., Bazzani, C., Ha, K. A., & Nayga, R. M., Jr. (2021). Does the origin of inputs and processing matter? Evidence from consumers' valuation for craft beer. *Food Quality and Preference*, *89*, 104146. https://doi.org/10.1016/j.foodqual.2020.104146
339. Wanyama, R., Gödecke, T., Jager, M., & Qaim, M. (2019). Poor consumers' preferences for nutritionally enhanced foods. *British Food Journal*, *121*(3), 755-770. https://doi.org/10.1108/BFJ-09-2018-0622

340. Garcia, M., Carpio, C., Hudson, D., Boonsaeng, T., & Wang, C. (2023). Mexican consumers' perceptions and preferences for US and Texas beef. *Agribusiness*, *40*(4), 727-748. https://doi.org/10.1002/agr.21844
341. Tian, Y., Zhu, H., Zhang, L., & Chen, H. (2022). Consumer preference for nutritionally fortified eggs and impact of health benefit information. *Foods*, *11*(8), 1145. https://doi.org/10.3390/foods11081145
342. Nguyen, A. T., Ha, V. D., Ngo, H. K., Le, N. A., Khong, P. M., Do, N. T. T., Trinh, M. T., Nguyen, T. D., Ngo, T. Q. K., Vu, L. C., Do, M. L. T., Le, A. T., Tran, B. M., & Nguyen, V. T. (2023). Understanding the importance of eco-labeling for organic foods at UNESCO Biosphere Reserves: A case study of the cocoa powder at the Dong Nai, Vietnam. *Sustainability, 15*(12), 9603. https://doi.org/10.3390/su15129603
343. Ragasa, C., Andam, K. S., Asante, S. B., & Amewu, S. (2020). Can local products compete against imports in West Africa? Supply- and demand-side perspectives on chicken, rice, and tilapia in Ghana. *Global Food Security*, *26*, 100448. https://doi.org/10.1016/j.gfs.2020.100448
344. Li, T., McCluskey, J. J., & Messer, K. D. (2018). Ignorance is bliss? Experimental evidence on wine produced from grapes irrigated with recycled water. *Ecological Economics*, *153*, 100-110. https://doi.org/10.1016/j.ecolecon.2018.07.004
345. de-Magistris, T., Pascucci, S., & Mitsopoulos, D. (2015). Paying to see a bug on my food: How regulations and information can hamper radical innovations in the European Union. *British Food Journal*, *117*(6), 1777-1792. https://doi.org/10.1108/BFJ-06-2014-0222
346. Loureiro, M. L., & Umberger, W. J. (2007). A choice experiment model for beef: What US consumer responses tell us about relative preferences for food safety, country-of-origin labeling and traceability. *Food Policy*, *32*(4), 496-514. https://doi.org/10.1016/j.foodpol.2006.11.006
347. Villanueva, A. J., Salazar-Ordoñez, M., Granado-Díaz, R., & Rodríguez-Entrena, M. (2021). Consumers' preferences for traditional meat products: Production system and objective quality cues in Iberian ham. *Italian Journal of Animal Science*, *20*(1), 1987-2001. https://doi.org/10.1080/1828051X.2021.1982419
348. Hou, B., Hou, J., & Wu, L. (2020). Consumer preferences for traceable food with different functions of safety information attributes: Evidence from a menu-based choice experiment in China. *International Journal of Environmental Research and Public Health*, *17*(1), 146. https://doi.org/10.3390/ijerph17010146
349. Palma, M. A., Collart, A. J., & Chammoun, C. J. (2015). Information asymmetry in consumer perceptions of quality-differentiated food products. *Journal of Consumer Affairs*, *49*(3), 596-612. https://doi.org/10.1111/joca.12053
350. Barreiro-Hurlé, J., Colombo, S., & Cantos-Villar, E. (2008). Is there a market for functional wines? Consumer preferences and willingness to pay for resveratrol-enriched red wine. *Food Quality and Preference*, *19*(4), 360-371. https://doi.org/10.1016/j.foodqual.2007.11.004
351. Bai, L., Zhu, Z., & Zhang, T. (2021). How to improve food quality in the domestic market: The role of "same line same standard same quality"—evidence from a consumer choice experiment in China. *Sustainability*, *13*(10), 5709. https://doi.org/10.3390/su13105709

352. van Wezemael, L., Caputo, V., Nayga, R. M., Jr., Chryssochoidis, G., & Verbeke, W. (2014). European consumer preferences for beef with nutrition and health claims: A multi-country investigation using discrete choice experiments. *Food Policy*, *44*, 167-176. https://doi.org/10.1016/j.foodpol.2013.11.006
353. Lusk, J. L. (2019). Consumer preferences for cage-free eggs and impacts of retailer pledges. *Agribusiness*, *35*(2), 129-148. https://doi.org/10.1002/agr.21580
354. Gerini, F., Alfnes, F., & Schjøll, A. (2016). Organic- and animal welfare-labelled eggs: Competing for the same consumers? *Journal of Agricultural Economics*, *67*(2), 471-490. https://doi.org/10.1111/1477-9552.12154
355. Zhu, Z., Shen, Q., & Gao, Z. (2022). Consumer choices in agricultural markets with multitier collective labels and private brands. *Agribusiness*, *38*(4), 905-922. https://doi.org/10.1002/agr.21747
356. Rozan, A., Stenger, A., & Willinger, M. (2004). Willingness-to-pay for food safety: An experimental investigation of quality certification on bidding behaviour. *European Review of Agricultural Economics*, *31*(4), 409-425. https://doi.org/10.1093/erae/31.4.409
357. Ortega, D. L., Caputo, V., & Maredia, M. (2023). Effectiveness of nutritional information in increasing demand for enriched yoghurt among poor households in Kenya: Implications for agribusiness marketing strategies. *Agribusiness*, *39*(1), 285-290. https://doi.org/10.1002/agr.21784
358. Luckstead, J., Snell, H. A., Nalley, L. L., Nayga, R. M., Jr., & Sarpaning, J. (2022). A multi-country study on consumers' valuation for child-labor-free chocolate: Implications for child labor in cocoa production. *Applied Economic Perspectives and Policy*, *44*(2), 1021-1048. https://doi.org/10.1002/aepp.13165
359. Asioli, D., Bazzani, C., & Nayga, R. M., Jr. (2022). Are consumers willing to pay for in-vitro meat? An investigation of naming effects. *Journal of Agricultural Economics*, *73*(2), 356-375. https://doi.org/10.1111/1477-9552.12467
360. Jiang, Y., Wang, H. H., & Jin, S. (2023). Mobilising the public to fight poverty using anti-poverty labels in online food markets: Evidence from a real experimental auction. *Journal of Agricultural Economics*, *74*(1), 168-190. https://doi.org/10.1111/1477-9552.12502
361. Hu, Y., House, L. A., & Gao, Z. (2022). How do consumers respond to labels for crispr (gene-editing)? *Food Policy*, *112*, 102366. https://doi.org/10.1016/j.foodpol.2022.102366
362. Sanou, A., Liverpool-Tasie, L. S. O., Caputo, V., & Kerr, J. (2021). Introducing an aflatoxin-safe labeling program in complex food supply chains: Evidence from a choice experiment in Nigeria. *Food Policy*, *102*, 102070. https://doi.org/10.1016/j.foodpol.2021.102070
363. Schulze, M., Spiller, A., & Risius, A. (2021). Do consumers prefer pasture-raised dual-purpose cattle when considering meat products? A hypothetical discrete choice experiment for the case of minced beef. *Meat Science*, *177*, 108494. https://doi.org/10.1016/j.meatsci.2021.108494
364. Gilmour, D. N., Bazzani, C., Nayga, R. M., Jr., & Snell, H. A. (2019). Do consumers value hydroponics? Implications for organic certification. *Agricultural Economics*, *50*(6), 707-721. https://doi.org/10.1111/agec.12519
365. Rolfe, J., De Valck, J., Rajapaksa, D., Flint, N., Star, M., & Akbar, D. (2023). Willingness to pay for higher environmental standards for avocado production in Great Barrier Reef catchments. *Food Quality and Preference*, *110*, 104940. https://doi.org/10.1016/j.foodqual.2023.104940

366. Profeta, A., & Hamm, U. (2019). Consumers' expectations and willingness-to-pay for local animal products produced with local feed. *International Journal of Food Science and Technology*, *54*(3), 651-659. https://doi.org/10.1111/ijfs.13933
367. di Santo, N., Califano, G., Sisto, R., Caracciolo, F., & Pilone, V. (2024). Are university students really hungry for sustainability? A choice experiment on new food products from circular economy. *Agricultural and Food Economics*, *12*(1), 21. https://doi.org/10.1186/s40100-024-00315-9
368. Roselli, L., Carlucci, D., & De Gennaro, B. C. (2016). What is the value of extrinsic olive oil cues in emerging markets? Empirical evidence from the US E-commerce retail market. *Agribusiness*, *32*(3), 329-342. https://doi.org/10.1002/agr.21454
369. Chang, M. Y., Huang, C. C., Du, Y. C., & Chen, H. S. (2022). Choice experiment assessment of consumer preferences for yogurt products attributes: Evidence from Taiwan. *Nutrients*, *14*(17), 3523. https://doi.org/10.3390/nu14173523
370. Mazzocchi, C., Orsi, L., Zilia, F., Costantini, M., & Bacenetti, J. (2022). Consumer awareness of sustainable supply chains: A choice experiment on Parma ham PDO. *Science of the Total Environment*, *836*, 155602. https://doi.org/10.1016/j.scitotenv.2022.155602
371. Yue, C., & Tong, C. (2009). Organic or local? Investigating consumer preference for fresh produce using a choice experiment with real economic incentives. *HortScience*, *44*(2), 366-371. https://doi.org/10.21273/HORTSCI.44.2.366
372. Grashuis, J., & Su, Y. (2023). Consumer preferences for state-sponsored designations: the case of the Missouri Grown label. *Journal of Agricultural and Resource Economics*, *48*(1), 103-116. https://doi.org/10.22004/ag.econ.316756
373. Echeverría, R., Hugo Moreira, V., Sepúlveda, C., & Wittwer, C. (2014). Willingness to pay for carbon footprint on foods. *British Food Journal*, *116*(2), 186-196. https://doi.org/10.1108/BFJ-07-2012-0292
374. Yoon, S., Gao, Z., & House, L. (2022). Do efforts to reduce packaging waste impact preferences for meal kits?. *Food Quality and Preference*, *96*, 104410. https://doi.org/10.1016/j.foodqual.2021.104410
375. Ballco, P., Jurado, F., & Gracia, A. (2020). Do health claims add value to nutritional claims? Evidence from a close-to-real experiment on breakfast biscuits. *Food Quality and Preference*, *85*, 103968. https://doi.org/10.1016/j.foodqual.2020.103968
376. Chen, J., Lai, J., Chen, X., & Gao, Z. (2023). Effects of shared characteristics between eco-labels: A case for organic and local food. *International Journal of Consumer Studies*, *47*(1), 285-298. https://doi.org/10.1111/ijcs.12835
377. Nguyen, L., Govindasamy, R., & Mentreddy, S. R. (2024). Turmeric trends: analyzing consumer preferences and willingness to pay. *Frontiers in Sustainable Food Systems*, *8*, 1359040. https://doi.org/10.3389/fsufs.2024.1359040

Supplementary Text 5.8: Subgroup classification criteria

Classification of special food attributes

- Quality and Safety (Grunert, 2005). This refers to food attributes that emphasize the origin of ingredients, production technologies and standards, and safety supervision. This classification includes attributes that show the superior production standards, such as certifications like Vietnam GAP and Demeter, as well as some claims like grass-fed, pesticide-free, hometown-produced (origin), homemade (origin), and locally produced food (origin). It also includes food products with specific ingredient transparency, such as genetically modified (GM) or non-GM labeling. In addition, religious or ethical food attributes, including halal and vegan, are included in this classification, as they often imply strict safety, hygiene, and processing standards. Organic is considered a comprehensive food attribute that encompasses quality & safety, sustainability, and nutrition & health (Baydeniz et al., 2024). However, for clarity and categorization, organic is classified as one of the quality attributes, primarily reflecting its role in highlighting the product's superior quality and production standards. Attributes, such as 'antibiotic-free', 'pesticide-free', and 'hormone-free', are related to food safety that indicate the use or absence of certain substances during production, reflecting the product's safety status.
- Sustainability (Grunert et al., 2014; Piracci et al., 2024). This focuses on the environmental, social, and ethical impacts of food production. This attribute is associated with issues such as environmental protection, biodiversity, labor rights, and animal welfare throughout the food production and logistics. The attributes 'barn-raised', 'free-range', and 'green', indicating efforts to produce food in a way that minimizes environmental damage and promotes animal welfare, are classified into this attribute type.
- Health and Nutrition (Barreiro Hurle et al., 2010). This refers to the nutritional and chemical-related composition of foods and their perceived or actual benefits to human health. This classification of special food attributes includes nutrition claims, nutrients, and so on. Food attributes with health-related certifications, such as inspections conducted by health authorities, also fall under this category. Additionally, attributes related to allergen information, insect-based, and 'all-natural' contribute to the health and nutrition dimension.

Classification of food type

- Animal-based food. This refers to the food products deriving from animals or mainly containing animal-origin ingredients. This category includes a wide range

of products such as eggs, animal-based milk, cheese, butter, yogurt, ham, sausage, and infant formula.

- Plant-based food. This includes all foods that originate from plants, such as fruits, vegetables, legumes, nuts, seeds, and unprocessed grains.
- Processed food. This is defined as products that are manufactured through the complex processing of multiple ingredients. This category encompasses commonly consumed items such as bread, cookies, jam, wine, tea, coffee, beer, juice, ice cream, snacks, sugar, spices, etc.

Supplementary Text 5.9: Supplementary references

Altman, D. G., & Bland, J. M. (2005). Standard deviations and standard errors. *Bmj*, *331*(7521), 903. https://doi.org/10.1136/bmj.331.7521.903

Barreiro Hurle, J., Gracia, A., & De Magistris, T. (2010). The effects of multiple health and nutrition labels on consumer food choices. *Journal of Agricultural Economics, 61*(2), 426-443. https://doi.org/10.1111/j.1477-9552.2010.00247.x

Baydeniz, E., Ergün, B., Türkoğlu, T., & Aytekin, E. (2024). Revealing the organic food consumption intention in Afyonkarahisar: a study on the impact of health, safety, value and attributes. *British Food Journal*, *126*(7), 2895-2917. https://doi.org/10.1108/BFJ-08-2023-0740

Bhatt, S., Ye, H., Deutsch, J., Jeong, H., Zhang, J., & Suri, R. (2021). Food waste and upcycled foods: can a logo increase acceptance of upcycled foods?. *Journal of Food Products Marketing*, *27*(4), 188-203. https://doi.org/10.1080/10454446.2021.1955798

Borenstein, M., & Higgins, J. P. (2013). Meta-analysis and subgroups. *Prevention Science*, *14*(2), 134-143. https://doi.org/10.1007/s11121-013-0377-7

Breidert, C., Hahsler, M., & Reutterer, T. (2006). A review of methods for measuring willingness-to-pay. *Innovative Marketing*, *2*(4).

Clark, B., Stewart, G. B., Panzone, L. A., Kyriazakis, I., & Frewer, L. J. (2017). Citizens, consumers and farm animal welfare: A meta-analysis of willingness-to-pay studies. *Food Policy*, *68*, 112-127. https://doi.org/10.1016/j.foodpol.2017.01.006

Cuijpers, P., Griffin, J. W., & Furukawa, T. A. (2021). The lack of statistical power of subgroup analyses in meta-analyses: a cautionary note. *Epidemiology and Psychiatric Sciences*, 30, e78. https://doi.org/10.1017/S2045796021000664

D'Souza, A., & Jolliffe, D. (2012). Rising food prices and coping strategies: Household-level evidence from Afghanistan. *Journal of Development Studies*, *48*(2), 282-299. https://doi.org/10.1080/00220388.2011.635422

Dijkman, B., Kooistra, B., & Bhandari, M. (2009). How to work with a subgroup analysis. *Canadian Journal of Surgery*, *52*(6), 515.

Grunert, K. G. (2005). Food quality and safety: consumer perception and demand. *European Review of Agricultural Economics*, *32*(3), 369-391. https://doi.org/10.1093/eurrag/jbi011

Grunert, K. G., Hieke, S., & Wills, J. (2014). Sustainability labels on food products: Consumer motivation, understanding and use. *Food Policy*, *44*, 177-189. https://doi.org/10.1016/j.foodpol.2013.12.001

Higgins, J. P., & Thompson, S. G. (2002). Quantifying heterogeneity in a meta-analysis. *Statistics in Medicine*, *21*(11), 1539-1558. https://doi.org/10.1002/sim.1186

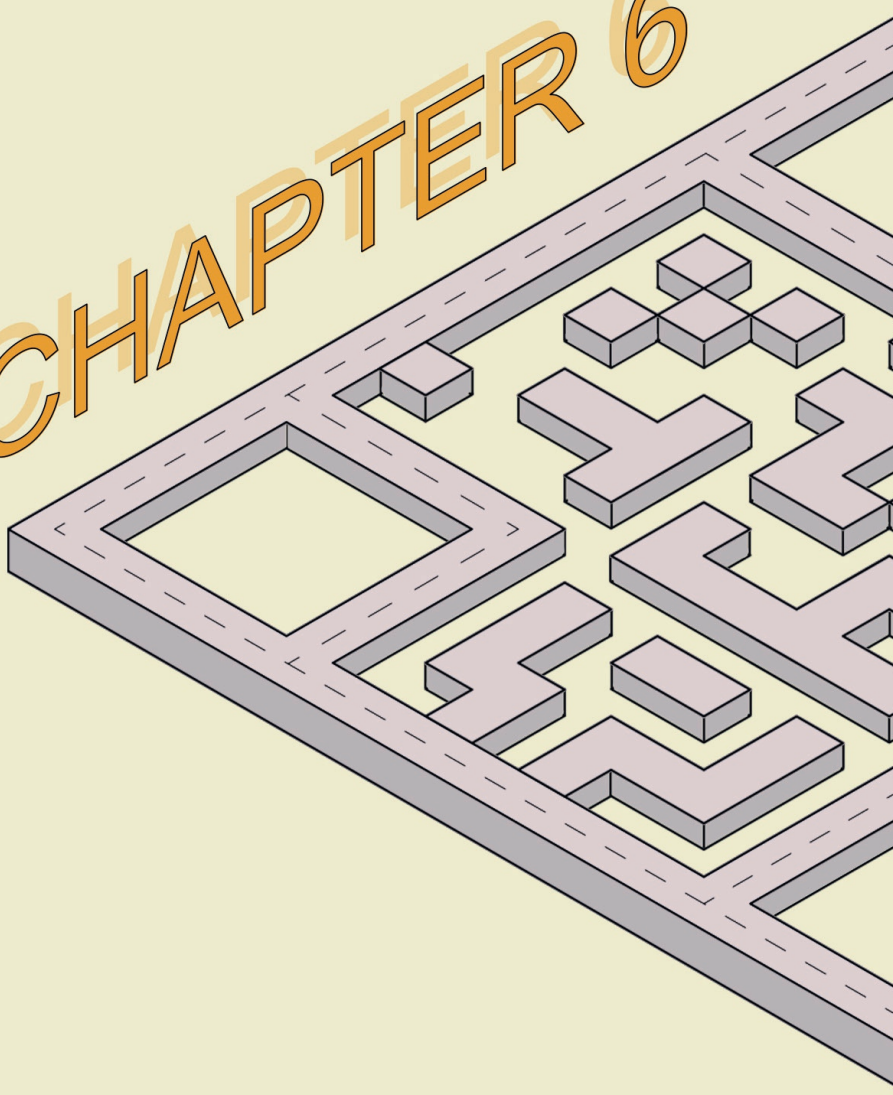
Idris, N. R. N., & Robertson, C. (2009). The effects of imputing the missing standard deviations on the standard error of meta analysis estimates. *Communications in Statistics—Simulation and Computation*, *38*(3), 513-526. https://doi.org/10.1080/03610910802556106

Luning, P. A., & Marcelis, W. J. (2020). *Food quality management*. Wageningen Academic Publishers. https://doi.org/10.3920/978-90-8686-899-5

Piracci, G., Lamonaca, E., Santeramo, F. G., Boncinelli, F., & Casini, L. (2024). On the willingness to pay for food sustainability labelling: A meta-analysis. *Agricultural Economics*, *55*(2), 329-345. https://doi.org/10.1111/agec.12826

Tran, D., Schouteten, J. J., Gellynck, X., & De Steur, H. (2024). How do consumers value food traceability?-A meta-analysis. *Food Control*, 110453. https://doi.org/10.1016/j.foodcont.2024.110453

CHAPTER 6



Chapter 6

Food counterfeiting detection based on the spatial-temporal analysis of consumers scanning QR codes - A feasibility analysis

This chapter is prepared for submission as:

Pengfei Li, Sara W. Erasmus, Ana M. Jiménez-Carvelo, Hui Wang, Saskia M. van Ruth. Food counterfeiting detection based on the spatial-temporal analysis of consumers scanning QR codes - A feasibility analysis.

Abstract

Counterfeiting is a persistent challenge in the food sector, significantly affecting the profitability of food business operators and posing substantial risks to consumer safety too. Despite various attempts to improve food fraud controls, food counterfeiting detection remains a challenge. To address this challenge, spatial-temporal analysis of consumers scanning food packaging QR codes is a promising approach to counterfeiting detection. This paper presents a feasibility analysis of this approach. Firstly, the spatial-temporal scanning information related to counterfeiting, including date, time, and coordinates (longitudes and latitudes), is selected, and collected from the dataset. The normal spatial-temporal patterns of a batch of food with the same QR codes are then analyzed, and the changes caused by four types of counterfeiting are identified and used to establish the relationship between counterfeiting and spatial-temporal anomalies in scanning. Finally, potential approaches for counterfeiting detection based on spatial-temporal patterns are proposed and studied through a conceptual analysis. The results indicate that different types of food counterfeiting can indeed cause anomalous changes in spatial-temporal patterns, and outlier detection methods can identify the batches of counterfeiting food. This proves that it is feasible to detect food counterfeiting based on the spatial-temporal patterns of scanning QR codes, which provides a theoretical basis for future applications in the food industry.

Keywords

Anomaly detection; Food fraud; Location; Outliers; Spatial-temporal pattern

6.1 Introduction

A trademark is defined as a distinguishing sign used by its owners to attract consumers (Nasirov, 2020). Well-known trademarks are one of the important marketing strategies in the business world (Simin & Živkucin, 2021). Consumers regard products with reputable trademarks as high quality, trust the products from the brand, and are more willing to buy them, which is known as consumers' loyalty (Aurier & Séré de Lanauze, 2012). This is why a lot of resources are invested over a long period to build and maintain reputable trademarks. The holders of registered trademarks are protected by regulations to prevent their unauthorized use by third parties and to avoid the erosion of their value.

Counterfeiting has been an increasingly serious and long-standing problem in many fields, including food (Soon & Manning, 2019), drugs (Gopikarani et al., 2023), and luxury handbags (Peng et al., 2022), where premium brands are typically targeted by fraudsters. The World Trade Organization (WTO) defines counterfeiting as '*an unauthorized representation of a registered trademark carried on goods identical or similar to goods for which the trademark is registered, with a view to deceiving the purchasers into believing that they are buying the original goods*'. The total value of global counterfeiting products reaches $1.2 trillion per year (Soon & Manning, 2019). According to the report 'The Global Trade in Fakes' published by the Organization for Economic Co-operation and Development (OECD) and the European Union Intellectual Property Office (EUIPO), trading with counterfeit goods amounted to roughly $449 billion in 2019 (OECD, 2021). As one of the oldest crimes historically, counterfeiting in the food field dates to 27 BC (Spink & Moyer, 2011). As a result of the globalization of supply chains in the food industry, various forms of counterfeiting can be detected at present in food.

According to the distinct characteristics, four types of counterfeiting have been defined (van Ruth et al., 2022):

a) **Full fakes** are a common type of counterfeiting, where all aspects of a branded food, including shape, packaging, label, color, and taste, are copied fully by counterfeiters.

b) **Original packaging refills**, called packaging counterfeiting, refer to low-quality food repackaged by recycled original packaging to pretend to be genuine. In other words, the packaging is genuine while the product is fake.

c) The form of the **non-compliant materials** is the food that was found not to meet specifications earlier are resold illegally as high-quality products.

d) **Product overruns**, called 'third shift', are those where the outsourced manufacturers continue production after the contract with the brand owner is terminated or the quantity of food has reached the production agreements (Soon & Manning, 2019).

Despite efforts to prevent them, the illegal trade and sales of counterfeits are continuing to grow for numerous reasons. Firstly, while blockchain technology can help prevent counterfeit food from entering legitimate supply chains, it is challenging to supervise the parallel markets where counterfeit food is often sold. Secondly, the internet (e-commerce) has accelerated the scale of counterfeiting sales, providing counterfeiters with opportunities to evade investigation by concealing their identities and providing false information. Additionally, the involvement of multiple entities in the food supply chains increases the likelihood of traffickers and counterfeiters committing crimes, including authorized retailers selling counterfeits alongside genuine food, making it difficult for authorities to detect potential counterfeiting.

Taking innovative methods to timely detect possible counterfeit food, rather than implementing reactive countermeasures after the counterfeit food has caused severe consequences, is a priority in mitigating counterfeiting risks (Spink & Moyer, 2011). Currently, big data is universally regarded as a feasible approach to crack down on counterfeit products (Ming-Yi et al., 2020). The data of consumers scanning QR codes, which is a branch of big data, provides a wealth of information, including geospatial locations with timestamps, offering insights into the movement of food products. The spatial-temporal analysis of consumers scanning QR codes on food packaging, as an advanced modern approach, has significant potential in detecting counterfeit food products (Jiménez-Carvelo et al., 2022). Once identified as counterfeit, the affected batch of food can be removed from the market by the official competent regulatory department to defuse the counterfeiting crisis and prevent further losses. However, limited research has been reported on the principles of this approach. The paper aims to propose a framework for an early warning system applied to counterfeit food detection based on the spatial-temporal analysis of consumers scanning QR codes. This paper proposes that by collecting the spatial-temporal data of consumers scanning QR codes (coordinates, timestamp, etc.) and analyzing the characteristics of the spatial-temporal patterns, the anomalies in the dataset related to counterfeiting can be identified.

6.2 Related work

QR code is a type of two-dimensional barcode used to store information in the form of small black-and-white square patterns. In the context of food fraud, QR code is utilized

as a security and traceability measure to prevent counterfeiting and ensure the authenticity of food products.

In this context, there are two general ways for fraud detection based on QR codes: 1) the cross-checking mechanism of authentication codes (Certilogo, 2025); 2) the spatial-temporal analysis of scanning data. The cross-checking mechanism of authentication codes is to check whether the authentication code linked with the QR code on food packaging can be matched with that disclosed online. Once two authentication codes are matched, the food is identified as authentic (Huque et al., 2015). However, two authentication codes are eventually exposed to the public. Offenders can copy them by cloning, which is then presented on the packaging of the counterfeit food. In this way, this type of authentication method may be invalid, causing huge food safety risks. Thus, the spatial-temporal analysis of scanning data appears to be a more feasible way to detect counterfeit food. Some studies have explored methods for spatial-temporal analysis, including spatial methods, temporal methods, and spatial-temporal methods, as shown in **Table 6.1**.

The core of spatial methods is to analyze the distance of scans of the unique QR code on individual products to achieve counterfeiting detection, although the proposed criteria for judging counterfeiting in previous studies are slightly different. Li et al. (2017) proposed that the food with a unique QR code that was scanned many times in different locations is counterfeiting. The champagne company Billet deploys unique QR codes on each label of their products, and the system can alert the clients only if two scans of a QR code appear in two locations far apart from each other (PEAK, 2019). However, how to make sure the threshold of the reasonable distance between two scans is not clear. Rogerson and Parry (2020) proposed that the wine whose unique QR code is scanned two times in a location should be authentic. From the above, at least two scans of a unique QR code on the individual product are a prerequisite for counterfeiting detection of spatial methods.

The one-time scanning of a QR code is the principle of the temporal method. The food is considered genuine only when its attached QR code is first scanned, meaning there is only one opportunity to judge its authenticity (Bala Krishna & Dugar, 2016). Consumers may access false information that the authentic food is counterfeit when its QR code is scanned more than once. To overcome the drawbacks of this method, the dairy company Danone (Food Navigator Europe, 2020) created inner QR codes, which can be exposed to consumers after purchasing and unpacking it. This method has gained a certain achievement, but consumers cannot access the QR codes to judge the authenticity of food before purchasing.

Table 6.1. Lists of papers on the application of spatial-temporal data of scanning QR codes for detecting counterfeit food.

Category of methods	Food types	QR code types	Available spatial-temporal data		Judgment methods for counterfeiting detection	References
			Time	Location		
Spatial methods	Tortoise jelly	Unique QR code	√	√	Whether the attached QR code has been scanned many times in different places.	Li et al. (2017)
	Champagne	Unique QR code	√	√	Whether the distance between two scans of a QR code is anomalous.	PEAK (2019)
	Wine	Unique QR code	-	√	Whether the current location of the scanning QR code is matched with that of the last.	Rogerson & Parry (2020)
Temporal methods	General products	Unique QR code	√	-	Whether a QR code is scanned over once.	Bala Krishna & Dugar (2016)
	Infant formula	Unique inner QR code	√	-	Whether an inner QR code is scanned over once.	Food Navigator Europe (2020)
Spatial-temporal methods	Wine	Unique QR code	√	√	Whether the spatial-temporal data is reasonable	Popović et al. (2021)
	General food	-	√	√	Whether the spatial-temporal data is within a reasonable range	Jiménez-Carvelo et al., 2022
	Lobster	Unique QR code	√	√	Whether a unique QR code is scanned twice at almost the same time in two far locations	Verma (2019)

'√' indicates that this type of spatial-temporal data is obtained in the article, '-' means the data is not obtained or mentioned in the article.

The spatial-temporal methods emphasized the importance of taking both spatial and temporal data in counterfeiting detection. In the studies of Popović et al. (2021) and Jiménez-Carvelo et al. (2022), it is proposed that the spatial-temporal data of authentic food should be expected. However, it does not mention the specific processes of the methods regarding ensuring a reasonable range. Verma (2019) proposed a scenario of counterfeiting food in which a unique QR code is scanned twice at almost the same time in two far locations. It is valuable to explore the specific and advanced spatial-temporal methods for food counterfeiting detection.

6.3 Methodology

As illustrated in **Fig. 6.1**, the food counterfeiting detection approach based on the spatial-temporal analysis of consumers scanning QR codes consists of five parts: data collection, data processing, anomaly detection, anomaly analysis, and anomaly elimination. This approach has three important functions: 1) The anomalies caused by counterfeiting in spatial-temporal patterns of consumers scanning QR codes are analyzed; 2) Some possible outlier detection approaches are proposed to differentiate the anomalous spatial-temporal data from the dataset; 3) Based on the values of anomalies, the corresponding food counterfeiting type is identified so that the effective measures may be taken to eliminate it at their sources.

6.3.1 Data collection

QR code, a common product identifier on food packaging, can be scanned by consumers to access the linked websites (Qian et al., 2012). The information about the food provided by the websites can contribute to consumers' food selection. Currently, one of the main usages of QR codes on the packaging is for food traceability. The common QR code for traceability is the same QR code on individual products in the same batch, but different in different batches (Li et al., 2017). This type of QR code has been widely used in the packaging of various foods (Acuti et al., 2022; Chen et al., 2020; Li et al., 2016; Qian et al., 2012; Tarjan et al., 2014). The single food products in a batch are produced and packed together by manufacturers and appear at the same time and location during delivery and transportation through the supply chain (Scholten et al., 2016). The batch-level food is monitored through the supply chain, which has the advantages of low cost and high flexibility in operation (Pizzuti & Mirabelli, 2015; Tsang et al., 2019). Thus, all the single products in a batch have the same traceability information, which is linked to the same QR codes.

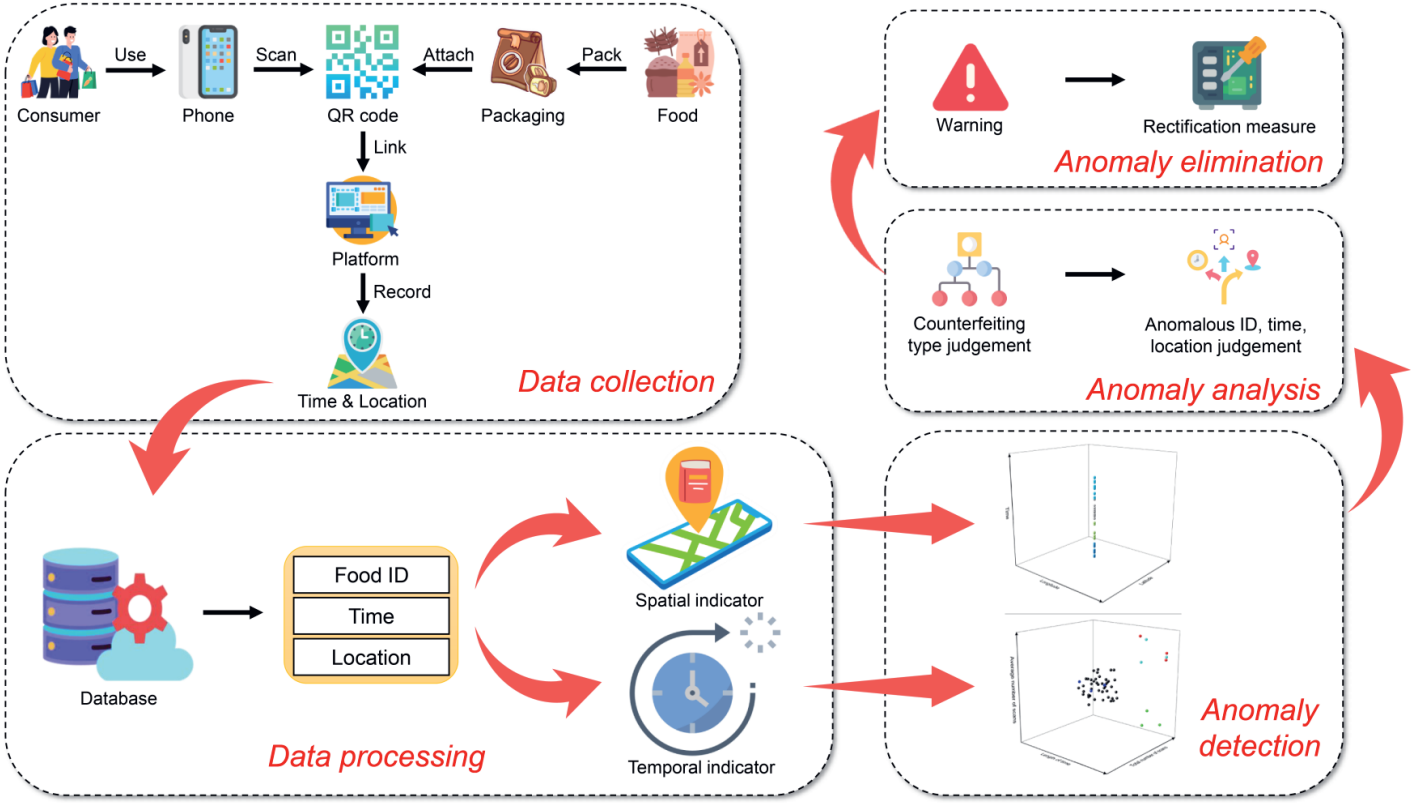


Fig. 6.1. Food counterfeiting detection approach based on the spatial-temporal analysis of consumers scanning QR codes.

The genuine food is packed by its packaging, which contains a printed or pasted (sticker) QR code. Thus, the genuine food and its packaging with QR codes can be regarded as a whole, which means that they must appear at the same time and locations when there is no counterfeiting. Consumers can track the food in which they have an interest as soon as the food packaging QR code linked with the website is scanned by their mobile device with a QR-code reader. In other words, the scanning process can be activated and completed only when the consumer and the food are at the same time and location. The time and location of consumer scanning can be regarded as the information about when and where the food with the QR code appears. The information, including the basic information of the batch of food and scanning time, is automatically collected and recorded on the dataset of the platform (Narang et al., 2012). The location of scanning (GPS coordinates) can also be sent to the platform after consumers authorize access (Hossain et al., 2018). With the system of platform tracking and counting the consumers' scans, there are tremendous amounts of digital data of time and location, which include three main attributes related to counterfeiting food detection. The first attribute refers to the identity information of food products (ID). The information on production and logistics related to a certain batch of food can be stored and retrieved by selecting its identity information in the structured dataset. The second attribute is the timestamp of scanning (t). The new data of specific date and time are collected and stored in the dataset over time. Each scanning record in the dataset corresponds to a specific date and time. The third is the location of scanning, which is always stated by longitude and latitude. Thus, the locations of scans are presented as (x, y). These three attributes form the data object, and the values of each attribute are updated in the dataset based on the practical situation of each scanning. A spatial-temporal scanning point is defined as a quadruple (ID, t, x, y), implying that a certain object is at location (x, y) at time t.

The scanning information of batch i, denoted as SI_i, represents a set of multiple scanning points. $SI_i=\{(IDi, t_{i1}, x_{i1}, y_{i1}), (IDi, t_{i2}, x_{i2}, y_{i2}), \ldots, (IDi, t_{ij}, x_{ij}, y_{ij})\}$, where timestamp t is arranged in ascending order, implying that $tj < tj+1$, j is the number of scans of batch i. Due to the same QR codes in a batch, the spatial-temporal information of all the single products in this batch can be sorted after choosing the identity of the batch in the dataset. Each such sequence of a batch is itself a dataset comprising a series of scanning points of QR codes on a single product packaging, and each scan in the sequence of a batch corresponds to an operation of consumer scanning QR codes.

6.3.2 Data processing

The principle of detecting counterfeit food based on spatial-temporal scanning patterns is to observe or infer whether it is reasonable over locations and time. After analyzing the spatial-temporal characteristics under normal situations, the real-time observations of data are judged whether they have these characteristics. These expected characteristics represent how the normal data should be spatially and temporally distributed given known factors or background information. Clusters of data points that are unlikely under the expected assumption are regarded as anomalies. Confirming the expected and unexpected spatial-temporal characteristics is key to distinguishing the anomalies from the normal data.

The subjects of scanning QR codes on the packaging of individual products are consumers. In other words, the process of scanning QR codes can be triggered when consumers select food at sale points and desire to scan QR codes for extra information. Therefore, the spatial-temporal patterns of the scanning dataset are inevitably affected by consumers' habits and behaviors of scanning and the food supply of sale points. To be specific, a batch of genuine food is generally transported to a sale point and all single food products in this batch will be sold there, which means that only consumers who come to this sale point can access the QR codes on the packaging. Therefore, the spatial scanning data points of QR codes of authentic food transported to a sale point should cluster in the location of this sale point (**Fig. 6.2**). Consumers typically have fixed shopping habits, and the number of single food products in every batch is equal, causing the sales duration of each batch of food at a certain sale point to be similar (Acuti et al., 2022). The duration of scanning QR codes in a batch is almost the same as the duration of food sales in this batch, because only if a batch of food is on the shelf for sale, their QR codes are exposed and accessible to consumers. In addition, consumers' acceptance and adoption of QR codes are stable, leading to a similar possibility of consumers scanning QR codes (Rotsios et al., 2022). Thus, the total number of scans per batch should be similar. Generally, the single food products in a batch are placed on the shelf at the same time as soon as the last batch of food is almost sold out (Koulouris et al., 2021). Thus, it can be assumed that scans of different batches in a certain sale point appear one by one. The scans of different batches in a certain sale point per time unit (i.e., per day or week) always fluctuate because of the randomness in the scanning time of consumers. However, the fluctuation of scans changes around the average value, due to the similarity in the length of time of scans and the total number of scans per batch (**Fig. 6.3**). To better explain how counterfeiting affects the normal temporal patterns of scans, the scanning fluctuation lines for different batches in a certain sale point can be simplified as the smoothed waves (**Fig. 6.3**). The top of the wave seems to be the horizontal line, and its value is the average

value of scans. The connection between components of waves and temporal scanning characteristics is stated in **Table 6.2**.

Table 6.2. Corresponding components of wave and temporal scanning characteristics.

Wave component	Temporal scanning characteristics components
Wavelength	Length of time from the first scan to the last scan
Crest	Average scans per time unit
Trough	No scans
Displacement at time i	Number of scans at time i
Total displacement of a wave	Total number of scans of a batch of food
Average displacement of a wave	Average number of scans of a batch of food

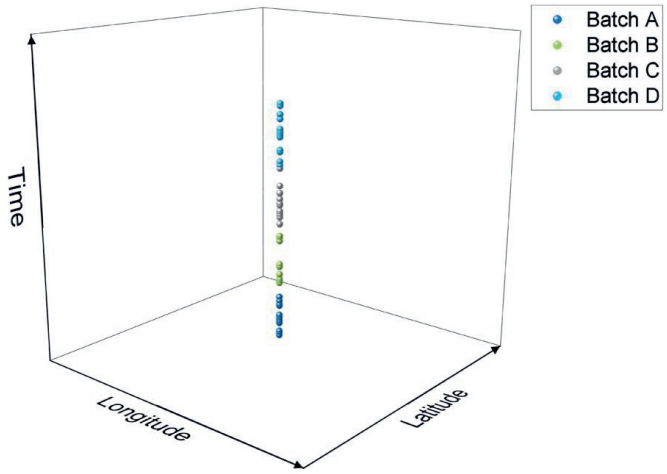


Fig. 6.2. The spatial scanning data of food QR codes for different batches at a sale point.

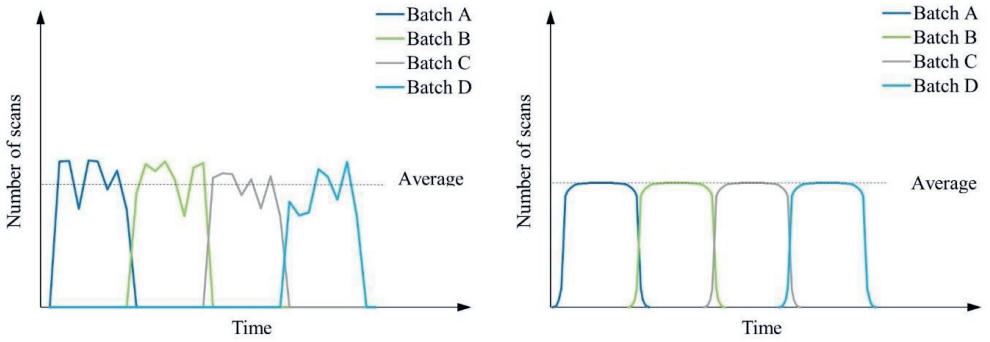


Fig. 6.3. The number of scans for different batches in single sales per time unit under normal situations and the simplified diagram.

Offenders always take a batch of food as a unit to commit counterfeiting, whose single products have the same packages and QR codes. Thus, the counterfeiting of a batch of food should be focused on in this study. Spatial-temporal patterns of consumers scanning QR codes are influenced by counterfeiting (Jiménez-Carvelo et al., 2022). Counterfeiting causes anomalies that can be expressed through abnormal patterns deviating from the inherent ones. The impact of the four types of counterfeiting on spatial patterns is reflected in whether the scans only cluster in the same locations. and the impact on temporal patterns is more complex, which is visualized and described as follows:

6.3.2.1. Full fake

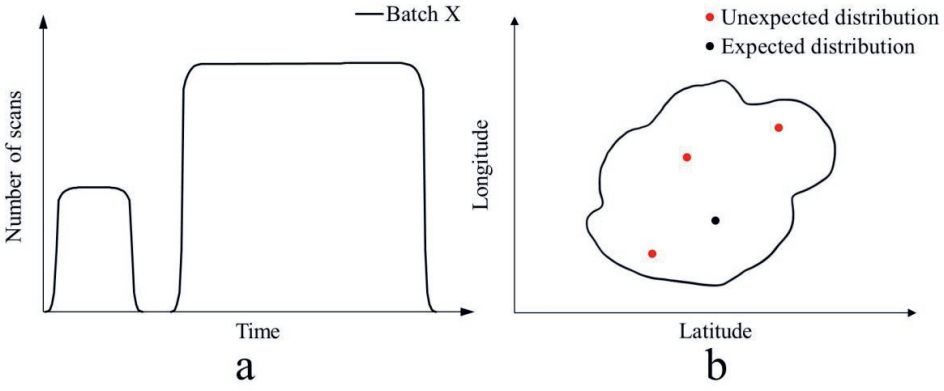


Fig. 6.4. The changes in spatial-temporal scanning patterns of a batch of food caused by full fake counterfeiting. a) the sketch picture shows the increase in time and scans caused by full fake counterfeiting; b) in a certain area, the scans appear in the unexpected sale points where the full fake food is sold.

After a batch of food is placed on the shelf of a certain sale point, consumers can scan the QR codes as normal. Thus, there is a wave appearing, which has the same temporal patterns as those of different batches in this sale point. The offenders can access the QR codes and then copy them illegally to paste on the counterfeit food packaging (Jiménez-Carvelo et al., 2022). Counterfeit food with QR codes can infiltrate legitimate supply chains through grey areas and is transported to some sale points for sale (Balamurugan et al., 2022; Patidar et al., 2022). Thus, there are some unexpected scans clustering in these sale points. If offenders produce counterfeit food with QR codes for a long time, the amount of counterfeit food and its sales duration will increase significantly, which results in the extension of the length of scanning time of this QR code. Due to the consumers' access to the QR codes of this batch in many sale points at the same time, the total number of scans and that per time unit can be considered as the superposition of data for sale points and will be much higher than those in the original sale point (as shown in **Fig. 6.4**).

6.3.2.2. Original packaging refills

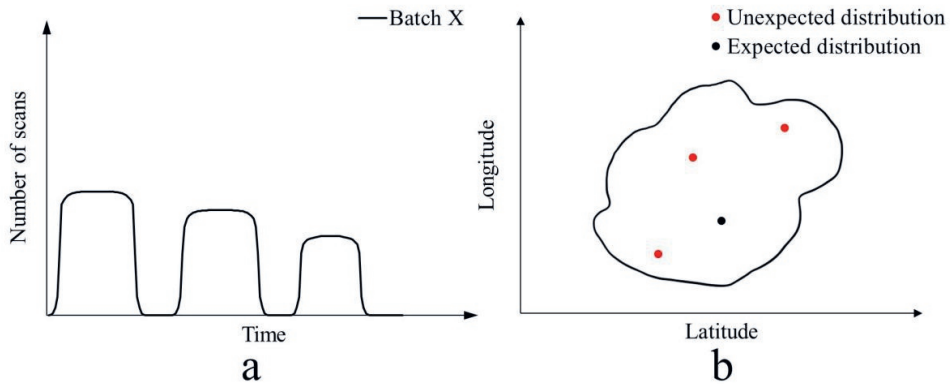


Fig. 6.5. The changes in spatial-temporal scanning patterns of a batch of food caused by original packaging refills' counterfeiting. a) the sketch picture shows the increase in time and scans caused by full fake counterfeiting; b) in a certain area, the scans appear in the unexpected sale points where the refilled food with original packaging is sold.

A batch of authentic food with QR codes is delivered to a certain sale point for sale, there is a normal wave appearing. After the authentic food is sold out, its packaging with the QR codes can be collected and reused in low-quality food illegally, which is on the market for sale again. A well-documented example of this form of counterfeiting was the products made of true bottles with fake wines (Lecat et al., 2017; Marvin et al., 2022). Thus, there are some waves appearing after the first wave (as shown in **Fig.**

6.5). The packaging, like the wine bottle, can be recycled again and again once it is sold. The number of waves depends on the times the original packages are refilled. There are some scans at different sale points at different times. The length of scanning time will be longer because the QR codes with the packaging are exposed to consumers many times. The number of scans of the batch will be higher, but its number of scans per time unit may be lower when the possibility of consumers scanning QR codes is similar in the different sale points. This is because some packages are destroyed, causing the number of packages with QR codes to decrease gradually.

6.3.2.3. Non-compliant materials

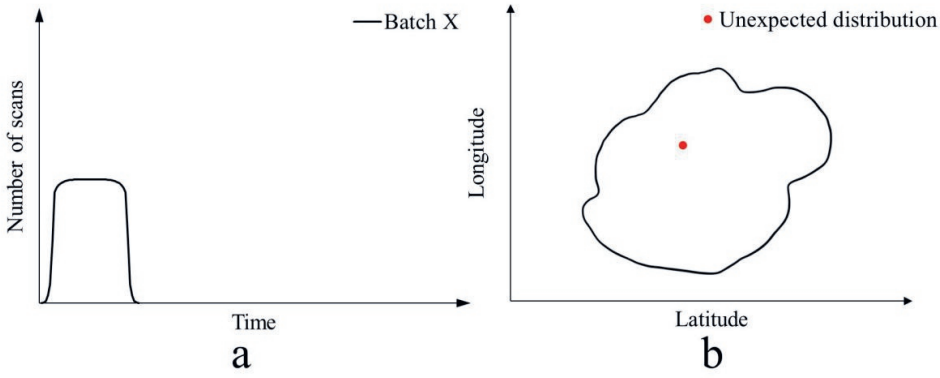


Fig. 6.6. The changes in spatial-temporal scanning patterns of a batch of food caused by non-compliant materials counterfeiting. a) the sketch picture shows the temporal patterns of a batch of non-compliant food; b) in a certain area, the scans appear in a sale point unexpectedly.

The non-compliant food should have been rejected to enter the supply chain and destroyed immediately, and there should be no scan. However, the offenders, usually outsource suppliers, continue to deliver this food into the market by falsifying the quality safety marks or certificate of food (Berman, 2008), and the batch of non-compliant food and its QR codes will be recorded in the system. Once there is a or many scans of the QR codes of the non-compliant food, it means that the batch of food is circulating in the market illegally, and the QR code temporal patterns of the batch are regarded as abnormal. When a batch of non-compliant food is on sale at a certain sale point, the wave will be the same as those of other certified batches in this sale point (as shown in **Fig. 6.6**).

6.3.2.4. Product overruns

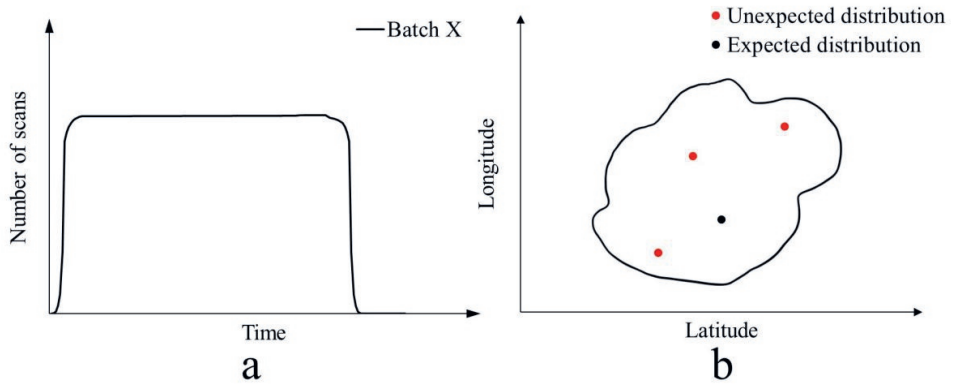


Fig. 6.7. The changes in spatial-temporal scanning patterns of a batch of food caused by product overruns' counterfeiting. a) the sketch picture shows the increase in time and scans caused by product overruns' counterfeiting; b) in a certain area, the scans appear in the unexpected sale points where the overrunning food is sold.

The food of overruns has the same production process, raw materials, and packaging with QR codes as those of genuine products. The offenders produce more food than they should and can transport the food to many sale points. In this case, consumers can access the food and its QR codes at the different sale points. Due to product overruns, the number of food products in the market is much higher. The total number of scans, the scans per time unit, and the length of scanning can be considered as the superposition of data for many sale points. Thus, the wavelength and displacement will be much higher (as shown in **Fig. 6.7**).

6.3.3. Anomaly detection

As mentioned above, there are significant differences between the normal spatial-temporal patterns and anomalous patterns caused by counterfeiting. A spatial indicator and three temporal indicators are extracted from the dataset of scanning a QR code. The spatial indicator is the number of locations for scanning a QR code, which can be calculated by comparing the longitude and latitude of each scan of a QR code. If all the longitudes and latitudes of scans of the QR code are the same, it can be concluded that the batch of food whose single products have this QR code only appears at one sale point.

If the locations of scanning QR codes are not authorized by the consumers to access, the method of temporal patterns is indispensable. Three indicators, including length of time, total number of scans, and average number of scans, form the framework to

evaluate the temporal characteristics of QR code scans. Thus, the spatial-temporal characteristics of scans of a QR code can be regarded as vectors, including the four indicators mentioned above. Due to the deviation in the four indicators caused by counterfeiting, counterfeiting detection is the process of looking for anomalies in an enormous dataset. Anomalies, also called outliers, are defined as observed data points that deviate from other points or are not expected to exist (Schneider & Xhafa, 2022). In general, these abnormal data points are generated by a different mechanism (Niu et al., 2020). Under normal situations, scanning points of a QR code gather spatially to the location of the sale point. In addition, the similarity in consumers' behaviors of scanning QR codes of a certain food leads to the spatial-temporal patterns of QR codes from different batches at a sale point, so that the temporal indicators of QR codes scanned at a sale point are within a reasonable range. As shown previously, the four types of counterfeiting affect the temporal patterns in different ways, and the values of three temporal indicators of counterfeit food are always distributed into expected areas. In particular, once there is a scan of a QR code that is recorded by the supervision system as belonging to non-compliant food, it indicates that the corresponding batch of counterfeit food has entered the market illegally, although its temporal patterns are always similar to those of authentic food. Compared with the historical data of batches at this sale point, the values of three temporal indicators of QR codes for the other three types of counterfeit food are different, which makes them sparse and isolated. The density of the three temporal indicators for the four categories of counterfeiting, i.e. full fake, original packaging refills, and product overruns, are low because their quantity is always lower than that of authentic products. Potential distributions of temporal indicators of counterfeiting are shown in **Fig. 6.8**.

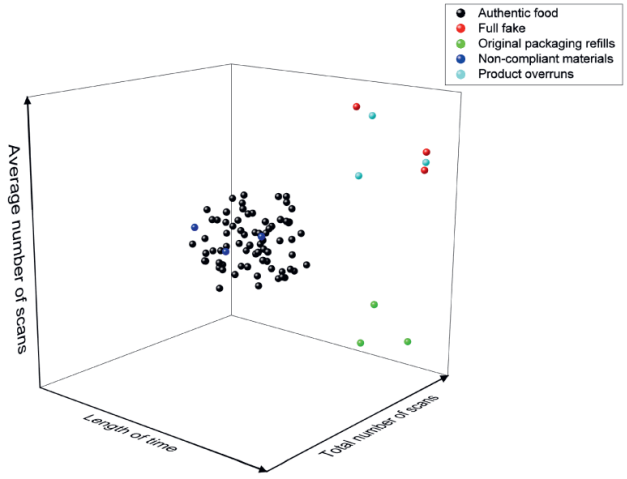


Fig. 6.8. Possible distributions of three temporal indicators of food batches at a sale point.

Detecting food counterfeiting involves identifying outliers in the temporal features of scanning QR codes, where an abnormal event can be indicated by an obvious rare pattern. Thus, selecting feasible methods is vital to realize outlier detection. Given that the anomalies related to counterfeiting in the real dataset are unmarked, mapping the relationship between the anomalous spatial-temporal data and the corresponding counterfeiting is unknown, which means that supervised learning algorithms, like classification models, are not feasible. There are many feasible unsupervised approaches to outlier detection, which have been successfully used in other fields (Du et al., 2022; Fu et al., 2021). These general methods of detecting outliers can be classified into four categories: distribution-based approaches, distance-based approaches, density-based approaches, and clustering approaches.

Distribution-based approaches assume that the data points are under a certain distribution and detect the anomalies by checking whether observation data complies with the distribution model, and the most frequent assumption is Gaussian distribution (Alghushairy et al., 2020). The data points that deviate significantly from the model are marked as outliers. However, its disadvantage is that, once inconsistency exists between the assumed distributions and that in real data, the models are invalid (Zhou et al., 2017). Each attribute of data needs to be analyzed individually while building models, so this type of approach has low efficiency in processing moderately high-dimensional datasets (Abhaya & Patra, 2022; Zhu et al., 2011).

Distance-based approaches detect the outliers on the basis of the distances among all the data points (Wang et al., 2015). The distances from a point to its several nearest neighbors are ranked, and the data points whose distances exceed the set threshold are flagged as outliers. Consequently, two parameters, the number of nearest neighbors and the reasonable distance threshold, have a significant impact on the results (Park et al., 2019). The approach realizes the outlier detection only by distance analysis, which is suitable for datasets without a certain distribution (Xu et al., 2022). Its demerit is that a large amount of distance calculations must consume much time (Alghushairy et al., 2020).

Density-based approaches compare the relative density of data points with that of their neighbors and distinguish the data points which are located in low-density areas as outliers (Abhaya & Patra, 2022; Reunanen et al., 2020). The approaches have a good performance in processing data with uneven density distribution, but it has high time complexity (She & Zeng, 2022). Many density-based approaches, such as Local Outlier Factor (LOF) and Connectivity-based Outlier Factor (COF), are the mainstream algorithms for detecting global and local outliers (Zhou et al., 2019).

Clustering approaches apply standard clustering techniques to partition the dataset into clusters with different sizes and shapes (Entezami et al., 2024). The point that is not in any cluster or a small and sparse cluster is considered an outlier (Bigdeli et al., 2017). The cluster approaches always perform well in outlier detection, but the premise is that some parameters can be set appropriately (Degirmenci & Karal, 2022).

6.3.4 Anomaly analysis and elimination

The information on the batches of food and their QR codes which correspond to the anomaly points are collected and recorded in the system. Given the mapping relationship between counterfeiting types and spatial-temporal anomalies, the possible types of counterfeiting can be judged theoretically. The potential time and locations of counterfeits' appearances can be judged by analyzing the spatial-temporal data of anomalies. Once a batch of food is marked as counterfeit, a systematic warning should be made. To be specific, consumers who scan the QR codes will be notified that the food products may be counterfeit. Food business operators and supervision departments should take measures to check the authenticity of food that is flagged as counterfeit.

6.4 Discussion and outlook

The method proposed for counterfeiting detection is based on the assumption that one batch of food products with the same QR codes is transported to a sale point. The actual situation may be more complex in practice. To be specific, as for the luxury products, such as expensive wines, may have a unique QR code on the packaging of single items. The spatial-temporal patterns of unique QR codes and the changes caused by the counterfeiting are different from those of the same QR codes in a batch. In addition, once a batch of food products is unpacked and sold in many sale points of a chain retailer, the spatial-temporal patterns of scanning QR codes will no longer be regular.

The spatial-temporal dataset of QR code scanning applied for counterfeiting detection originates from the collections of each consumer's operation. Consumers' scanning behaviors, as a form of consumer behaviors, are influenced inevitably by both subjective and objective factors and determine the spatial-temporal patterns of QR code scanning. Subjective factors refer to consumers' shopping habits, which are formed gradually in long-term economic and social activities and are not easily changed. The time consumers shop determines that of QR codes exposure to them, which further affects the time of scanning (Yang et al., 2022). For example, many consumers purchase food at the sale points much more frequently on weekends than on weekdays (Castellari et al., 2017), which results in more scans on weekends,

because the scans are more likely to appear in the peak shopping time period of sale points (Jiménez-Carvelo et al., 2022). Objective factors include some external factors that may affect the possibility of consumers scanning QR codes and lead to changes in the number of scans. The study of Li & Messer (2019) indicates that, comparing only 1.2% consumers scanning QR codes on food packaging by using their own phones, 52.6% consumers access the information through QR codes when the electronic devices with scanner software are provided for free. It means the conveniency of scanning can remarkably increase consumers' willingness to use QR codes. The study of Violino et al. (2019) shows that some incentives acquired through QR codes, such as financial rewards, can greatly improve consumers' interests in scanning. The reported food safety incidents have been proven to raise consumer concerns about food origin. As an important channel for obtaining more food information, scanning QR codes will also attract more consumers' attention at that time, and the number of scans will also increase accordingly (Ha et al., 2019). Ultimately, these factors that influence consumers' scanning behaviors should be considered to avoid the false warnings of the spatial-temporal anomalies caused by non-counterfeiting.

The feasibility analysis of counterfeiting detection based on spatial-temporal data of scanning QR codes has been evaluated in this paper, but the validity of the proposed approaches needs to be demonstrated in the future. A large amount of real data should be used to verify the accuracy of approaches. The diversity and completeness of the data can ensure the approaches' stability and conclusions' reproducibility (Bellini, 2019). QR code scanning data from different types of food packaging, time, and regions can be used to explore the applicability of the approaches. Sensitivity analysis is also vital in model validation (Kerr & Goethel, 2014). The effect of parameters and initial conditions of approaches on their output needs to be analyzed by numerous iterations.

The spatial-temporal data of consumers scanning QR codes involves some private information, including consumers' shopping time, location, and food choices. Given the sensitivity and personal nature of the information, the security and privacy of data are essential barriers to overcome to make this approach feasible in the future. As scanning data is stored in the database owned by private companies, consumers' concerns about how to ensure that the data is not used for commercial purposes have existed for a long time. The regulations need to clarify the scope of owners' use of the data to protect consumers' privacy. In addition, data risk management should be strengthened to prevent data leakage (Hlávka, 2020).

6.5 Conclusions

This work proposes a counterfeiting detection approach based on spatial-temporal data of consumers scanning QR codes to address the challenges caused by various types of counterfeiting through big data analysis. The influence of each type of counterfeiting on normal spatial-temporal patterns of data is explored to clarify the mapping relationship between counterfeiting type and spatial-temporal anomalies. After extracting the spatial and temporal indicators, the approaches used to detect their outliers are provided with the proposed conceptual feasibility analysis. The warning signs can be drawn and shown to consumers who access the website through the QR codes. In the meantime, the system generates warning information reports sent to food business operators and supervision departments.

References

Abhaya, A., & Patra, B. K. (2022). RDPOD: an unsupervised approach for outlier detection. *Neural Computing and Applications*, *34*(2), 1065-1077. https://doi.org/10.1007/s00521-021-06432-6

Acuti, D., Vocino, A., Mazzoli, V., & Donvito, R. (2022). The effects of QR delivered content on perceived product value. *Journal of Strategic Marketing*, *30*(5), 510-532. https://doi.org/10.1080/0965254X.2020.1813794

Alghushairy, O., Alsini, R., Soule, T., & Ma, X. (2020). A review of local outlier factor algorithms for outlier detection in big data streams. *Big Data and Cognitive Computing*, *5*(1), 1. https://doi.org/10.3390/bdcc5010001

Aurier, P., & Séré de Lanauze, G. (2012). Impacts of perceived brand relationship orientation on attitudinal loyalty: An application to strong brands in the packaged goods sector. *European Journal of Marketing*, *46*(11/12), 1602-1627. https://doi.org/10.1108/03090561211260004

Bala Krishna, M., & Dugar, A. (2016). Product authentication using QR codes: a mobile application to combat counterfeiting. *Wireless Personal Communications*, *90*(1), 381-398. https://doi.org/10.1007/s11277-016-3374-x

Balamurugan, S., Ayyasamy, A., & Joseph, K. S. (2022). IoT-Blockchain driven traceability techniques for improved safety measures in food supply chain. *International Journal of Information Technology*, *14*(2), 1087-1098. https://doi.org/10.1007/s41870-020-00581-y

Bellini, T. (2019). Prepayments, Competing Risks and EAD Modelling. *IFRS 9 and CECL Credit Risk Modelling and Validation*.

Berman, B. (2008). Strategies to detect and reduce counterfeiting activity. *Business Horizons*, *51*(3), 191-199. https://doi.org/10.1016/j.bushor.2008.01.002

Bigdeli, E., Mohammadi, M., Raahemi, B., & Matwin, S. (2017). A fast and noise resilient cluster-based anomaly detection. *Pattern Analysis and Applications*, *20*(1), 183-199. https://doi.org/10.1007/s10044-015-0484-0

Castellari, E., Cotti, C., Gordanier, J., & Ozturk, O. (2017). Does the timing of food stamp distribution matter? A panel-data analysis of monthly purchasing patterns of US households. *Health Economics*, *26*(11), 1380-1393. https://doi.org/10.1002/hec.3428

Certilogo. (2025). Digital Product Passport. Retrieved from *https://discover.certilogo.com/pages/digital-product-passport*. Accessed May 27, 2025

Chen, T., Ding, K., Hao, S., Li, G., & Qu, J. (2020). Batch-based traceability for pork: A mobile solution with 2D barcode technology. *Food Control*, *107*, 106770. https://doi.org/10.1016/j.foodcont.2019.106770

Degirmenci, A., & Karal, O. (2022). Efficient density and cluster based incremental outlier detection in data streams. *Information Sciences*, *607*, 901-920. https://doi.org/10.1016/j.ins.2022.06.013

Du, X., Yu, J., Chu, Z., Jin, L., & Chen, J. (2022). Graph autoencoder-based unsupervised outlier detection. *Information Sciences*, *608*, 532-550. https://doi.org/10.1016/j.ins.2022.06.039

Entezami, A., Sarmadi, H., Behkamal, B., & De Michele, C. (2024). On continuous health monitoring of bridges under serious environmental variability by an innovative multi-task unsupervised learning method. *Structure and Infrastructure Engineering*, *20*(12), 1975-1993. https://doi.org/10.1080/15732479.2023.2166538

Food Navigator Europe. (2020). Danone on its blockchain 'first': 'Every individual baby formula pack can be traced back'. Retrieved from *https://www.foodnavigator.com/Article/2020/02/17/Danone-on-its-blockchain-first-Every-individual-baby-formula-pack-can-be-traced-back*. Accessed July 27, 2022

Fu, S., Zhong, S., Lin, L., & Zhao, M. (2021). A re-optimized deep auto-encoder for gas turbine unsupervised anomaly detection. *Engineering Applications of Artificial Intelligence*, *101*, 104199. https://doi.org/10.1016/j.engappai.2021.104199

Gopikarani, N., Gayathri, B., Praja, S. S., & Sridharan, S. (2023). Safemedchain—drug counterfeit prevention and recommendation using blockchain and machine learning. *Journal of Intelligent & Fuzzy Systems*, *44*(1), 499-517. https://doi.org/10.3233/JIFS-220636

Ha, T. M., Shakur, S., & Do, K. H. P. (2019). Consumer concern about food safety in Hanoi, Vietnam. *Food Control*, *98*, 238-244. https://doi.org/10.1016/j.foodcont.2018.11.031

Hlávka, J. P. (2020). Security, privacy, and information-sharing aspects of healthcare artificial intelligence. In *Artificial Intelligence in Healthcare* (pp. 235-270). Academic Press.

Hossain, M. S., Zhou, X., & Rahman, M. F. (2018). Examining the impact of QR codes on purchase intention and customer satisfaction on the basis of perceived flow. *International Journal of Engineering Business Management*, *10*, 1847979018812323. https://doi.org/10.1177/1847979018812323

Huque, S. M. R., Hossain, S. T., & Rana, M. B. (2015, October). Trustworthiness of Organic Produces in Urban Market Innovation through Quick Response (QR) Code. In *Regional Conference on Marketing & Innovation in Organic Farming*. International Federation of Organic Agriculture Movements (IFOAM) Organics International.

Jiménez-Carvelo, A. M., Li, P., Erasmus, S. W., Wang, H., & van Ruth, S. M. (2022). Spatial-temporal event analysis as a prospective approach for signalling emerging food fraud-related anomalies in supply chains. *Foods*, *12*(1), 61. https://doi.org/10.3390/foods12010061

Kerr, L. A., & Goethel, D. R. (2014). Simulation modeling as a tool for synthesis of stock identification information. In *Stock identification methods* (pp. 501-533). Academic Press.

Koulouris, A., Misailidis, N., & Petrides, D. (2021). Applications of process and digital twin models for production simulation and scheduling in the manufacturing of food ingredients and products. *Food and Bioproducts Processing*, *126*, 317-333. https://doi.org/10.1016/j.fbp.2021.01.016

Lecat, B., Brouard, J., & Chapuis, C. (2017). Fraud and counterfeit wines in France: an overview and perspectives. *British Food Journal*, *119*(1), 84-104. https://doi.org/10.1108/BFJ-09-2016-0398

Li, H., Zhang, B., Zhang, L., Xue, Y., He, M., & Ren, C. (2016). A food traceability framework for dairy and other low-margin products. *IBM Journal of Research and Development*, *60*(5/6), 10-1. https://doi.org/10.1147/JRD.2016.2598610

Li, T., & Messer, K. D. (2019). To scan or not to scan. *Journal of agricultural and resource economics*, *44*(2), 311-327.

Li, Z., Liu, G., Liu, L., Lai, X., & Xu, G. (2017). IoT-based tracking and tracing platform for prepackaged food supply chain. *Industrial Management & Data Systems*, *117*(9), 1906-1916. https://doi.org/10.1108/IMDS-11-2016-0489

Marvin, H. J., Hoenderdaal, W., Gavai, A. K., Mu, W., van den Bulk, L. M., Liu, N., Frasso, G., Ozen, N., Elliott, C., Manning, L., & Bouzembrak, Y. (2022). Global media as an early warning tool for food fraud; an assessment of MedISys-FF. *Food Control*, *137*, 108961. https://doi.org/10.1016/j.foodcont.2022.108961

Ming-Yi, S., Chong-Yu, L., Chuan-Biao, W., Xiong, X. U., & Sheng-Nan, L. (2020). Design and development of quality traceability system for circulation of Chinese herbal medicine based on blockchain and NB-IOT. *China Journal of Chinese Materia Medica*, *45*(17), 4267-4272. https://doi.org/10.19540/j.cnki.cjcmm.20200603.311

Narang, S., Jain, V., & Roy, S. (2012). Effect of QR codes on consumer attitudes. *International Journal of Mobile Marketing*, *7*(2).

Nasirov, S. (2020). Trademark value indicators: Evidence from the trademark protection lifecycle in the US pharmaceutical industry. *Research Policy*, *49*(4), 103929. https://doi.org/10.1016/j.respol.2020.103929

Niu, Z., Yu, K., & Wu, X. (2020). LSTM-based VAE-GAN for time-series anomaly detection. *Sensors*, *20*(13), 3738. https://doi.org/10.3390/s20133738

OECD. (2021). Global Trade in Fakes. Retrieved from *https://www.oecd-ilibrary.org/governance/global-trade-in-fakes_74c81154-en, 2021*. Accessed June 29, 2023

Park, C. H. (2019). Outlier and anomaly pattern detection on data streams. *Journal of Supercomputing*, *75*(9), 6118. https://doi.org/10.1007/s11227-018-2674-1

Patidar, A., Sharma, M., Agrawal, R., & Sangwan, K. S. (2022). Traceability and transportation issues in the food supply chain. In *Operations and Supply Chain Management in the Food Industry: Farm to Fork* (pp. 73-93). Singapore: Springer Nature Singapore.

PEAK. (2019). Tracking technology now ensures your Champagne will be genuine. Retrieved from *https://www.thepeakmagazine.com.sg/lifestyle/connected-champagne-tracking-qr-rfid*. Accessed May 18, 2023

Peng, J., Zou, B., He, X., & Zhu, C. (2022). Hybrid attention network with appraiser-guided loss for counterfeit luxury handbag detection. *Complex & Intelligent Systems*, *8*(3), 2371-2381. https://doi.org/10.1007/s40747-021-00633-1

Pizzuti, T., & Mirabelli, G. (2015). The Global Track&Trace System for food: General framework and functioning principles. *Journal of Food Engineering*, *159*, 16-35. https://doi.org/10.1016/j.jfoodeng.2015.03.001

Popović, T., Krčo, S., Maraš, V., Hakola, L., Radonjić, S., van Kranenburg, R., & Šandi, S. (2021). A novel solution for counterfeit prevention in the wine industry based on IoT, smart tags, and crowd-sourced information. *Internet of Things*, *14*, 100375. https://doi.org/10.1016/j.iot.2021.100375

Qian, J. P., Yang, X. T., Wu, X. M., Zhao, L., Fan, B. L., & Xing, B. (2012). A traceability system incorporating 2D barcode and RFID technology for wheat flour mills. *Computers and Electronics in Agriculture*, *89*, 76-85. https://doi.org/10.1016/j.compag.2012.08.004

Reunanen, N., Räty, T., & Lintonen, T. (2020). Automatic optimization of outlier detection ensembles using a limited number of outlier examples. *International Journal of Data Science and Analytics*, *10*(4), 377-394. https://doi.org/10.1007/s41060-020-00222-4.

Rogerson, M., & Parry, G. C. (2020). Blockchain: case studies in food supply chain visibility. *Supply Chain Management: An International Journal*, *25*(5), 601-614. https://doi.org/10.1108/SCM-08-2019-0300

Rotsios, K., Konstantoglou, A., Folinas, D., Fotiadis, T., Hatzithomas, L., & Boutsouki, C. (2022). Evaluating the use of QR codes on food products. *Sustainability*, *14*(8), 4437. https://doi.org/10.3390/su14084437

She, C., & Zeng, S. (2022). An efficient local outlier detection optimized by rough clustering. *Journal of Intelligent & Fuzzy Systems*, *42*(3), 2071-2082. https://doi.org/10.3233/JIFS-211433

Schneider, P., & Xhafa, F. (2022). *Anomaly detection and complex event processing over iot data streams: with application to EHealth and patient data monitoring*. Academic Press.

Scholten, H., Verdouw, C. N., Beulens, A., & van der Vorst, J. G. A. J. (2016). Defining and analyzing traceability systems in food supply chains. In *Advances in food traceability techniques and technologies* (pp. 9-33). Woodhead Publishing.

Simin, M. J., & Živkucin, S. (2021). Application of the agricultural and food products trademark serving to increase the agricultural sector competitiveness. *Економика пољопривреде*, *68*(3), 645-658. https://doi.org/10.5937/ekoPolj2103645J

Soon, J. M., & Manning, L. (2019). Developing anti-counterfeiting measures: The role of smart packaging. *Food Research International*, *123*, 135-143. https://doi.org/10.1016/j.foodres.2019.04.049

Spink, J., & Moyer, D. C. (2011). Defining the public health threat of food fraud. *Journal of Food Science*, *76*(9), 157-163. https://doi.org/10.1111/j.1750-3841.2011.02417.x

Tarjan, L., Šenk, I., Tegeltija, S., Stankovski, S., & Ostojic, G. (2014). A readability analysis for QR code application in a traceability system. *Computers and Electronics in Agriculture*, *109*, 1-11. https://doi.org/10.1016/j.compag.2014.08.015

Tsang, Y. P., Choy, K. L., Wu, C. H., Ho, G. T. S., & Lam, H. Y. (2019). Blockchain-driven IoT for food traceability with an integrated consensus mechanism. *IEEE Access*, *7*, 129000-129017. https://doi.org/10.1109/ACCESS.2019.2940227

van Ruth, S. M., Chen, L., Dick, A., & Erasmusa, S. W. (2022). Insights in Toxic Counterfeit Cuisine. In *Counterfeiting and Fraud in Supply Chains* (pp. 23-47). Emerald Publishing Limited.

Verma, S. (2019). Modelling product distribution and quality parameters in high-value Australian fisheries chain.

Violino, S., Pallottino, F., Sperandio, G., Figorilli, S., Antonucci, F., Ioannoni, V., Fappiano, D., & Costa, C. (2019). Are the innovative electronic labels for extra virgin olive oil sustainable, traceable, and accepted by consumers?. *Foods*, *8*(11), 529. https://doi.org/10.3390/foods8110529

Wang, X. T., Shen, D. R., Bai, M., Nie, T. Z., Kou, Y., & Yu, G. (2015). An efficient algorithm for distributed outlier detection in large multi-dimensional datasets. *Journal of Computer Science and Technology*, *30*(6), 1233-1248. https://doi.org/10.1007/s11390-015-1596-0

Xu, H., Zhang, L., Li, P., & Zhu, F. (2022). Outlier detection algorithm based on k-nearest neighbors-local outlier factor. *Journal of Algorithms & Computational Technology*, *16*, 17483026221078111. https://doi.org/10.1177/17483026221078111

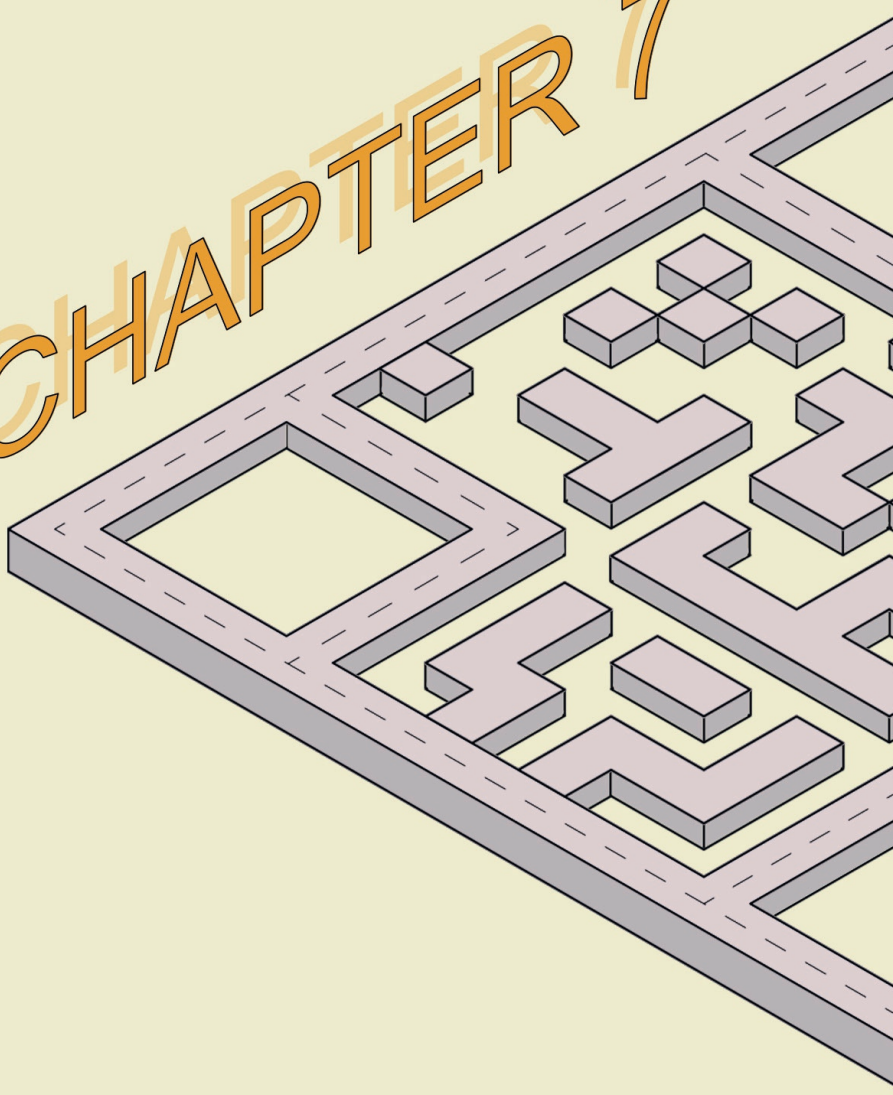
Yang, S. H., Phan, H. T. T., Hsieh, C. M., & Li, T. N. (2022). What intentions and interesting information can attract consumers to scan QR code while buying eggs?. *Foods*, *11*(9), 1259. https://doi.org/10.3390/foods11091259

Zhou, H., Li, J., Li, J., Zhang, F., & Cui, Y. (2017). A graph clustering method for community detection in complex networks. *Physica A: Statistical Mechanics and Its Applications*, *469*, 551-562. https://doi.org/10.1016/j.physa.2016.11.015

Zhou, H., Liu, H., Zhang, Y., & Zhang, Y. (2019). An outlier detection algorithm based on an integrated outlier factor. *Intelligent Data Analysis*, *23*(5), 975-990. https://doi.org/10.3233/IDA-184227

Zhu, C., Kitagawa, H., Papadimitriou, S., & Faloutsos, C. (2011). Outlier detection by example. *Journal of Intelligent Information Systems*, *36*(2), 217-247. https://doi.org/10.1007/s10844-010-0128-1

CHAPTER 7



Chapter 7

General Discussion

7.1 Introduction

In recent years, incidents of food counterfeiting have increased, attracting public attention as they pose significant risks to food safety, undermine the integrity of the food supply chain, and erode public trust (Haji et al., 2022). As a promising technology, QR codes have shown their considerable potential in preventing food counterfeiting (Chen et al., 2020). Although this technology is acknowledged positively by the food supply chain actors, it has not been widely used yet, and its usage faces various challenges (Liu et al., 2018). Consequently, this thesis aims to gain an in-depth understanding of the perceptions, attitudes, and behavioral intentions of both the the technology providers and users toward the adoption of QR codes, in order to inform strategies that enhance the food supply chain integrity. **Chapter 2** provided a comprehensive systematic review of the applications of QR codes in information transmission, clarifying the function and principle in food authentication. In **Chapter 3**, a qualitative analysis was conducted based on interviews with Italian and Indian wine supply chain entities. This chapter explored the driving forces, obstacles, and strategies related to the adoption of QR code anti-counterfeiting measures, offering in-depth insights from the perspectives of food supply chain actors. **Chapter 4** examined the factors that influence consumers' behavioral intention to use authentication QR codes, conducting a questionnaire survey to capture consumer attitudes and preferences regarding the use of such technology. In **Chapter 5**, a meta-analysis of consumers' willingness to pay for special food attributes conveyed by food labels was conducted, investigating how WTP varied across information carriers. **Chapter 6** proposed the concept of a method regarding food counterfeiting detection based on the spatial-temporal pattern analysis of QR code scanning and explored the feasibility of this innovative method. The key findings from **Chapters 2-6** are summarized in **Table 7.1,** followed by a discussion on the main findings, the implications for future research, and limitations and recommendations.

7.2 Influence of actors' perception on QR code adoption

Based on the overall findings of this thesis, this section focuses on five key aspects that are associated with supply chain actors' perceptions of QR code technology for food authenticity, as well as consumers' behavioral intentions to use it. These aspects include practical utility, technological complexity, attitude and awareness, costs, and consumers' willingness to pay for food authentication information.

Table 7.1. Summary of the main findings described in this thesis.

Chapter	Objectives	Main findings
2	To review the current applications of food package QR codes in food transmission	• The applications of food package QR codes include traceability, quality evaluation, anti-counterfeiting, and marketing. • The limitations of QR code applications in food packaging include low consumer engagement, high technical and marginal costs, information overload, and technical barriers.
3	To investigate the drivers, barriers, and strategies for the implementation of identification devices for authentication in the Italian and Indian wine supply chain	• Drivers include efficient traceability, consumer trust, regulatory compliance, brand enhancement, ease of use, counterfeiting risks, counterfeiting monitoring, and keeping competitive. • Implementation costs, traditional mindset, antiquated production lines, lacking technicians, forged devices, no counterfeiting, low visibility, and unequal returns are the main barriers to implementing identification devices for anti-counterfeiting. • Collaboration enhancement, cost optimization, regulatory support, multi-technology integration, simplified systems, raising awareness, and training programs are identified as strategies to overcome the barriers.
4	To explore the factors influencing consumers' behavioral intention to use authentication QR codes on food packages	• Perceived usefulness and perceived ease of use are found to impact British and Chinese consumers' attitudes significantly. • Attitude, authenticity awareness, and facilitating conditions are key factors influencing behavioral intention. • Dairy products and meat and poultry products may require the authentication QR codes the most.

Table 7.1. Continued.

Chapter	Objectives	Main findings
5	To investigate consumers' willingness to pay for special food attributes	• Overall consumers' WTP for the special food attribute is 28%. • The presence of special food attributes is associated with an increase in food prices in most cases (87%). • There is a significant difference in consumers' WTP across information carriers.
6	To propose a promising approach to counterfeiting detection based on the spatial-temporal analysis of consumers scanning QR codes on food packaging	• Food counterfeiting causes anomalies in the spatial-temporal patterns of consumers scanning QR codes. • The relationship between food counterfeiting types and anomalies in spatial-temporal patterns is established. • Four indicators representing the spatial-temporal data characteristics are extracted. • Unsupervised outlier detection approaches are suitable for anomaly detection.

7.2.1 Practical utility

Utility is generally defined as a subjective measure of an individual's satisfaction of needs, representing the extent to which a technology, product, or action is suitable for achieving a specific goal (Schuh et al., 2020). Accordingly, technology can be considered to generate utility when it effectively fulfills individual needs. Thus, the utility of a technology highlights the positive impacts of a technology on the users, and is a standard of evaluating the promotion potentials (Johnson & Huber, 1997). Users are more likely to adopt specific technologies or applications when they perceive them as effective, with the utility playing a critical role in shaping this perception (Effendy et al., 2021). The practical utility of food QR codes for authentication represents its ability of authenticating food products and ensuring food supply chain integrity through linking to a reliable and robust authentication platform. Given that all the supply chain actors have requirements on food authenticity, the practical utility of the food QR code for authenticity is key to the user's adoption of this device. The findings of this thesis support this viewpoint. To be specific, in **Chapter 3**, actors in the Italian and Indian wine supply chain acknowledged the practical utility of food QR codes, particularly in product authentication. Some of the interviewed actors have already adopted this technology in their business practices. In **Chapter 4**, the findings demonstrated that the perceived usefulness impacts Chinese and British consumers' attitudes toward authentication QR codes on food packaging. Generally, the practical utility of a technology shapes the users' perceived usefulness. The higher the practical utility of the food authentication QR code is, the higher the consumers' perceived usefulness of this technology is. In **Chapter 5**, the findings show that consumers are willing to pay an extra 28% for the special food attributes conveyed through barcodes (including QR codes). This means that consumers will value the special food attributes and QR codes and have the willingness to pay for them, only when their perception of such technology is established. The aim of **Chapter 6** is to improve the practical utility of QR codes for authentication by proposing an optimized authentication mechanism based on the spatial-temporal patterns of consumer scanning QR codes. This mechanism can be successful in detecting counterfeiting if the QR codes are illegally copied and pasted on counterfeits.

The findings of **Chapter 3** show that the Italian and Indian wine supply chain actors are concerned that implementing QR codes may require upgrading their existing antiquated production lines. **Chapter 4** also indicates that, from the consumer perspective, the ease of use of the QR code technology for food authentication affects its perceived usefulness. Therefore, while the perceived practical utility of QR codes drives its adoption, such positive perceptions may diminish once the technology is considered too complex or difficult to use or implement.

7.2.2 Technological complexity

The complexity of a technology influences the ease with which consumers acquire information through QR codes. Rather than being a straightforward, measurable physical quantity, technological complexity is an abstract concept (Tani & Cimatti, 2008). Previous research suggests that in service contexts, consumers perceive technological tools with greater ease of use as more beneficial and, consequently, more effective (Oredina et al., 2024). This is because users spend less time familiarizing themselves with the technology's features and functionalities, leading to more efficient utilization (Seo & Lee, 2021).

This thesis describes how the technological complexity of QR codes affects the willingness of food supply chain actors to adopt them. Specifically, as outlined in **Chapter 2**, key technical barriers include pattern distortion on curved surfaces, susceptibility to wear and fading, and the inability to read multiple QR codes simultaneously. These limitations reduce the readability of QR codes, creating obstacles and inconveniences for users. In **Chapter 3**, experts highlighted the need to upgrade outdated production lines to integrate QR codes into wine packaging. The necessary adjustments to production processes, along with additional operations for affixing QR codes, increase the complexity and cost of adoption. Furthermore, due to the technological complexity of digital platforms linked to QR codes and the lack of professional training, supply chain actors often face difficulties in resolving technical challenges, making it necessary to employ professional technicians for system maintenance. Findings from **Chapter 4** indicate that consumers' perceived ease of use significantly influences their attitudes toward authentication QR codes. In general, as technological complexity increases, consumers find the technology more difficult to use (Barnard et al., 2013). Prior studies (Violino et al., 2019; Habashneh et al., 2024) further emphasize that consumers place a high value on easy access to information through QR codes. In **Chapter 5**, consumers are willing to pay an extra 23% for special food attributes conveyed by barcodes (QR code), compared with 23% through texts and 34% by logos. It also implies that consumers tend to prefer intuitive methods, such as logos, to access product information.

In **Chapter 3**, printing QR codes may require upgrading antiquated production lines, which Italian and Indian wine supply chain actors perceive as a barrier that negatively affects their attitude toward adoption. **Chapter 4** also demonstrates that British and Chinese consumers' attitudes toward using authentication QR codes are influenced by the perceived ease of use. Therefore, the perceived complexity of implementation shapes both actors' and consumers' attitudes and awareness. When QR code is seen

as a user-friendly technology, both supply chain actors and consumers tend to hold more favorable attitudes and demonstrate greater awareness of its potential benefits.

7.2.3 Attitude and awareness

An individual's attitude is the overall evaluation of certain items, awareness, or behavior, and this evaluation often affects their actions (Ajzen et al., 2018). In most cases, attitude arises prior to behavior because people typically form an evaluation or inclination towards something before taking action (Ajzen, 1985). The findings of our study also show the influence of the attitude of food supply chain actors towards QR codes on their willingness to adopt this technology. To be specific, in **Chapter 3**, experts mentioned that some owners of wine companies have traditional and conservative thoughts, which leads to a lack of innovation awareness and reduced willingness to adopt new technologies. As a result, they do not have the willingness to adopt the QR code for enhancing wine authenticity since it does not lead to direct profits for their companies. Adjei et al. (2017) also pointed out that the phenomenon that people working in agricultural production refuse to adopt innovative technology is not rare. In **Chapter 4**, it was found that consumers' attitude towards authentication QR codes has a significant impact on the intention to use. In other words, the more positive the consumers' attitude towards the authentication QR codes is, the higher the intention to use consumers have. In **Chapter 5**, consumers would like to pay an extra 23% for special food attributes conveyed by barcodes (QR code), which reflects their attitude towards that technology to some extent. Consumers' willingness to pay for a technology often means they have evaluated it from multiple perspectives.

It is worth noting that although attitude plays a crucial role in determining behavior, in reality, attitude cannot fully determine behavior as many factors may weaken the influence of attitude on behavior (Kroesen er al., 2017).

It should be emphasized that positive attitudes and awareness toward QR codes for food authentication do not directly lead to the adoption of the technology. As shown in **Chapters 3** and **5**, both supply chain actors and consumers will consider the associated costs before they use or invest in the technology. Therefore, while a positive attitude and awareness may increase both Italian and Indian wine supply chain actors' willingness to invest in and consumers' willingness to pay for the technology, the actual adoption and usage are still constrained by cost considerations.

7.2.4 Costs

The decision to adopt a technology is to some extent influenced by its cost (Banks et al., 2007). When considering the adoption of an innovative technology, users often undertake a systematic evaluation of the full implementation costs (Bottani & Rizzi,

2008). Although some companies may have the financial capacity to invest, high implementation costs will often hinder adoption—especially when the expected benefits or profits associated with the innovative technology remain uncertain. Hochstrasser (1992) proposed that there are two categories of costs generated by the adoption of an innovative technology: direct costs and indirect costs.

Direct costs are those that can be directly attributed to the implementation and operation of a specific technology (Zahir Irani, 2000). In the context of this study, the direct costs associated with QR codes primarily encompass the initiation and maintenance of the QR codes themselves, as well as the associated digital platforms. As outlined in **Chapter 2**, initiation costs include expenditures related to the necessary equipment for generating, printing, and attaching QR codes—such as computers, code generators, printers, and tags. Maintenance costs refer to the operation and maintenance of websites and databases that support the QR code system. **Chapter 3** further expands on this by highlighting expert insights, which indicate that companies may need to upgrade their production lines to accommodate QR code generation and application, contributing to initiation costs. Experts also identified the continued operation and maintenance of production machinery and digital platforms as significant cost-related barriers to the adoption of QR code technology.

Indirect costs refer to the organizational and human costs associated with the adoption of new technologies (Ryan & Harrison, 2000). As discussed in **Chapter 2**, several experts highlighted the need to recruit skilled technicians to ensure the effective management of the platforms linked to QR codes, leading to increased labor costs. Furthermore, some experts noted that certain supply chain entities exhibit resistance to technological innovation due to a reluctance to invest in technologies or equipment that do not yield immediate or direct financial profits. This hesitation is often rooted in concerns over opportunity costs. According to Flake et al. (2015), opportunity cost is defined as the perceived loss of time and the potential to engage in alternative, possibly more profitable, activities. The implementation of QR codes may require substantial resources, which could limit a firm's ability to pursue other strategic initiatives—particularly when resources are constrained.

It is important to recognize that the adoption of QR code technology for conveying food-related information may lead to an increase in the final retail price of food products. Such price increase is primarily attributed to the tendency of food companies to transfer the additional costs of adopting technology to consumers, rather than absorbing these costs themselves. Findings presented in **Chapter 5** showed that, while consumers generally value the special food information provided by QR codes, their willingness to pay a premium for such information in actual purchasing scenarios remains limited.

When the price premium associated with the implementation of QR codes for information transmission exceeds consumers' acceptable payment threshold, their purchase intentions may decline, potentially resulting in reduced food product sales. Therefore, for food companies, a scientifically accurate evaluation of the costs and potential benefits associated with QR code adoption is essential. In particular, achieving a balance between implementation costs and consumers' willingness to pay—while also considering overall market acceptance—is a critical factor in ensuring the long-term commercial usage of this technology.

Moreover, the financial feasibility of QR code adoption on the supply side (food enterprises) is closely linked to consumers' willingness to pay for food authenticity information, which ultimately determines whether the investment is perceived as economically justified.

7.2.5 WTP for authentication

There are two studies that focus on the consumers' willingness to pay for food authenticity information. Yang et al. (2020a) proposed that Canadian consumers are willing to pay 0.37% for authenticity information of arctic food products, while consumers are willing to pay 8.3% for authenticity information (Yang et al., 2020b). This is an approximate value since it varies across location, time, food type, and information carriers (**Chapter 5**). According to the findings in **Chapter 5**, the special food attributes conveyed by a QR code will not increase the consumers' WTP compared with those conveyed by text.

In conclusion, the supply chain actors' perception of QR code adoption and consumers' willingness to use are not determined by any single factor, but rather by the dynamic interaction among the factors mentioned above. While this thesis primarily focuses on five key aspects, other external or situational influences, such as contextual and cultural elements, may also affect adoption decisions.

7.3 Methodological considerations

Chapter 2 introduced the principles and advantages of QR codes in the context of food information transmission and summarized existing literature to highlight their potential in ensuring food authenticity and enhancing the integrity of the food supply chain. This comprehensive review established a clear theoretical foundation for the subsequent research. To fully realize the potential of QR codes, it is essential to explore the perceptions of various supply chain actors from multiple perspectives. Accordingly, **Chapter 2** not only provides critical background knowledge but also points out the research direction for the following chapters.

Chapters 3 and 4 both explore the factors influencing the adoption of QR codes; however, they differ in terms of the research subjects and methodologies employed. Specifically, **Chapter 3** investigated the perceptions of Italian and Indian wine supply chain actors regarding QR code implementation through interviews. The interviewees from these entities provided direct, credible, and practical insights into the drivers, barriers, and strategies for QR code adoption. Given that supply chain entities, particularly brand owners, possess the authority to make final decisions on the implementation of QR codes, it is crucial that they conduct a comprehensive analysis, measurement, and survey before adoption, which enables them to be knowledgeable enough to offer valuable and targeted information. **Chapter 4** utilized a questionnaire survey involving Chinese and British consumers to gather their perception of the intention to use authentication QR codes. A questionnaire survey allows for the inclusion of a larger sample size, leading to more robust and representative findings. Unlike interviews, which are typically used in qualitative research, questionnaire surveys, as a common quantitative method, contribute to statistical analysis and, in this case, highlight the differences in responses between Chinese and British consumers. In summary, both methods are important and necessary, as they serve different purposes and complement each other in understanding QR code adoption.

This thesis examined different types of QR codes across its chapters, each with a distinct focus. **Chapter 2** explored general QR codes, providing a review that identifies four primary applications aimed at enhancing the integrity of the food supply chain. **Chapters 3 and 4** investigated the perceptions of supply chain actors regarding QR codes specifically designed to ensure food authenticity and traceability. **Chapter 5** focused on the comparison of consumers' willingness to pay for various food attributes conveyed by QR codes with other ways. In **Chapter 6**, the study introduced the concept of utilizing the spatiotemporal patterns of consumer scanning QR codes (QR codes on the package of single food products are the same in a batch and different in different batches) as a potential approach for detecting counterfeiting. Regardless of the specific information linked with the QR codes, the system consistently records the time and location of each scan (Verma, 2019). In summary, this thesis provided a comprehensive exploration of different types of QR codes from multiple perspectives, highlighting their diverse applications and roles in the food supply chain.

The studies presented in **Chapters 3 and 4** were conducted in different geographical regions, which has a positive implication on the overall research design. Specifically, **Chapter 3** focuses on Italian and Indian wine supply chains. Italy, a country renowned for its wine industry, is characterized by a long history and a well-established wine supply chain. The relatively high adoption rate of identification technologies among supply chain actors in Italy ensures that respondents are qualified to provide practical

and in-depth insights into the drivers and barriers to adopting such technologies. India is an emerging wine market, with its supply chain continuously expanding. A comparison of wine markets with varying degrees of maturity in relation to the drivers, barriers, and implementation strategies of identification technologies can contribute to the development of more tailored and effective implementation strategies. **Chapter 4** investigated consumer perspectives in China and the United Kingdom. By comparing consumers from these two countries, the study explored how structural factors shape their intention to use authentication QR codes. This cross-regional approach allows for a broader understanding of the contextual factors that shape technology acceptance. Future research could benefit from examining both supply chain actors and consumers within the same national context, thereby providing greater coherence of findings within a single national context, depending on the research goals.

The type of food product also influences the necessity of implementing QR codes for authentication purposes. Generally, the greater the fraud vulnerability of a food product is, the more essential it becomes to convey authenticity information. In **Chapter 3**, wine is selected as the research object due to its high market value and high susceptibility to food fraud (Romano et al., 2021). By concentrating on the wine sector, a case study is conducted to investigate the underlying reasons why QR codes have not been widely adopted within the Italian wine industry. The insights derived from this case may offer valuable implications for other food sectors. This is because the wine industry shares common challenges with other food sectors in terms of traceability, authenticity assurance, and brand protection, making the findings broadly relevant. In **Chapter 4**, an open-ended question—"With what food category in mind have you filled out this questionnaire?"—was included at the end of the survey. The responses from Chinese and British participants indicated which food categories they were primarily considering while completing the questionnaire. All the food types are selected by both Chinese and British consumers, though the frequency of selecting food types varies between the two groups. This variation can be attributed to differences in food safety concerns as well as cultural and social contexts between Chinese and British consumers.

Overall, the methodological design of this thesis combines different research methods, geographical contexts, food categories, and QR code types to generate a more comprehensive understanding of QR code adoption. Future studies could employ longitudinal experimental designs to test the robustness and reliability of the results. Moreover, alternative methods such as group discussions that bring together the the technology providers and users may offer deeper insights into their shared and divergent perspectives on the adoption of QR codes for enhancing the food supply chain integrity.

7.4 Challenges in future practical applications

If QR codes are not attached on the packaging of food products, particularly counterfeits, a severe issue arises: regardless of how perfect a QR code-based authentication mechanism may be, it will be ineffective. However, the widespread adoption of QR codes seems to be inevitable in the future. QR codes are increasingly incorporated into product packaging, gradually replacing traditional barcodes (QR Code Tiger, 2025). I expect that in the future, the majority of products circulating in the market will have QR codes attached. Consequently, food products lacking QR codes may face challenges in market entry. Furthermore, as consumer awareness of food authenticity and safety continues to rise, there is an increasing demand for detailed product information. This growing consumer expectation is likely to drive the adoption of QR codes as an effective tool for information dissemination. Once consumers develop the habit of using QR codes to obtain product information, food brand owners will be actively implementing QR codes to maintain consumer trust. In summary, the adoption of QR codes will be widespread and their role in authentication is expected to become increasingly significant over time.

The creation of fake QR codes linked to the fraudulent authentication platforms poses a severe challenge to the authentication mechanism. Generating fake QR codes is not difficult technically for the offenders. Once fake QR codes appear on food packaging, they undermine the effectiveness of authentication mechanisms and increase the risk of consumer deception. To address this issue, governments and authorized institutions have established legally regulated authentication platforms. Food brands are required to register their products in these official platforms, ensuring that QR codes direct consumers to a verified authentication platform rather than an arbitrary third-party website. For instance, in Indonesia, the Indonesian Food and Drug Supervisory Agency (BPOM) has developed the BPOM Mobile application, which enables consumers to authenticate the safety of registered food products by checking their distribution permit numbers and scanning the QR codes displayed on product labels (Muthmainnah & Efrilianda, 2024). This highlights the importance and necessity of establishing a unified and widely recognized authentication platform to ensure the reliability and credibility of QR code-based systems.

7.5 Research implications for implementation

In the context of increasing competitive pressure and rapid technological advancement driven by globalization, food companies are continuously open to innovation to maintain and strengthen their market positions (Bigliardi & Galati, 2013). Gaining a competitive advantage increasingly depends on the successful introduction of technological innovations that enhance product functionality in both existing and

emerging markets (Betz, 2003). QR code technology, as a specific innovative technology, offers the potential to significantly enhance the integrity and transparency of food supply chains.

This thesis has provided a comprehensive overview of QR code applications in information transmission and explored the perceptions and understanding of this technology from the perspective of both supply chain actors and consumers. These insights serve as valuable references for decision-makers within the food industry, supporting the evaluation and potential adoption of QR code systems. However, the strategic selection of technology is critical. Incorrect evaluation and adopting unsuitable technologies can result in substantial resource waste, reduced organizational flexibility, and elevated opportunity costs, potentially undermining efforts to ensure food authenticity (Thamhain, 2014). Conversely, identifying and investing in appropriate technologies, such as QR codes, at an early stage enables more effective resource utilization and can establish a foundation for long-term competitive success. The findings of this thesis will hopefully contribute to the optimization of innovation strategies and technology selection in the context of combating food fraud.

QR code for food authentication provides consumers with a simple, accessible, and effective way for authenticating food products. By scanning QR codes, consumers can acquire reliable information regarding product authenticity, which helps build trust in food quality and safety. This technology not only enhances consumers' access to useful information but also plays a role in protecting their health by reducing the risk of food fraud. In addition, it mitigates potential economic losses associated with food fraud, thereby strengthening consumers' confidence in the overall food supply chain. This study further explored the factors influencing consumers' intention to scan authentication QR codes, as well as the premium they are willing to pay for special information conveyed by QR codes. The findings offer valuable insights for developing more user-friendly QR code platforms that can boost consumer engagement and promote widespread adoption. The implementation of well-designed QR code systems empowers consumers, supports informed decision-making, and contributes to a more transparent and trustworthy food supply chain.

The adoption of QR code technology for food authentication has substantial implications for the food supply chains. By embedding reliable information related to product authenticity directly into packaging, QR codes strengthen the food supply chain integrity and serve as a critical tool in addressing food fraud. Moreover, the implementation of QR code-based authentication systems contributes to the establishment of a more transparent, trustworthy, and effectively regulated commercial environment. Through the access to data on product authenticity, QR codes

significantly reduce information asymmetry between food producers and consumers. The integration of QR code authentication thereby supports the development of a more resilient and ethical food market ecosystem.

7.6 Research limitations and recommendations

This thesis employed a multi-method approach to gain an in-depth understanding of the perceptions, attitudes, and behavioral intentions of both the technology providers and users toward the adoption of QR codes. The research combines a comprehensive literature review with empirical insights from both supply chain actors and consumers. A conceptual method regarding the spatial-temporal patterns of consumers scanning QR codes used to detect the counterfeiting food products is also proposed. In light of the findings and limitations, several recommendations for future research have been identified.

In **Chapter 3**, interviews were conducted with actors in the wine supply chains of Italy and India to explore their perceptions of the drivers and barriers of QR code adoption for supply chain integrity. These results highlight the complexity and context-dependence of technology adoption within food supply chains. Future research should focus on evaluating the transferability of these findings across different settings. Specifically, investigating whether the identified drivers and barriers hold true in other regions, industries, or supply chain structures could help determine the extent to which the current conclusions are generalizable. Moreover, it is vital to develop tailored strategies that address the specific characteristics of supply chain actors. For example, small-scale supply chain actors may face financial and technical barriers that differ substantially from those in a large scale and need more policy and financial support on technology adoption. Such tailored strategies may effectively promote the adoption of QR code technologies in diverse supply chain environments.

One of the limitations is that there is no research on how the perception of supply chain actors and consumers on QR codes changes over time. In other words, the participants' viewpoints are constructed based on the current status of the supply chain, the current technological level of identification devices, and their understanding of the topic. Thus, the perception of supply chain actors and consumers on QR codes may change with the development of technology. The adoption of QR codes may become less challenging as the technology gets more prevalent and prices decline, or there could be new technological tools that are developed. Solutions such as gradually implementing them may also help mitigate worries about the reliability and costs of these devices.

To facilitate the implementation of QR codes aimed at enhancing food supply chain integrity, several recommendations can be proposed. First, raising public awareness of QR code applications is essential. Awareness campaigns should target various demographic groups, particularly younger generations who tend to be more open to technological innovations, while emphasizing the role of QR codes in ensuring food authenticity and safety. In addition, policymakers should promote and financially support initiatives that provide training in QR code-based authentication technologies. Such efforts can strengthen the technical capacity of supply chain actors by developing skilled professionals responsible for maintaining and operating authentication platforms. Furthermore, financial support in the form of subsidies or funding should be provided to supply chain actors to alleviate the initial costs associated with the adoption of QR code-related equipment and software. This economic assistance can lower financial pressure to entry and accelerate the widespread use of QR code technologies across the food supply chain.

This study provides both empirical and theoretical insights into food packaging QR codes for food authenticity; however, several scientific areas need to be further explored. First, future research could focus on the integration of advanced technologies such as Internet of Things (IoT), cloud computing, and artificial intelligence with QR codes, in order to achieve a higher level of food information transparency and supply chain integrity. Second, it is recommended to further identify and validate additional factors that may influence consumers' and enterprises' intention to use QR codes, such as privacy concerns and social norms, to build a more comprehensive theoretical framework. Finally, future studies could conduct in-depth analyses across different types of food categories, examining the applicability and variations of QR code adoption among diverse food products, thereby providing more targeted promotion strategies.

References

Adjei, P. O. W., Kosoe, E. A., & Forkuor, D. (2017). Facts behind the myth of conservative rurality: major determinants of rural farmers' innovation adoption decisions for sustainable agriculture. *GeoJournal*, *82*, 1051-1066. https://doi.org/10.1007/s10708-016-9728-9

Ajzen, I. (1985). From intentions to actions: A theory of planned behavior. In *Action control: From cognition to behavior* (pp. 11-39). Berlin, Heidelberg: Springer Berlin Heidelberg.

Ajzen, I., Fishbein, M., Lohmann, S., & Albarracín, D. (2018). The influence of attitudes on behavior. *The handbook of attitudes, volume 1: Basic principles*, 197-255.

Banks, J., Hanry, D., Pachano, M. and Thompson, L. (2007), *RFID Applied*, Wiley, Hoboken, NJ.

Barnard, Y., Bradley, M. D., Hodgson, F., & Lloyd, A. D. (2013). Learning to use new technologies by older adults: Perceived difficulties, experimentation behaviour and usability. *Computers in Human Behavior*, *29*(4), 1715-1724. https://doi.org/10.1016/j.chb.2013.02.006

Bigliardi, B., & Galati, F. (2013). Models of adoption of open innovation within the food industry. *Trends in Food Science & Technology*, *30*(1), 16-26. https://doi.org/10.1016/j.tifs.2012.11.001

Bottani, E., & Rizzi, A. (2008). Economical assessment of the impact of RFID technology and EPC system on the fast-moving consumer goods supply chain. *International Journal of Production Economics*, *112*(2), 548-569. https://doi.org/10.1016/j.ijpe.2007.05.007

Chen, T., Ding, K., Hao, S., Li, G., & Qu, J. (2020). Batch-based traceability for pork: A mobile solution with 2D barcode technology. *Food Control*, *107*, 106770. https://doi.org/10.1016/j.foodcont.2019.106770

Effendy, F., Hurriyati, R., & Hendrayati, H. (2021, September). Perceived usefulness, perceived ease of use, and social influence: intention to use e-wallet. In *5th Global Conference on Business, Management and Entrepreneurship (GCBME 2020)* (pp. 311-315). Atlantis Press.

Flake, J. K., Barron, K. E., Hulleman, C., McCoach, B. D., & Welsh, M. E. (2015). Measuring cost: The forgotten component of expectancy-value theory. *Contemporary Educational Psychology*, *41*, 232-244. https://doi.org/10.1016/j.cedpsych.2015.03.002

Habashneh, A., Assayed, A., & AlMajali, A. (2023). Using Blockchain for Agro-Food Traceability: A Case Study from Olive Oil Industry. In *Industry 4.0 Technologies: Sustainable Manufacturing Supply Chains: Volume 1—Theory, Challenges, and Opportunity* (pp. 35-45). Singapore: Springer Nature Singapore.

Haji, M., Kerbache, L., & Al-Ansari, T. (2022). Food quality, drug safety, and increasing public health measures in supply chain management. *Processes*, *10*(9), 1715. https://doi.org/10.3390/pr10091715

Hochstrasser, B. (1992). Justifying IT investments. In *Proceedings of the Advanced Information Systems Conference* (pp. 17-28).

Johnson, E. M., & Huber, G. P. (1977). The technology utility assessment. *IEEE transactions on Systems, Man, and Cybernetics*, *7*(5), 311-325. https://doi.org/10.1109/TSMC.1977.4309719

Kroesen, M., Handy, S., & Chorus, C. (2017). Do attitudes cause behavior or vice versa? An alternative conceptualization of the attitude-behavior relationship in travel behavior modeling. *Transportation Research Part A: Policy and Practice*, *101*, 190-202. https://doi.org/10.1016/j.tra.2017.05.013

Liu, C., Li, J., Steele, W., & Fang, X. (2018). A study on Chinese consumer preferences for food traceability information using best-worst scaling. *PloS one*, *13*(11), e0206793. https://doi.org/10.1371/journal.pone.0206793

Muthmainnah, A., & Efrilianda, D. A. (2024). User experience evaluation of BPOM mobile application using user experience questionnaire and focus group discussion method. *Journal of Advances in Information Systems and Technology*, 6(1), 28-44.

QR Code Tiger, (2025). QR codes to replace barcodes on all products starting 2027—GS1. Available from *https://www.qrcode-tiger.com/qr-code-will-replace-the-barcode*. Accessed October 27, 2025

Romano, D., Rocchi, B., Sadiddin, A., Stefani, G., Zucaro, R., & Manganiello, V. (2021). A SAM-based analysis of the economic impact of frauds in the Italian wine value chain. *Italian Economic Journal*, *7*, 297-321. https://doi.org/10.1007/s40797-020-00137-w

Ryan, S. D., & Harrison, D. A. (2000). Considering social subsystem costs and benefits in information technology investment decisions: a view from the field on anticipated payoffs. *Journal of Management Information Systems*, *16*(4), 11-40. https://doi.org/10.1080/07421222.2000.11518264

Seo, K. H., & Lee, J. H. (2021). The emergence of service robots at restaurants: Integrating trust, perceived risk, and satisfaction. *Sustainability*, *13*(8), 4431. https://doi.org/10.3390/su13084431

Smart, A. U., Bunduchi, R., & Gerst, M. (2010). The costs of adoption of RFID technologies in supply networks. *International Journal of Operations & Production Management*, *30*(4), 423-447. https://doi.org/10.1108/01443571011029994

Tani, G., & Cimatti, B. (2008, December). Technological complexity: a support to management decisions for product engineering and manufacturing. In *2008 IEEE International Conference on Industrial Engineering and Engineering Management* (pp. 6-11). IEEE.

Thamhain, H. J. (2014). Assessing the effectiveness of quantitative and qualitative methods for R&D project proposal evaluations. *Engineering Management Journal*, *26*(3), 3-12. https://doi.org/10.1080/10429247.2014.11432015

Verma, S. (2019). Modelling product distribution and quality parameters in high-value australian fisheries chain.

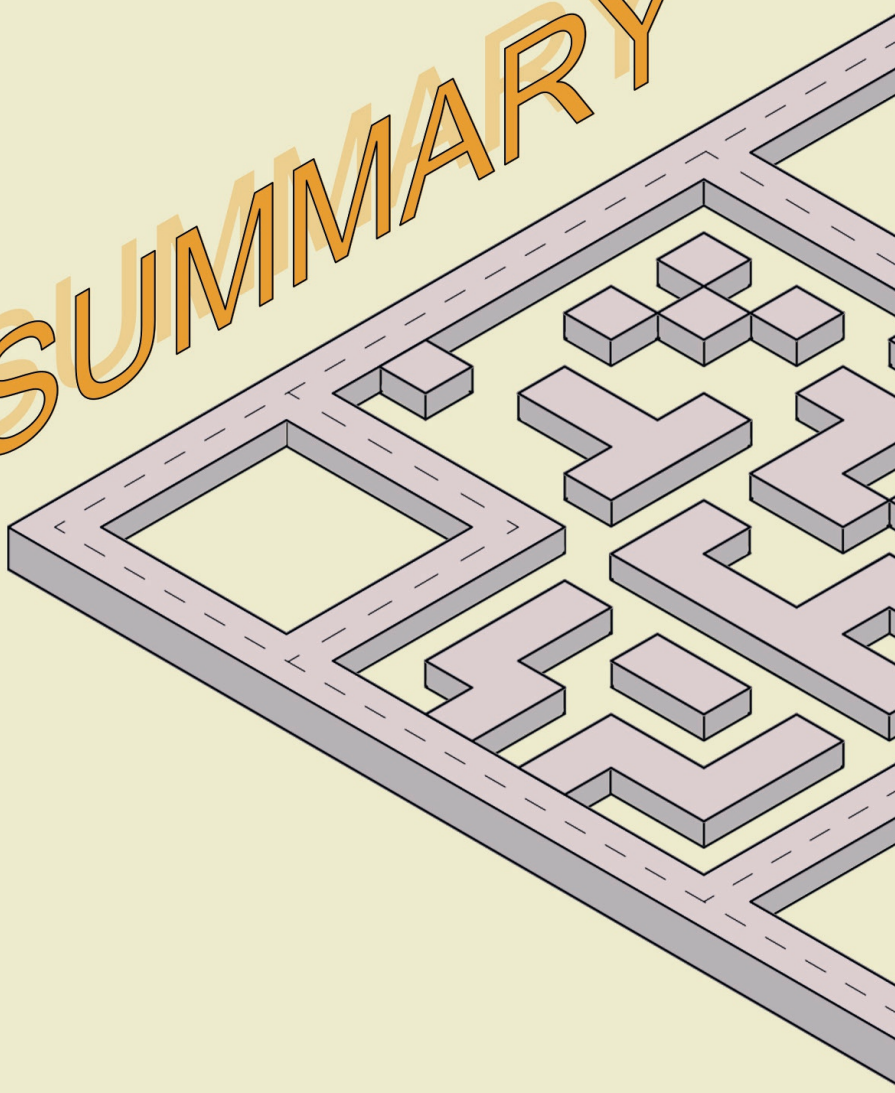
Violino, S., Pallottino, F., Sperandio, G., Figorilli, S., Antonucci, F., Ioannoni, V., Fappiano D, & Costa, C. (2019). Are the innovative electronic labels for extra virgin olive oil sustainable, traceable, and accepted by consumers?. *Foods*, *8*(11), 529. https://doi.org/10.3390/foods8110529

Yang, Y., Hobbs, J. E., & Natcher, D. C. (2020a). Assessing consumer willingness to pay for Arctic food products. *Food Policy*, *92*, 101846. https://doi.org/10.1016/j.foodpol.2020.101846

Yang, Y., Hobbs, J. E., & Natcher, D. C. (2020b). The Arctic as a food producing region: Consumer perceptions and market segments. *Canadian Journal of Agricultural Economics/Revue Canadienne D'agroeconomie*, *68*(4), 387-410. https://doi.org/10.1111/cjag.12255

Zahir Irani, P. E. (2000). The propagation of technology management taxonomies for evaluating investments in information systems. *Journal of Management Information Systems*, *17*(3), 161-177. https://doi.org/10.1080/07421222.2000.11045650

SUMMARY



Summary

Summary

Quick response (QR) codes are increasingly used on food packaging, serving as a digital tool to convey diverse information to consumers. Due to its several advantages, including small size, being consumer-friendly, and enabling access to digital information, QR codes have the potential to contribute to food authentication and supply chain integrity. However, the widespread and effective implementation of this technology for enhancing food supply chain integrity depends not only on the positive adoption by food supply chains but also on the engagement and acceptance of consumers as users. Its further application is shaped by multiple factors. Thus, understanding the perceptions of the food supply chain actors and the behavioral intention to use from consumers is key to the wide adoption, as such insights can help uncover the full potential in food authenticity and propose tailored solutions to promote the adoption of QR codes for food authenticity.

To understand the current applications of QR codes in the food industry, a review (**Chapter 2**) was conducted, providing a brief overview of the QR code configuration and the technical principles of information transmission. Its advantages were highlighted through comparisons with other digital technologies. The applications of QR codes in the food industry were summarized into four main areas: traceability, quality evaluation, anti-counterfeiting, and marketing. Moreover, the limitations and challenges were discussed from several aspects, including insufficient consumer engagement, high technical and marginal costs, information overload, and technical barriers.

To explore the supply chain actors' perception of identification devices, the wine supply chain was selected as the study object, and the interviews were conducted with grape growers, winemakers, bottlers, and distributors from Italy and India to explore the drivers, barriers, and strategies influencing the implementation of identification technology in two diverse supply chains (**Chapter 3**). The drivers for implementing identification technologies are efficient traceability, consumer trust, regulatory compliance, brand enhancement, ease of use, counterfeiting risks, counterfeiting monitoring, and keeping competitive; the barriers include implementation costs, traditional mindset, antiquated production lines, lacking technicians, forged devices, no counterfeiting, low visibility, and unequal returns; the strategies are collaboration enhancement, cost optimization, regulatory support, multi-technology integration, simplified systems, raising awareness, and training programs.

To uncover the factors that influence consumers' behavioral intention to use the authentication QR codes, a questionnaire with multiple scale items was developed

(**Chapter 4**). The data from consumers recruited in the UK and China were used to test the proposed models. The results indicates that perceived usefulness and perceived ease of use were identified as the factors significantly influencing Chinese and British consumers' attitudes, while attitude is the most significant factor of behavioral intention. Attitude also significantly influenced authenticity awareness, and facilitating conditions significantly affected the perceived ease of use.

To investigate consumers' willingness to pay for special attributes, 377 consumer studies published between 2000-2024 were collected to conduct a global meta-analysis (**Chapter 5**). The findings showed that the overall consumers' WTP for special food attributes is 28%, and the presence of special food attributes is associated with an increase in food prices in most cases (87%). There is a significant difference in consumers' WTP across information carriers, while the consumers are willing to pay an extra 23% premium for the food attributes conveyed by the barcodes (including QR codes).

To develop a strategy for food fraud detection, a spatial-temporal analysis of consumers scanning food packaging QR codes (i.e., QR codes on the package of single food products are the same in a batch and different in different batches) is proposed in **Chapter 5** as a promising approach to counterfeiting detection. A feasibility analysis of this approach was elaborated in detail. The spatial-temporal scanning data related to counterfeiting, including date, time, and coordinates (longitudes and latitudes), were selected as the essential variables in the model. The normal spatial-temporal patterns of a batch of food with the same QR codes are analyzed, and the changes caused by four types of counterfeiting are identified to establish the relationship between counterfeiting and spatial-temporal anomalies in scanning. Potential approaches for counterfeiting detection based on spatial-temporal patterns are proposed through a conceptual analysis.

The general discussion in **Chapter 7** reviewed all the findings from **Chapters 2-6** and offered suggestions and potential directions for future research.

In conclusion, this thesis highlights the significant role of QR codes in enhancing food supply chain integrity. Through a combination of literature review, interviews, surveys, and meta-analysis, factors influencing technology adoption from supply chain actors' and consumers' perspectives were identified, providing strategic insights to promote wider and more effective use of QR code technology in the food supply chain. Moreover, this thesis also proposed a novel spatial-temporal approach for detecting food fraud based on the data of consumers' scanning QR codes, introducing innovative possibilities for enhancing authenticity monitoring and ultimately fighting food fraud.

Acknowledgements

Acknowledgements

Thanks, all.

Axis Y1008, Wageningen University

Pengfei Li

About the author



Pengfei Li was born in Xinxiang, China, on 20 July 1993. He obtained his bachelor's degree in Agricultural Mechanization Engineering from South China Agricultural University in 2015, followed by a master's degree in Agricultural Mechanization and Automation from the same university in 2018. In 2021, supported by funding from the China Scholarship Council, he began his PhD studies at Wageningen University & Research under the supervision of Prof. Kasper A. Hettinga and Dr Sara Erasmus. His research project is 'Integrative analysis of QR codes for food supply chain integrity'. The results of his research are presented in this thesis.

List of publications

- **Li, P.**, Yang, J., Jiménez-Carvelo, A. M., & Erasmus, S. W. (2024). Applications of food packaging quick response codes in information transmission toward food supply chain integrity. *Trends in Food Science & Technology*, *146*, 104384. https://doi.org/10.1016/j.tifs.2024.104384
- **Li, P.**, Moroni, L., Jadhav, M., Hettinga, K. A., & Erasmus, S. W. (2026). Drivers, barriers, and strategies of identification technology implementation for wine authentication. *Food Control*, *183*, 111954. https://doi.org/10.1016/j.foodcont.2025.111954
- Jiménez-Carvelo, A. M., **Li, P.**, Erasmus, S. W., Wang, H., & van Ruth, S. M. (2022). Spatial-temporal event analysis as a prospective approach for signalling emerging food fraud-related anomalies in supply chains. *Foods*, *12*(1), 61. https://doi.org/10.3390/foods12010061

Overview of completed training activities

Discipline specific activities	Organizing institute	Year
Advanced Food Analysis	VLAG	2022
EU-China-Safe Training Program	WUR	2022
Food Fraud and Mitigation (FQD36306)	FQD	2022
15th Food Safety Technology Forum	AOAC China Section	2023
Food Fraud Unmasked Symposium	UCD	2024
International Conference: Global commodity chains from a risk assessment perspective	BfR Academy	2024
Spotlight on Food Fraud Cafe	UCD	2024
QingBai Forum	Anhui Agricultural University	2025
General courses	**Organizing institute**	**Year**
VLAG PhD week	VLAG	2022
Project and time management	WGS	2022
Introduction to R	VLAG	2022
Philosophy and Ethics of Food Science and Technology	VLAG	2023
Scientific Writing	WGS	2024
Assisting in teaching and supervision activities	**Organizing institute**	**Year**
Assistance in the Food Fraud and Mitigation course (FQD36306)	FQD	2022, 2023
Thesis supervision (7 master's theses and 1 bachelor's thesis)	FQD	2022-2024
Other activities	**Organizing institute**	**Year**
Preparation of research proposal	FQD	2022
Food Fraud and Mitigation (FQD36306)	FQD	2022
FQD colloquia	FQD	2023
Article review	Journal of Infrastructure, Policy and Development	2024

Approved by Graduate School VLAG

Colophon

The research described in this thesis was conducted in the Food Quality and Design group at Wageningen University and Research.

This research described in this thesis was financially supported by the China Scholarship Council.

Cover designed by Pengfei Li and OFG Design Studio

Printed by ProefschriftMaken

