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

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ABSTRACT

Background: 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 and exploited in recent years – attracting increasing attention.
Scope and approach: 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 a 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.
Key findings and conclusions: 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.

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, Zare, Salimi, Ghomi, & Makvandi, 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 clear and trustworthy food labels to convey information about the product's identity and contents, and on how to handle, prepare and consume it safely. Countries have 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 2D codes is the Quick Response (QR) code. The QR code was invented by a Japanese firm in

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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, Jung, & Chang, 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, McKernan, Elliott, & Dean, 2022), biotechnology in food production (McFadden & Lusk, 2018), allergen information (Radu, Alexe, Pădure, Macri, & Belc, 2018), and Halal certification (Tan, Gligor, & Ngah, 2022). The practical information helps consumers in decision-making of selecting food.

The collection of data through the reading of QR codes provides valuable information for supply chain analysis. This can lead to operational improvements, trend identification, and process optimization to ensure quality and safety over time. QR codes, as a technology available for consumers to use, are increasingly of interest, especially in their use for information transmission. 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 of 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. The QR code

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, Luo, & Chen, 2013), and its structure is shown in Fig. 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).

QR codes have 40 versions in total. Different versions of QR codes have different sizes, different numbers of modules, and error correction levels (Pan, Liu, Yan, Yang, & Chu, 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. Technical principle

The framework of QR code technology in food packaging mainly includes two parts, coding and decoding (Fig. 2). The content of QR codes is decided by the information the food companies desire to

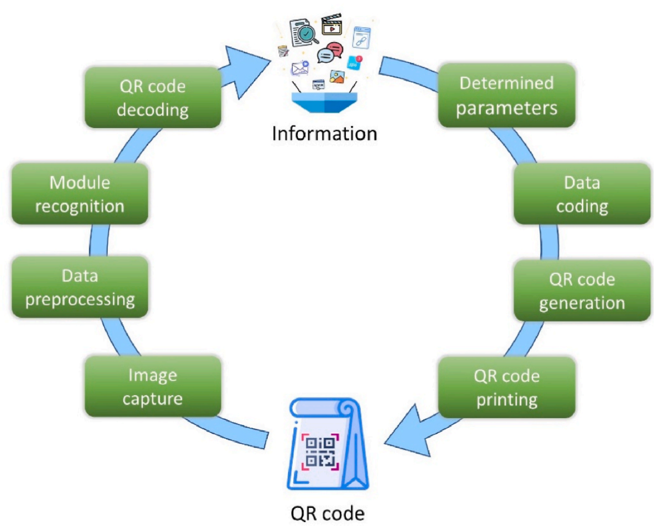

Fig. 2. The framework of QR code technology applied in food packaging (icons used from flaticon.com).

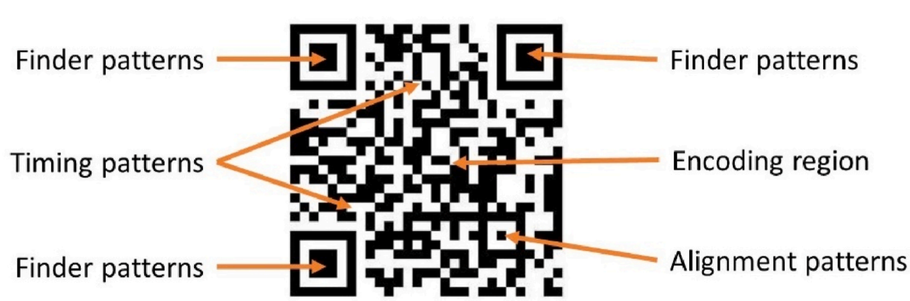

Fig. 1. The structure of a QR code.

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 them. 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, Zhu, Singh, & Pavlovich, 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.

2.3. 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, Saha, Singh, & McDonald-Maier, 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 m) is longer than that of the QR code (50 cm) (Chung, 2016). The memory capacity of RFID is about 32,000 alphanumeric characters, several times more than that of a QR code (Lou, Andrechak, Riben, & Yong, 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 dollars, meanwhile, QR codes are just printed by an inkjet printer, which means that the average cost for each QR code is around 0.0003 dollars (Li, Liu, Liu, Lai, & Xu, 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.

3. Applications in food information transmission

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, Donnelly, & Olsen, 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. 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. 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 technology, employing a distributed database, can ensure the transparency, integrity, and security of information through data encryption and decentralized transmission (Kamble, Gunasekaran, & Sharma, 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

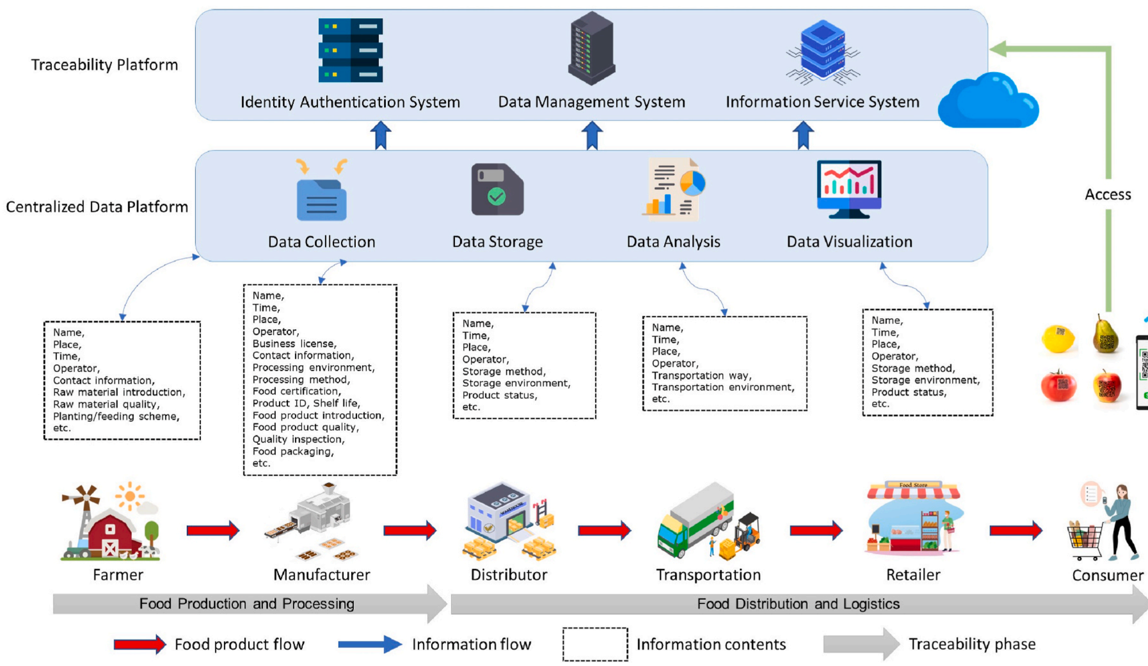

Fig. 3. Product flow and information flow in the food traceability system (icons used from biorender.com and flaticon.com).

internet speed (Mehannaoui, Mouss, & Aksa, 2023). 5G makes information transmission effective and simple, so the traceability information is easily accessible for consumers (Tang et al., 2021). The 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, Phan, Hsieh, & Li, 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 1 lists papers on the applications of QR codes in food traceability.

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, making the methods 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. 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, Lavilla, de la Calle, Romero, & Bendicho, 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. 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 (section 3.3).

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

Table 1
Lists of papers on QR code application in food traceability.

Food category	Product	Research theme	Reference
Aquatic products	General aquatic products	QR code application in traceability	Zhang, Yue, and Li (2014)
		Traceability system development	Xiao, Fu, Zhang, Peng, and Zhang (2017)
	Fish	QR code application in traceability	Seino et al. (2004)
		Traceability modeling	Zhang, Wang, Yan, Glamuzina, and Zhang (2019)
		Traceability system development	Gao, Xiao, and Chen (2019); Lin et al. (2020)
	Tuna	QR code application in traceability	Rogerson and Parry (2020)
Dairy products	Cheese	Traceability system development	Varavallo, Caragnano, Bertone, Vernetti-Prot, and Terzo (2022)
	Dairy products	Traceability system development	Li et al. (2016)
	Fruit yogurt	QR code readability analysis	Tarjan, Šenk, Tegeltija, Stankovski, and Ostojic (2014)
	Milk	Traceability system development	Latif et al. (2021)
		QR code application in traceability	Khanna, Jain, Burgio, Bolshev, and Panchenko (2022)
Horticultural products	Apple	QR code identification equipment design	Qian, Du, Zhang, Fan, and Yang (2017)
		Traceability system development	Xie, Wan, Tolón Becerra, and Li (2022)
	Buckwheat	Traceability system development	Wang et al. (2021)
	Grain general	QR code identification equipment design	Liang et al. (2019)
		Traceability code generation	Deng and Feng (2021)
	Olive	QR code application in traceability	Liu, Li, Steele, and Fang (2018)
		Web application development	Bayano-Tejero, Sola-Guirado, Gil-Ribes, and Blanco-Roldán (2019)
	Rice	Traceability system development	Sutopo, Susmartini, and Herdiman (2021)
	Vegetables general	QR code application in traceability	Qiao, Wei, and Yang (2013)
		Traceability modeling	Dong, Fu, Stankovski, Wang, and Li (2020)
		Traceability system development	Hu, Zhang, Moga, and Neculita (2013); Yang et al. (2016); Yang, Wang, Han, and Qiao (2018)
	Water spinach	Consumers' perceptions of QR codes	Tran et al. (2022)
	Wheat	QR code application in traceability	Qian et al. (2012)
		Traceability evaluation	Qian, Fan, et al. (2017)
Meat products	Beef	Consumers' perceptions of QR codes	Spence, Stancu, Elliott, and Dean (2018); Magalhaes, Campo, and Maza (2021); Shew, Snell, Nayga, and Lacity (2022)
		Traceable resource unit transformation	Fan et al. (2019)
		Traceability system development	Liang, Cao, Fan, Zhu, and Dai (2015)
	Pork	Management system development	Chen, Du, Cheng, and Po (2016)
		Traceability system development	Bai et al. (2017); Peng et al. (2018); Chen, Ding, Hao, Li, and Qu (2020)
Other products	Egg	Traceability system development	Bumblauskas, Mann, Dugan, and Rittmer (2020)
	Food general	Consumers' perceptions of QR codes	Lin, Shi, and Zhou (2022)
	Olive oil	Traceability system development	Violino et al. (2020)

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, Hagen, & Papautsky, 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.

Currently, 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.

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, Huisman, & Luning, 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. 5a. The unique authentication code for each food product linked to a QR code on food packaging is disclosed online in the authentication system and available to consumers. Consumers can compare the authentication code and its corresponding pattern acquired by scanning the food QR code with that disclosed online to authenticate the source of food (Chen, Ding, et al., 2020). If they are the same, the food is identified as authentic. 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, Tian,

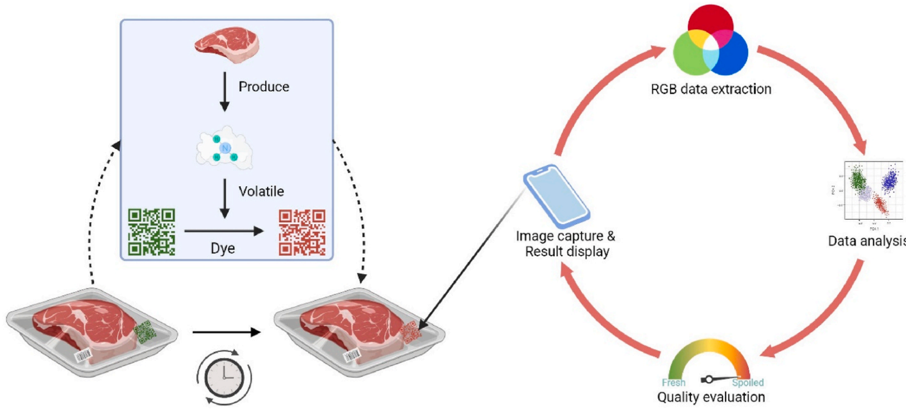

Fig. 4. Schematic of QR code application as a food quality sensor. Fresh food in sealed packaging (meat for example) produces volatile substances with time, which react with chemical substances formed as QR codes. The color of the QR code varies with the increase in volatile substances concentration 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). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

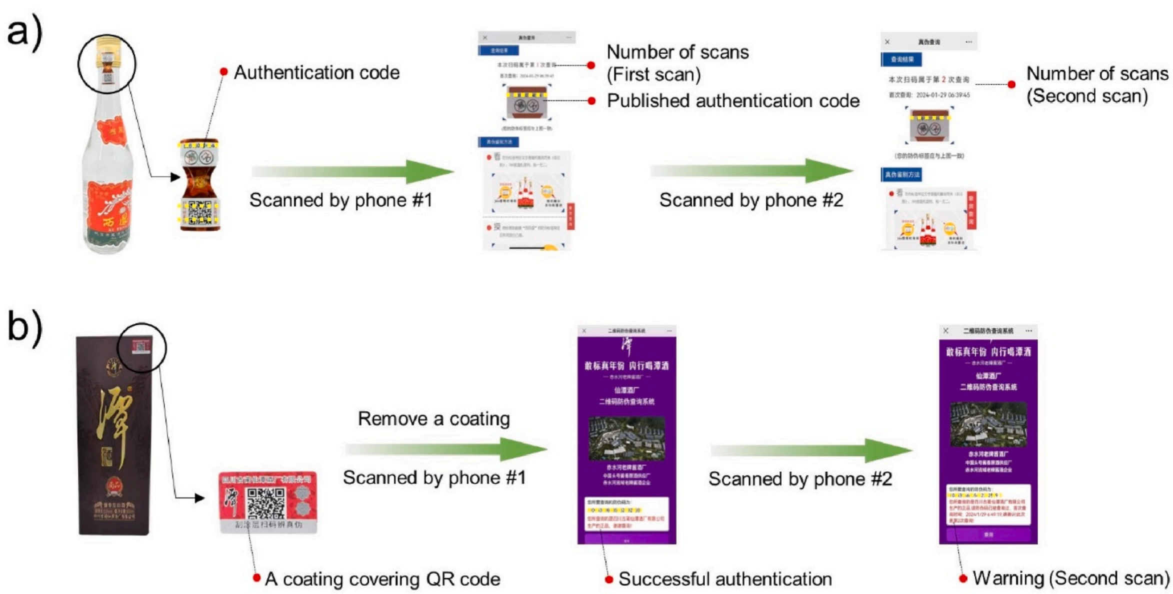

Fig. 5. QR codes and their linked authentication system interfaces; a) shows a QR code, an authentication code, and the pattern on an alcohol label used for authentication through the cross-checking mechanism; b) shows a QR code partially covered by the coat for authentication based on the one-off authentication scanning methods. 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. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Zhang, Yang, & Yin, 2018).

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, Li, Erasmus, Wang, & van Ruth, 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. Bala 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 'authentic' 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. 5b). A unique QR code on the packaging box of the alcohol is partially covered by a coating. After removing the coating, 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 the consumers of the risk of counterfeiting and inform them of the number of authentications.

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.

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.

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.

Sharing instructional videos of cooking is another way to boost business. Food companies, especially those selling meat products, always link a textual recipe (Shinde et 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.

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.

Table 2
Lists of approaches to applications of QR codes in marketing promotion.

Approaches	Food company	Category	Content linked with QR codes	Reference
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, Khanna, Kale, and Varghese (2021)
	Chef's Basket	Pasta	A video of recipes	Scanova (2021)
	Itoham	Processed/ precooked food	Animated recipes	Dou and 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.

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).

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.

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, Palos-Sanchez, Saura, & Martin-Velicia, 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).

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.

4.5. Technical barriers

Decoding of QR codes becomes challenging when QR codes are pasted on curved surfaces of food or the packaging, since corresponding 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 (Qian, Xing, Zhang, & Yang, 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 (Wang, Feng, Jiang, Pan, & Yu, 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, Vignesh, & Alam, 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.

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, McCarthy, & O'Reilly, 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 food supply chain integrity needs in different countries can promote further implementation of QR codes. Since genetically modified food has always been controversial in America (Zheng, Nayga, Yang, & Tokunaga, 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 (European Parliament and of the Council, 2021), it is recommended that the full nutritional 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 (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 generation (Atkin & Thach, 2012; Rotsios et al., 2022). Many large companies, such as Carrefour (Sunny, Undralla, & Pillai, 2020) and Walmart (NFCW, 2019), are also promoting the use of QR codes on food packaging.

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 potential in food transmission, which are expected to enhance the food supply chain integrity and help establish resilient food systems. The future studies are warranted to focus on how to further improve the practical utilization of QR codes to increase their market prospects.

CRediT authorship contribution statement

Pengfei Li: Conceptualization, Investigation, Data Curation, Writing - Original Draft, Visualization,. Jingjie Yang: Methodology, Investigation, Data Curation, Writing - Original Draft, Visualization. Ana M. Jiménez-Carvelo: Methodology, Investigation, Writing - Review & Editing, Supervision. Sara W. Erasmus: Conceptualization, Writing - Review & Editing, Supervision, Project administration.

Declaration of competing interest

The authors claim no competing interest.

Data availability

No data was used for the research described in the article.

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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., et al. (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*. https://doi.org/10.1016/j.compag.2019.104980. Article 104980.

Bez Batti, E. A., Nascimento, A. B. D., Geraldo, A. P. G., Fernandes, A. C., Bernardo, G. L., Proenca, R. P. D. C., et al. (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*. https://doi.org/10.3389/fnut.2022.875913. Article 875913.

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 13 June 2022).

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

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*. https://doi.org/10.1016/j.ijinfomgt.2019.09.004. Article 102008.

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 4 June 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, 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*. https://doi.org/10.1016/j.foodcont.2019.106770. Article 106770.

Chen, P. J., Du, Y. C., Cheng, K. A., & Po, C. Y. (2016). Development of a management system with RFID and QR code for matching and breeding in Taiwan pig farm. In *2016 13th international Conference on Electrical Engineering/electronics, computer, telecommunications and information technology, chiang mai, Thailand*.

Chen, Y., Fu, G., Zilberman, Y., Ruan, W., Ameri, S. K., Zhang, Y. S., et al. (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*. https://doi.org/10.1016/j.foodchem.2021.129243. Article 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 12 December 2022).

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

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 26 January 2024).

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*. https://doi.org/10.3390/su13063486. Article 3486.

Dieline. (2012). *The 'headline news' cup sleeve*. Retrieved from https://thedieline.com/blog/2012/5/22/the-headline-news-cup-sleeve.html. (Accessed 2 July 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., et al. (2023). QRsens: Dual-purpose Quick Response code with built-in colorimetric sensors. *Sensors and Actuators B: Chemical, 376*. https://doi.org/10.1016/j.snb.2022.133001. Article 133001.

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 26 January 2024).

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

Fan, B., Qian, J., Wu, X., Du, X., Li, W., Ji, Z., et al. (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 and Agriculture Organization of the United Nations (FAO). (2016). *Handbook on food labelling to protect consumers*. Rome Italy: FAO.

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 2 February 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*. https://doi.org/10.1016/j.compag.2019.105013. Article 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 22 June 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 useable 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., et al. (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*. https://doi.org/10.1016/j.ijinfomgt.2019.05.023. Article 101967.

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). https://doi.org/10.3390/foods11172716. Article 2716.

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, 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

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, 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), 10–11. https://doi.org/10.1147/JRD.2016.2598610

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). https://doi.org/10.1371/journal.pone.0139558. Article e0139558.

Liang, K., Chen, X., He, R., Li, J., Okinda, C., Han, D., et al. (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

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, 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

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*. https://doi.org/10.3389/fpubh.2022.857039. Article 857039.

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*. https://doi.org/10.1371/journal.pone.0206793. Article e0206793.

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). https://doi.org/10.3390/foods10020232. Article 232.

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 5 May 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*. https://doi.org/10.1016/j.foodcont.2022.109409. Article 109409.

Mishra, N., Mistry, S., Choudhary, S., Kudu, S., & Mishra, R. (2020). Food traceability system using blockchain and QR code. In *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 18 May 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 8 April 2022).

Morsy, M. K., Zór, K., Kostesha, N., Alstrom, T. S., Heiskanen, A., El-Tanahi, H., et al. (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 26 January 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 27 January 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 27 January 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 7 January 2023).

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, 415*, 4039–4060. 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). https://doi.org/10.1111/jfpe.12685. Article e12685.

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

Popović, T., Krčo, S., Maraš, V., Hakola, L., Radonjić, S., Van Kranenburg, R., et al. (2021). A novel solution for counterfeit prevention in the wine industry based on IoT, smart tags, and crowd-sourced information. *Internet of Things, 14*. https://doi.org/10.1016/j.iot.2021.100375. Article 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*. https://doi.org/10.1016/j.fpsl.2021.100638. Article 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). Research on vegetable supply chain traceability model based on two-dimensional barcode. In *2013 sixth international symposium on computational intelligence and design, hangzhou, China*. October.

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 8 July 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*. https://doi.org/10.1155/2018/3487398. Article 3487398.

Rogerson, M., & Parry, G. C. (2020). Blockchain: Case studies in food supply chain visibility. *Supply Chain Management: 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 15 July 2022).

Seino, K., Kuwabara, S., Mikami, S., Takahashi, Y., Yoshikawa, M., Narumi, H., et al. (2004). *Development of the traceability system which secures the safety of fishery products using the QR code and a digital signature*. Kobe, Japan: Oceans' 04 MTS/IEEE Techno-Ocean. November.

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

Shew, A. M., Snell, H. A., Nayga, 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). ML-based smart shopping system with recipe recommendation. In *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 5 March 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 19 October 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*. https://doi.org/10.1016/j.cie.2020.106895. Article 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*. https://doi.org/10.1016/j.compag.2020.105895. Article 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

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). https://doi.org/10.3390/foods11050722. Article 722.

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*. https://doi.org/10.3390/su14063321. Article 3321.

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

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

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*. https://doi.org/10.1016/j.infrared.2023.104680. Article 104680.

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

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

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). https://doi.org/10.1111/jfpe.12303. Article e12303.

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). https://doi.org/10.3390/agronomy12040921. Article 921.

Xu, Y., Liu, Z., Liu, R., Luo, M., Wang, Q., Cao, L., et al. (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., et al. (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, 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). https://doi.org/10.3390/foods11091259. Article 1259.

Yang, X. T., Qian, J. P., Li, J., Ji, Z. T., Fan, B. L., Xing, B., et al. (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

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). https://doi.org/10.3390/su10114007. Article 4007.

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., et al. (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*. https://doi.org/10.1016/j.cej.2021.130986. Article 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*. https://doi.org/10.1016/j.foodqual.2023.104841. Article 104841.