meat technology
Founder and publisher:
Institute of Meat Hygiene and Technology, Belgrade

UDK: 637.5.05:004/007
ID: 169240841
https://doi.org/10.18485/meattech.2025.66.1.2

Review paper

Determination and implementation of traceability tools for the meat and meat products supply chain to promote consumer awareness and public confidence

Sadegh Cheraghi Saray[1*], *Ali Hosseinkhani*[1], *Seyed Abbas Rafat*[1], *Hamed Hamishehkar*[2] and *Peyman Zare*[3]

[1] *Department of Animal Science, Faculty of Agriculture, University of Tabriz, Tabriz, Iran*
[2] *Drug Applied Research Center, Tabriz University of Medical Sciences, Tabriz, Iran*
[3] *Faculty of Medicine, Cardinal Stefan Wyszyński University in Warsaw, Warsaw, Poland*

A R T I C L E I N F O

Keywords:
Traceability
Meat sources
Animal products
Animal health
Public health

A B S T R A C T

Governments have focused on the design of tracking systems due to concerns about the security of imported foods and prevention of zoonotic diseases. The required infrastructure, data collection methods, and health benefits and components achieved through the implementation of traceability at the international level were reviewed and reported in the present study. The review demonstrated that the implementation of each electronic tracking system allows the identification of consumed meat from farm-to-fork. However, the Radio Frequency Identification (RFID) systems, DNA markers, and Wireless Sensor Networks (WSNs) were indicated as the most appropriate and accurate methods for tracking the origins of consumed meat. According to our findings, regulatory bodies and policymakers need to pay robust attention to this issue to prevent the penetration of counterfeit meat products and to maintain general public health.

1. Introduction

Food traceability is a preventive approach for creating and maintaining an information path that tracks a product's movement throughout the production process to ensure the origin of the food product (*Bougdira et al.*, 2019; *Ghag and Shedage*, 2025). Following outbreaks of zoonotic diseases and human health concerns, tracking systems were introduced for the meat supply chain (SC) (*Levings,* 2012; *El-Sayed et al.*, 2016; *Zhao et al.*, 2020). Animal identification is the basis of tracking systems in the meat SC, in which records of an animal are documented from its birth to slaughter, as is the supply of its meat to the consumer (*Zhao et al*., 2020; *Singh et al.*, 2025).

One of the fundamental steps in tracking is food labeling. Although this does not provide traceability *per se*, it is an important part of the tracking policy that allows for physical tracking of the product and can be used as an effective tool for product differentiation and quality affirmation (*Alfian et al*., 2017; *Fan et al*., 2024). In this regard, the European Food Safety Act (178/2002) and the European Beef Hygiene Act (1760/2000) specify that meat labels should contain the following mandatory information: 1) reference number for matching the slaughtered animal and its meat; 2) countries of the animal's birth, raising, and slaughter; 3) country/countries in which meat was fragmented, and; 4) slaughterhouse(s)' identity numbers. Optional information includes animal breed, the type of diet consumed, name of the owner(s), vaccination, transport ID, halal/non-halal slaughter, and other components that are written on the meatpacking box when leaving the slaughterhouse, based on each

***Corresponding author:** Sadegh Cheraghi Saray, *s.c.saray@tabrizu.ac.ir*

Paper received: April 7th 2025. Paper accepted: April 22nd 2025.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia.

country's regulations (*Cheraghi Saray and Rafat,* 2016). However, tags can be easily counterfeited if they are paper-based and use one-dimensional (1D) barcodes without reference to a central database (*Li et al.*, 2024). Therefore, researchers are focusing on other tracking systems that produce a very low possibility of counterfeit and fraud (*Deng and Feng*, 2021).

Two-dimensional (2D) barcodes (in particular quick response (QR) codes) have many advantages over 1D and linear barcodes and are a successful and relatively easy tracing method for consumers to use (*Li et al*., 2024). These barcode scans relay the product information recorded in a central database, such as texts, photos, and videos, to customers who scan the codes with a camera lens, typically in a smartphone (*Chen et al*., 2020; *Li et al*., 2024).

Another new tracking method is radio frequency identification (RFID), which can track and monitor objects in different SCs. To this end, a carcass or a container carrying the carcass can be labeled and attached to an RFID at the time of slaughter when the head, skin, and intestines are separated from the body, but there are no physical body parts for the identification of an animal source (*Yan et al*., 2018; *Ismail and Huda*., 2024). However, the identification (ID) of a slaughtered animal and the exclusive number of the slaughterhouse must also be linked together to allow for tracing. Under these conditions, RFID can connect the sensors and act as a detection black box for tracking, logistics, and anti-counterfeiting purposes (*Yiying et al*., 2019; *Qiao et al*., 2023).

Smith et al. (2008) also developed a retinal scanning method to identify animals at birth, weaning, fattening, and entry into the slaughterhouse. Despite the exclusivity of retinal scanning, the identity of meat cuts in the slaughterhouse is questionable with this method. To complete this approach, DNA tracking is another option for identifying composite meat components, such as minced meat and carcass parts of unknown origin *(Hrbek et al*., 2020; *Nastasijevic et al*., 2025). Since the meat has a unique identifier that cannot be manipulated, and due to the inheritability of DNA, this method, along with microsatellite markers, can explicitly prove the origin of meat and meat products by tracking individual cuts of meat (*Zhao et al*., 2017; *Nastasijevic et al*., 2025).

The use of wireless sensor networks (WSNs) is another method used to monitor the temperature and humidity of packaged, perishable meat products within the SC (*Aung and Chang*, 2014; *Gil et al*., 2025). By integrating RFID and WSNs, the system can track products from origin to slaughter and also provide information on environmental conditions, such as the temperature and humidity of packaged meat from the slaughterhouse to the time of reaching the consumer (*Yan et al*., 2018; *Davoudi et al*., 2024). Given the described techniques and studies, it can be argued that the necessary infrastructure and potential for the implementation of tracking systems now exist in the food industry of most countries. This is because advances in the field of information technology provide the required mechanisms to achieve fast and comprehensive monitoring methods in any country. However, the implementation of tracking systems requires improvement and integration between relevant institutions and the development of standards for the collection and publication of tracking data (*Cheraghi Saray and Rafat*, 2016; *Qian et al*., 2020b; *Ellahi et al*., 2025). Therefore, this review explains the importance of traceability of meat products and describes successful systems adopted at the international level, with the hope that the relevant institutions and organizations in every country approve and adopt the necessary rules and standards to implement national meat/meat product tracking policies that will advance the health and rights of consumers.

Impacts

- Pandemics of infectious and zoonotic diseases over the last few years have increased the food safety concerns of producers and consumers and the need to pay special attention to accurate traceability of animal products and animal health.
- The present review attempts to raise awareness of current developments in the traceability of meat products, animal health and subsequently, better utilization of animal resources, and finally, presents the tracing systems successfully adopted at the international level.
- Review of recent scientific developments showed that modern electronic devices (such as electronic barcodes, DNA markers, RFID, GPS, EPCIS and other biometric sensors) play a vital role in monitoring and solving the problems encountered by meat producers and other actors in the meat supply chain.
- The results of the present study are of considerable significance in terms of public health because accurate implementation of meat tractability systems can mitigate the risk of zoonotic diseases, increase animal health, improve food security, and contribute to enhancement of vital health standards in different countries all over the world.

2. Materials and Methods

2.1 Protocol

Here we present the results of the literature review for past peer-reviewed papers dealing with meat traceability, consumer awareness, public health and related topics. Papers were collected from the CAB Direct, PubMed, Scopus and ISI Web of Science with topics (title, abstract, and author keywords) including different methods of tracking systems and identity of consumed meat source from farm-to-fork. After removing the irrelevant papers, there were 317 fully peer-reviewed papers on this topic between 2000 and 2025 (Table 1). Reference lists in eligible articles and relevant reviews were hand-searched to identify and include further relevant papers. Subsequently, the results of relevant papers were merged, and consensus was reached by discussion among the authors on any disagreements. Finally, due to the wide range of traceability approaches, only the most relevant and frequently reported topics were selected for comparison and discussion.

2.2 EAN.UCC system in traceability

The EAN.UCC system provides internationally recognized standards for the unique identification of food products at all stages of production, transportation, and storage. It also provides facilities for electronic communication standards to enable the accurate and quick exchange of information between all stages of food production, processing, and distribution (*Zhao and Cao*, 2017). The system uniquely identifies products, locations, services, and assets, and includes a set of standard data structures, called Application Identifiers (AIs), which allow encoding of secondary information, such as batch number, expiry date, and other meat resource properties for encryption. The basis of the EAN.UCC system, which is used extensively in traceability, is an unambiguous numbering scheme used to identify goods and services throughout the SC (*Bai et al.*, 2017). Owing to the automated techniques for information recording in this system, the numbering method can be used at any stage of production, conversion, and distribution of meat and its products.

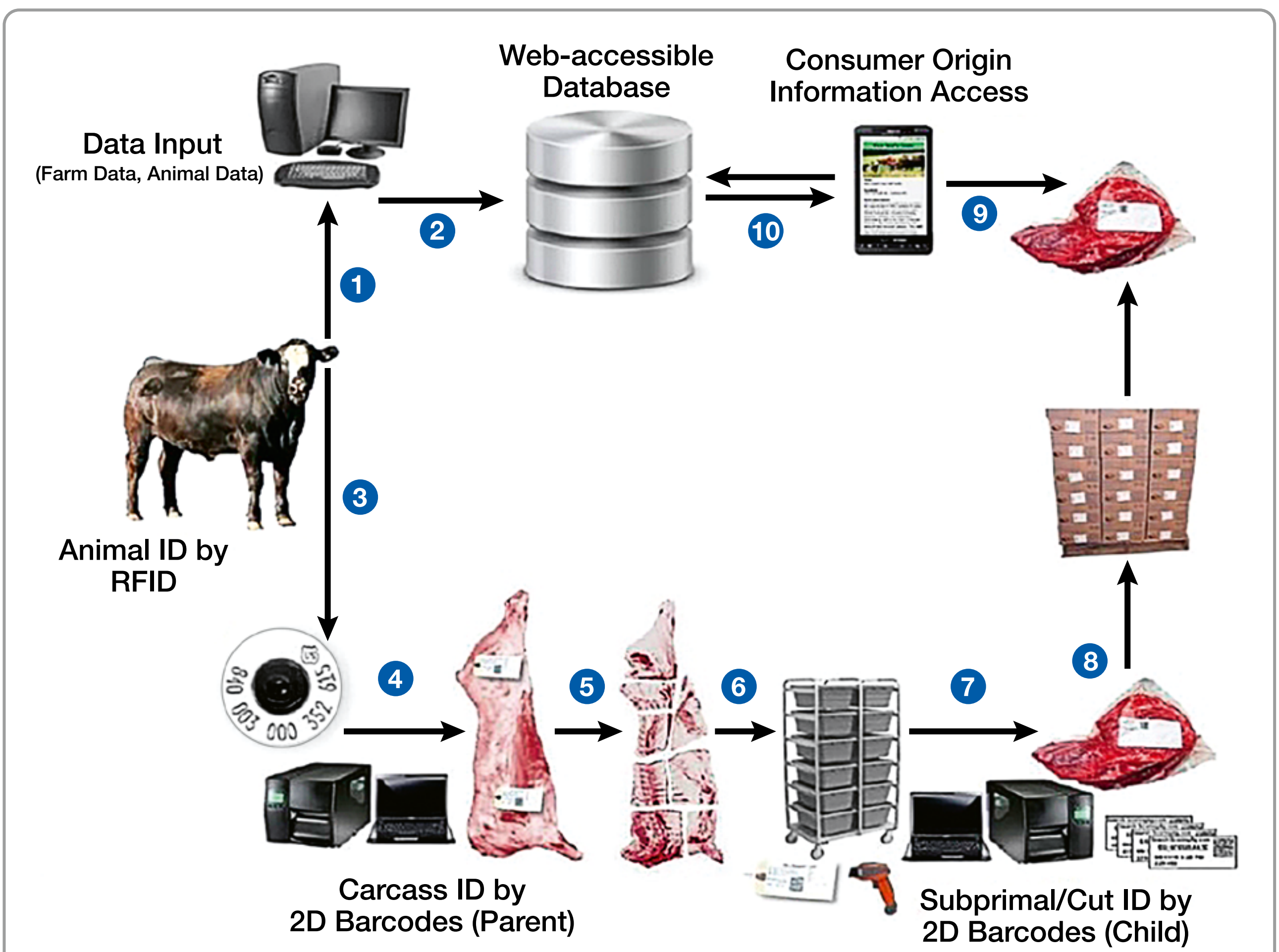

Figure 1. Different stages of meat tracking (adapted from Buskirk et al., 2013)

Table 1. Comprehensive search strategy for articles selection

Database	Searched keywords	Number of results	Number of selected articles
CAB Direct	(animal traceability/ animal health/ meat/ minced meat/ meat sources/ animal muscle composition/ animal tissues/ animal traceability system/ supply chain/ value chain/ supply networks/ consumer awareness/ consumer rights/ right to safety/ consumer protection/ health/ public health/ consumer's health/ zoonotic disease/ animal traceability/ slaughter stage traceability/ post-slaughter traceability/ traceability policies/ government policies/ regulations/ traceability benefit/ traceability benefit problem/ traceability tools/ barcodes/ RFID/ EPCIS/ DNA markers/ genetic traceability)	531	98
PubMed	(animal health/ traceability system/ meat traceability/ slaughterhouse processing/ post-slaughter traceability/ tissues traceability/ muscle composition traceability/ minced meat traceability/ food trace number/ packaging/ zoonotic disease/ meat transportation/ meat distribution industry/ consumer rights/ consumer health/ public health/ food safety/ animal resources)	87	27
Scopus	(meat industry/ meat sources/ meat traceability/ meat supply chain/ meat traceability systems/ meat traceability tools/ blockchain/ barcodes/ two-dimensional (2D) barcodes/ 2D tags/ quick response (QR) code/ radio frequency identification (RFID)/ wireless sensor networks (WSNs)/ electronic product code information services (EPCIS)/ DNA markers/ DNA tracking/ genetic traceability/ tracking technologies/ meat packaging/ freshness indicators/ temperature indicators/ gas indicators/ biosensors indicators/ consumer rights/ consumer awareness/ consumer confidence/ consumer health/ public health/ health benefits/ health concerns/ food safety/ food security/ zoonotic disease/ national policies/ governmental policies/ food safety policy/ meat traceability policies/ traceability benefits/ traceability costs/ animal resources/ animal products)	114	66
Web of Science	(animal product safety/ meat quality/ meat chain control/ meat traceability/ packaging traceability/ meat packaging/ identification/ animal identification/ animal authentication/ animal genetics/ genetic traceability/ DNA microsatellite markers/ animal muscle types/ minced beef/ beef supply chain/ food supply chain/ cold chain/ blockchain/ perishable food supply chain/ food monitoring for safety/ rapid alert system for food and meat/ automotive applications/ online temperature monitoring/ optimal temperature/ shelf life/ electronic pedigree/ labeling/ 2D barcode technology/ QR code/ RFID/ WSNs/ EPCIS/ food safety criteria/ border control/ microbial food safety policy/ governmental policies/ meat traceability policies/ public health/ veterinary public health/ zoonotic disease / food safety / food security / consumer health/ consumer trust/ consumer awareness/ consumer rights / animal resources / animal products / animal health)	217	92
Other Academic Databases	(animal health/ traceability technologies/ food traceability/ meat traceability/ blockchain / meat/ minced meat/ meat sources/ animal identification/ animal authentication/ veterinary public health/ zoonotic disease / food safety / food security / public health/ consumer health/ consumer trust/ online temperature monitoring/ automotive applications/ Mobile solution/ rapid alert system for food and meat/ electronic pedigree/ labeling/ QR code/ 2D barcode/ WSNs/ RFID/ EPCIS/ microbial food safety policy/ meat traceability policies/ national policies/ meat safety policy)	368	34

2.3 Traceability at the slaughter stage

After entry into a slaughterhouse, the identity and history of animals are transferred to and tracked by the slaughterhouse's central database. After slaughter, the skin is removed and the carcass divided into the hindquarters and forequarters. The slaughtered carcass then transfers to the cutting room, and the bony part of the carcass is first separated and each section is turned into primary cuts (*Cheraghi Saray and Rafat*, 2016; *Thakur et al.*, 2020). After preparing the required cuts, vacuum packing is often applied and the meat labelled with a special barcode. The label contains the product code, package code, country of origin, birth date, names and addresses of producers, carcass number, sex and cold weight of the carcass, ear tag number, date of slaughter, country of slaughter, name of slaughterhouse, carcass cutting plant, the date of packing, and expiry date. Finally, the product enters the cold or freezing rooms and a traceable code is recorded for it at the time of transport. At the same time, all information about the post-slaughter time and transport is recorded in the central database (*Buskirk et al*., 2013). A schematic of different stages of meat tracking is shown in Figure 1.

2.4 Post-slaughter traceability

To differentiate the meat of slaughtered animals originating from different feeding systems, a good approach is spectral characterization of the meat using reflective spectroscopy. In this method, the meat muscle type is detected and differentiated using principal component analysis (PCA) and independent modeling, and qualitative analysis of the obtained information determines the difference in meat muscles from two or more different feeding systems (*Horcada et al*., 2020; *Barragan et al*., 2021). Moreover, another approach can detect the meat of a particular animal that is turned into minced meat by simple carcass processing at a specific time (*Spence et al*., 2018). In this method, a single individual scan of the animal is already recorded at the slaughterhouse to preserve its identity. When the animal is slaughtered and divided into primary parts, each one is marked with a special barcode. Each piece of meat receives a unique food trace number before packaging, which links it to a group of animals slaughtered on a particular day. Therefore, using a food trace number, the source of meat is displayed after slaughter and packing and will be shown when final product is sold at butchery counters. Thus, this is a suitable method for tracking meat based on EAN.UCC standards, which is able to track complete or minced meat throughout the SC (*Cheraghi Saray and Rafat*, 2016; *Bai et al*., 2017) (Figure 2).

3. Different tracking tools and systems

3.1 RFID

RFID tags are one of the most effective methods for tracking animals, consisting of a circuit (preservation of a unique identifier number), an antenna (connected to a microchip), and a memory component (allows recording information and

Figure 2. Assignment of food trace number to each cut of meat. The food trace number is a unique reference number for traceable information used on a specific day and time of slaughter. Upon a customer's request about the origin of the meat, the slaughterhouse, processing plant or group of animals that originated there can be traced using this number (*Cheraghi Saray and Rafat*, 2016; *Yiying et al*., 2019).

Figure 3. A sample of RFID tags and their function

communicating with the reader), and all are connected to a computer system (Fig. 3). Radio waves are emitted from the RFID tag, converted into digital data by the operator, and added to the information systems of relevant companies or institutions. Various coatings are used to protect the circuit from dust, extreme temperatures, humidity, heat, and salt. The workable distance that between the tag and the reader or operator depends on the frequency band (*Velandia et al*., 2016; *Zhang et al*., 2017).

3.2 Two-dimensional labels (2D tags)

The QR code is one of the tracking systems that can embed significant information, such as text, video, advertising, personal information, etc., in the form of a 2D barcode. These codes can be easily scanned with smartphones to decrypt information and messages related to the meat products. In this method, even offline users can access the meat product information at any situation, simply by installing a 2D barcode scanning application on their smartphone (*Cheraghi Saray and Rafat*, 2012; *Chen et al*., 2020).

3.3 *DNA markers*

Despite the high cost of measurement methods based on the DNA marker tracking technique, these methods are very effective and have many advantages over paper-based tracking methods. Microsatellite markers can be used to detect the meat breed of an ID-less slaughtered animal (*Zhao et al.*, 2017). The analytical methods used in this method are mainly based on protein and DNA analysis. Protein-based methods include immunological methods, electrophoretic assays, and chromatographic techniques, each of which is measured according to the relevant standards (*Hamishehkar et al*., 2014; *Hrbek et al*., 2020). In general, DNA-based meat source traceability systems mainly follow a similar path. In these systems, tissues, hair follicles, and blood samples from carcasses or live animals are obtained from each animal or carcass before or during slaughter, and DNA analysis results are stored afterward. When the carcass enters the cutting room, any initial or packaged cut is identified as an animal or as within a group of animals that have passed simultaneously through the slaughter stages. When verification is required, the meat or packaging information is connected with the stored materials and with the DNA profiles. Finally, a group of stored DNA profiles, which should contain that from the carcass in question, is selected, and the relevant DNA profile are fully matched to the carcass or the animal group from which it originates (*Shackell*, 2008; *Kademi et al*., 2019; *Qian et al*., 2020a).

3.4 Electronic Product Code Information Services (EPCIS)

The EPCIS is an online system based on monitoring the temperature and humidity in the hot and cold meat SCs. During meat transportation, this system is used by RFID-based temperature sensors to record product temperature and predefined data at any time and place in the transportation chain (*Thakur and Foras*, 2015; *Wang et al*., 2017).

3.5 Other new tracking technologies

Other technologies, such as freshness indicators (estimation of a product's remaining shelf life), temperature indices (indicating temperature history during distribution and storage), gas indicators (monitoring changes in gas composition within packaged containers), and biosensors (detection, recording, and information on biochemical reactions) are new methods known as intelligent tracking for packaged meat products (*Han et al*., 2018). The design of such packages for meat sources and their integration with recording and data transfer devices have enhanced logistics activities that have a significant effect on the flow of meat sources from farm-to-fork, thereby increasing the efficiency of meat source tracking efforts (*Fang et al*., 2017).

4. Data mining

Some data are expected to be non-recordable for a variety of reasons. Data mining techniques are used to predict and estimate such data throughout the SC to ensure a complete record of meat products. The integration of data mining techniques with tracking systems ensures the quality and safety of meat food sources throughout the SC so the consumer can evaluate and judge the quality of meat products in any situation before purchasing (*Alfian et al*., 2017).

5. Results and Discussion

5.1 Different tracking tools and systems

5.1.1 Genetic traceability (DNA markers)

The results of review studies have shown that genetic traceability can play a very important role in food chains, because genetic traceability is a rapidly growing application due to the rapid development of genomics, not only in food identification but even in the control of nutrition (Cheraghi Saray and *Hosseinkhani*, 2013; *Qian et al*., 2020a). According to *Morcia et al.* (2016), DNA is a stable molecule that exists in all types of tissues and can retain sequence-specific information that can be accessed by a simple replication reaction. Therefore, next-generation sequencing technologies are able to produce large amounts of genetic data in a short time at a reasonable cost (*Ghosh et al*., 2018; *Zhao et al*., 2019). In addition, it has been shown that the nucleus genome could be identified for individual animal species by extracting information from genetic sequences. Accordingly, stability measurements could be designed for detection purposes and generally to characterize each animal, plant, and microorganism (*Romanenko*, 2017; *Hrbek et al*., 2020). Similar results have confirmed that the DNA marker technique is a suitable method for determining the origin of an animal meat sample (*Zhao et al*., 2017). This method requires using at least eight molecular markers that provide a high degree of mean heterozygosity in a population, so achieving unique identification of individuals in the population (*De-Camargo*, 2018). Currently, several classes of PCR-based DNA markers, along with direct sequence analysis, have been used frequently to identify plants and animals involved in the human food chain (*Morcia et al*., 2016). In addition to high accuracy, DNA marker traceability is a relatively simple technique, so these tests could enhance knowledge of

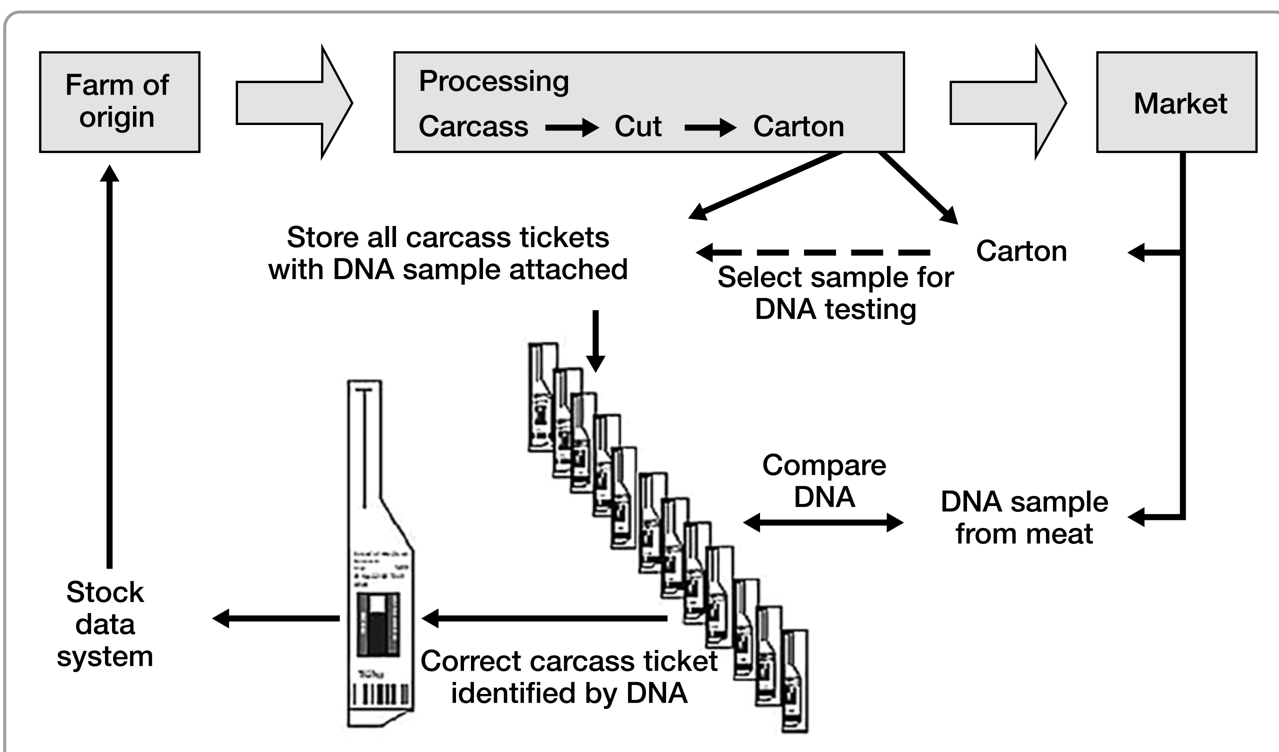

Figure 4. The general path of DNA-based meat traceability

the quality attributes of produced meat and increase consumer confidence (*Zhao et al*., 2019). DNA-based meat source traceability systems mostly follow the same general path as shown in Figure 4. It is noteworthy that the successful implementation of this method requires a basic knowledge of population structures related to meat food sources. Although the accuracy of DNA-based traceability steps is almost completely guaranteed, its main limitation is the cost. However, systems for counterfeit prevention strategies can be implemented at lower costs through national and international certification of meat sources (*Cheraghi Saray et al*., 2019; *Qian et al.*, 2020b; *Cao et al.*, 2021).

DNA-based traceability systems generally follow a common pathway. These systems typically utilize tissue samples, blood from a live animal, blood from a slaughtered carcass, or hair follicles from a live animal. Prior to slaughter (or during the process), a blood or tissue sample is taken from each live animal or slaughtered carcass and held in storage. When the carcass is transferred to the cutting room, each primal cut or packaged portion is identified in a manner that allows for the identification of the individual animal, or a group of animals processed concurrently through the slaughter facility. When a trace is required, a sample of the meat or its packaging information is sent to the DNA sample storage. In this storage, the sample can be unambiguously matched to the carcass or animal from which it originated, using DNA profiles. For any DNA-based system to be effective, a traceable production pathway through the processing facility is essential. Processors must adhere to standard operating procedures to prevent contamination. When these conditions are met, a validated and standardized analytical method can be employed, facilitating the matching of DNA profiles obtained from the carcass at the time of slaughter with samples of the packaged meat (*Shackel*l, 2008; *Cheraghi Saray and Rafat*, 2016).

5.1.2 RFID

Studies on RFID as one of the tracking system tools revealed that the use of RFIDs has grown along with the development and production of modern electronic devices that can be installed on the animal's ear, under the neck or ankle skin, or when placed in a protective layer, inside the animal's digestive tract (Figure. 5). Small RFID tags in different MHz and GHz frequency bands ensure system integrity and information (Zhao et al., 2020). The use of RFIDs increases both consumer confidence and, in addition to security and control of total production, enhances efficiency. This greatly reduces the system workload and can improve the development rate in addition to facilitating access to network services (Alfian et al., 2017). More sophisticated biometric technologies are becoming more sophisticated for living animals. Therefore, automated tracking systems and RFID-based tracking systems are currently available in many industries. However, RFID technology is expensive, and the high costs are to pay operators, install computer software, provide networks, and maintain related systems (Zhang et al., 2017; Alfian et al., 2020; Urbano et al., 2020). Therefore, the use of RFID is recommended only for companies or organizations that have economically evaluated and justified it. Figure 5 shows an example of the use of RFID in live animals before and after transport to the slaughterhouse.

Figure 5. a) Application of RFID in animals from birth and throughout the breeding period until arrival at the slaughterhouse and sending their meat to stores; **b)** Different locations for the installation and use of RFID tags in a live animal

5.1.3 Two-dimensional tags

Two-dimensional barcodes can store a large amount of information as a machine-readable pattern in black and white lines. These barcodes can act as a portable database that is scanned and decrypted by smartphones (*Chen et al*., 2020). The information embedded in this type of barcode is mainly obtained by translating and transferring the information placed in the RFID ear tag to a 2D barcode, which is first embedded on the carcass and then on each piece of packaged meat, and finally provided to the consumer. Hence, the transfer of RFID data to 2D tags leads to 100% accuracy in tracking meat through the SC (*Foster et al*., 2018; *Thakur et al*., 2020). A wide range of 2D barcodes are available, but the four most important examples described in the present study are shown in Table 2. The advantages of the 2D QR code tag have led to its widespread use in the food industry, particularly in the meat industry (*Gao et al*., 2009; *Kim and Woo*, 2016; *Focardi et al*., 2018). The QR code can be a useful tool for implementation of consumer rights by providing more information on food safety and quality. The QR code is also expected to be used more than ever to help eliminate consumers' distrust and strengthen their satisfaction when shopping. Therefore, comprehensive and accurate information, such as the nature, brand, origin, packaging quality, price, safety, stability, and environmental effects of the product, should be provided for each food product. These efforts are important mechanisms that can improve the consumer's decision to buy meat foods (*Kim and Woo*, 2016; *Zhang et al*., 2020). Figure 6 shows an example of the information embedded in a 2D barcode after being scanned by a smartphone. More extensive and accurate presentation of this information will satisfy the consumer and support the product sale.

Figure 6. Information embedded in a 2D barcode when scanning by the consumer

Table 2. Specifications of index samples for 2D barcodes (capacity features and standards for major 2D barcodes[a])

	QR Code	PDF417	Data Matrix	Maxi Code
Example code				
Developer (country)	DENSO (Japan)	Symbol Technologies (USA)	RVSI Acuity CiMatrix (USA)	UPS (USA)
Numeric	7,089	2,710	3,116	138
Alphanumeric	4,296	1,850	2,355	93
Binary	2,953	1,018	1,556	-
Features	Large capacity Small printout size High-speed scan	Large capacity	Small printout size	High-speed scan
Standards	AIM International JIS ISO	AIM International ISO	AIM International ISO	AIM International ISO

Legend: [a]Adapted from Gao et al. (2009).

Table 3. Transportation requirements for the perishable food products

Product	Temperature (°C)	Humidity	Other requirements
Cooked food	> 60–63 (hot holding temperature)		
Chilled food	0–4 (temperatures higher than 4°C cause faster growth of bacteria)		
Frozen food	≤ −18 (temperatures lower than −18 °C prevent bacteria growth)		
Fresh fruits and vegetables	0–8	90%–95%	Appropriate concentrations of O_2, He, CO_2, and C_2H_4

Note: The temperature requirements for food transportation can vary in different countries depending on their regulations (Farooq et al., 2016)

5.1.4 Electronic product code information services (EPCIS)

One of the policies developed for traceability systems is the design of general applications (e.g. applications that can be used in the smartphone) to enable consumer monitoring of food quality and to prevent the penetration of counterfeit products into food SCs. Most perishable food products, including cooked, chilled and frozen meats, require special storage conditions (Table 3), the full details of which are provided to consumers through designed applications (*Hamishehkar et al*., 2015; *Farooq et al*., 2016; *Wang et al*., 2017).

Among the literature reviewed in the present study, an example of EPCIS (Figure 7) can illustrate

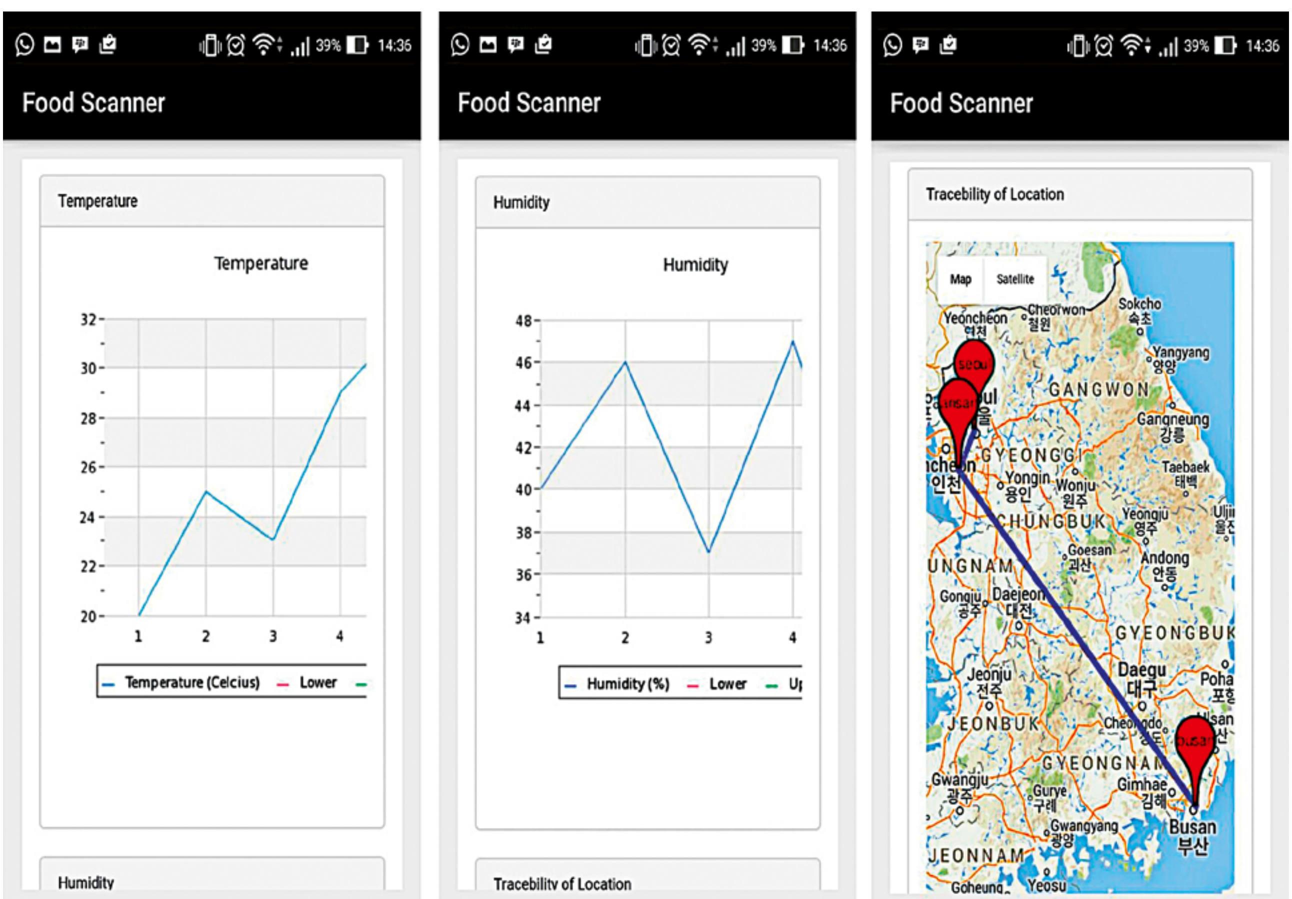

Figure 7. Screenshot of temperature, humidity, and map indicating meat tracking in a smartphone application (adapted from *Farooq et al*., 2016)

the performance of these applications. For instance, the consumer, after installing the smartphone application and scanning the product barcode at the time of purchase, observes graphics showing product temperature and humidity recorded along the depicted route map from the time of leaving the slaughterhouse to arrival at the store. The various pages of this application can graphically compare the product humidity and temperature data with the ideal temperature and humidity data for that product in the SC, and users can ascertain the actual transit route and the duration for which the product has undergone temperature and humidity fluctuations from the slaughterhouse to the store. Ultimately, the consumer is responsible for the final judgment and purchase decision; the data enable sensible discussion about the quality of transportation and the desirability of product transfer (*Thakur and Foras*, 2015; *Farooq et al*., 2016; *Wang et al*., 2017).

5.1.5 Traceability of animal muscle composition and tissues

Studies on tracking different meat sources with a focus on consumer demand to monitor the animals' diets and their meat production indicate that diets can be tracked for meat sources and raw milk using analytical methods. Dietary indicators are determined quantitatively or indirectly from the product or tissues of the slaughtered animal (*Zhao et al*., 2020). One study demonstrated that combined administration of different trackers would be useful, due to differences in costs and ease of implementation among different tracking methods (*Alfian et al.*, 2017). Findings on tracking muscle composition for animal meat raised for live weight gain and fed concentrate feeds due to a lack of forage in pastures revealed that the relative live weight gain using concentrates was associated with stronger changes in isotope C composition (*Monahan et al*., 2018; *Prache et al*., 2020). Also, some isotope C from the previous grazing period still remained in muscles even after 230 days of fattening. This relationship was not observed in their adipose tissues, which was attributed to relatively late fat deposition during the fattening period (*Prache et al*., 2005). In other similar studies, researchers could characterize meat spectra using visible-infrared spectroscopic detectors to differentiate beef that originated from different feeding systems. Their studies demonstrated differences in muscles and fleshy tissues from different nutritional systems by the use of PCA, independent modeling methods, and finally qualitative analysis of optical information (*Horcada et al*., 2020; *Dumalisile et al*., 2020; *Barragan et al*., 2021). The benefits of this type of tracking become even more important when consumers demand accurate information about the diet type and composition of slaughtered animals (*Hosseinkhani et al*., 2007; *Cheraghi Saray and Rafat*, 2016). Overall, the findings emphasize the fact that, for both meat and milk of a studied animal, the combined use of different tracers can be useful to detect the composition of different tissues or index compounds in specific sediments where forage or feed is grown (*Zhao et al.*, 2020). Accordingly, the combined administration of different tracers and examination of different tissues could improve our ability to predict and monitor the traceability of different meat sources.

5.1.6 Traceability of minced meat

Studies conducted over the last two decades show that, despite many endeavors in accurate traceability, minced meat or animal-derived products were usually exempt from full traceability. This weakness is mainly due to problems in determining and tracking the history of slaughtered animals, which contributes to the lack of accurate tracking of a mixed product (*Salih*, 2017; *Thesmar and Stevens*, 2019). For example, *Heaton et al.* (2005) reported that 9.5% of packaged liver and minced meat portions did not match the animals whose identities were recorded when entering the slaughterhouse. Similarly, other studies indicate tracing violations were committed mainly before the product entry into the processing plant (*Qian et al*., 2020b). However, in recent years and in most countries, data collected for minced meat traceability have been limited to the production date and place of the final production (*Han et al*., 2018; *Spence et al*., 2018). In this regard, researchers investigated a tracking technique based on DNA to separate the different parts of minced meat, and concluded that the physical separation of the compound ingredients might be the basis for the traceability within products (*Naveena et al*., 2018; Hrbek et al., 2020). In their study (*Naveena et al.*, 2018), the DNA-based identification method could differentiate different compound meat products. Other chemical technologies, such as enzyme-linked immunosorbent assay (ELISA), were able to detect species abnormalities in meat products (*Li et al*., 2019). Despite the sufficient knowledge about traceability and accurate identification of minced meat, conventional tests to accurately identify minced meat inputs are lacking (*Cherghi Saray and Rafat*, 2016; Salih, 2017). This can be explained by the fact that although accurate and on-time data collection is one of the priorities in the food (meat) SC, the main object of a traceability system is finding the best technology in order to reduce costs, risks, time, and energy expended to provide exact information about product transportation in the food SC (*Galvez et al*., 2018; *Thakur et al*., 2020). Moreover, tracing animal tissues is increasingly difficult given elapsed time after slaughter; this is due to the complexity of handling, equipment, and information requirements that need to be imposed for extensive tracking (*Bai et al*., 2017; *Horcada et al*., 2020; *Barragan et al*., 2021). Therefore, it is reasonable that the inefficiency of minced meat-related tracking in recent years is primarily due to the absence of low-cost, simple, and convenient technologies, and secondly, a lack of consumer concern about their rights to know the origin and identity of mixed meats (*Salih*, 2017; *Spence et al*., 2018). Therefore, governments need to be convinced to adopt appropriate policies to reduce the cost of authentication technologies and tests for the detection of violations and counterfeits committed in the minced meat SC. This requires raising people's awareness and knowledge in this field and increasing their demand for tracking mixed and derived meats, which will constitute a considerable portion of the market for meat food sources (*Cheraghi Saray and Rafat*, 2016).

5.1.7 Traceability in the transportation industry and distribution of meat

Findings related to traceability in meat transportation and distribution industries suggested that the origin of meat spoilage is transmission of bacteria from one animal to another during the slaughter process or at any stage of the production, processing, and meat distribution (*Cheraghi Saray et al*., 2014; *Zare et al*., 2014; *Odeyemi et al*., 2020). *Galvez et al*. (2018) demonstrated that tracking can be a tool for the successful identification, elimination of inappropriately contaminated products from the market, and for supporting product quality assurance processes. Therefore, the implementation of tracking for animals selected for slaughter might have a major contribution in reducing the identification costs of non-standard meat products (*Zare et al*., 2016; *Yan et al*., 2018; *Zhao et al*., 2020). With respect to pathogens, a study by Buhr (2003) is an excellent reference for recent research topics. This researcher reported that the veterinary services of one company identified *Salmonella* in routine tests on animal farms. Through traceability information systems, they proved in the shortest possible time that the *Salmonella* originated from the raising farm, and the need to recall feed, which could have contained the pathogen, was obviated. Economic analysis found that the use of traceability in this situation resulted in saving more than \$100,000 in feed recalls (*Buhr*, 2003). Figure 8 shows a simple

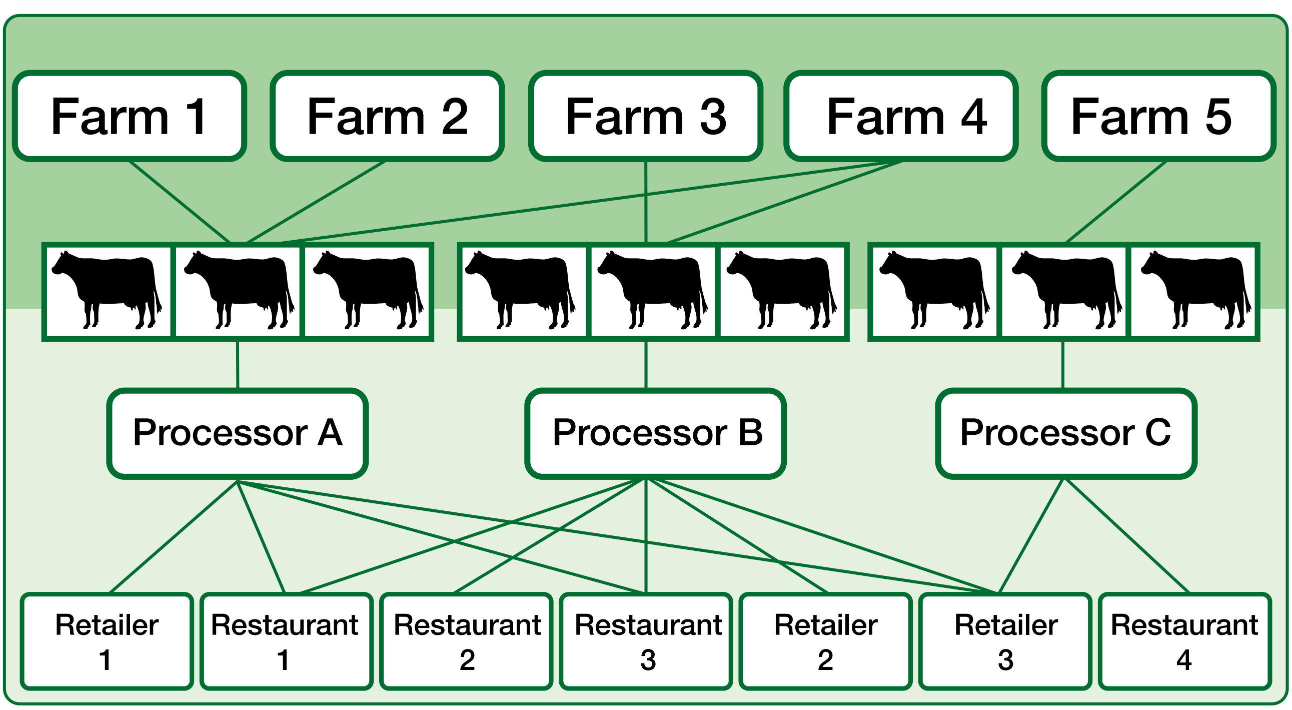

Figure 8. A simplified example of a beef supply chain (adapted from *Shackell*, 2008)

example of traceability "from farm to consumer" in the beef SC to further illustrate direct and indirect tracking of a sold product.

Figure 8 shows that fast tracking from farm to consumer can be both direct and indirect. In this diagram, the meat consumed in restaurants 1 and 3 is supplied from two processing slaughterhouses, A and B, where their meat is also supplied from cattle raised in four farms 1, 2, 3, and 4, one of which (farm 4) supplies meat to two processing slaughterhouses. Although retailers 1 and 2 provide meat from only one slaughterhouse (A and B, respectively), each of these slaughterhouses (A and B) is supplied by more than one farm, and farm 4 is common to both slaughterhouses. When there is a need for direct authentication of the sold meat, only the meat sold in Restaurant 4 can be traced to a single farm (Farm 5) among the four restaurants and three retailers. This is because Restaurant 4 purchases only from one slaughterhouse (C), and its meat came from only one livestock farm (5).

Given this example, adapted from *Shackell* (2008), it is understandable that there are many barriers to the direct traceability of meat in most cases, so the authenticity and origin of the consumed meat mostly depends on indirect tracking. Therefore, the design of traceable meat systems with indirect tracking capability, which also increases costs with the increasing the accuracy of their output information, is largely justified economically from the viewpoint of human health and is accepted by governments and consumers (*Jansen et al*., 2016; *Cheraghi Saray and Rafat*, 2016).

5.1.8 The role of regulatory and governmental authorities in meat traceability systems

Studies have shown that significant efforts have been made to draw meat traceability maps by different countries. China and the European Union have made the greatest efforts to address general consumer concerns about meat source traceability (*Jansen et al*., 2016; *Qian et al.*, 2020b). Since the consumer is the main motivation factor for designing global tracking systems, *Zhen et al.* (2019) carried out comprehensive studies in this regard and reported that some consumer behaviors toward food safety and risk factors were sometimes irrational. Hence, it can be suggested that consumers' tractability probably differs with the economic situation of each society (Thesmar and Stevens, 2019; Zhang et al., 2020). According to *Zhen et al.* (2019) and *Qian et al.* (2020b), traceability is a solution for consumer protection rather than a tool for the control of responsibilities. However, if consumer health is threatened by product(s), the producer will be able to troubleshoot via examining the various stages of the tracking system and make the necessary corrections. If the risk factors are of external origin or the corrections are beyond the capacity of the production unit, this is reported to the relevant authorities or institutions as soon as possible. However, retailers, wholesalers, and, in many cases, legislators insist on addressing tracking requests from the consumer perspective (*Sargeant et al*., 2007; *Wang et al*., 2018). As a result, some policies have been formulated in most countries such that the various stages of tracking systems are mainly implemented by consumer group representatives, private companies, and individual businesses, with governments ultimately making management decisions at the national and macro levels (*Salih*, 2017; *Wang et al*., 2018; *Galvez et al*., 2018; *Bougdira et al*., 2019; *Zhen et al.*, 2019). Therefore, there will be differences in the implementation of these systems in different countries, for which the main reasons are as follows: 1) the national livestock information system is unique for each country and is supported and implemented under the national laws of that country; 2) no two countries are exactly the same in terms of distance, nature, structure, and industry in the food SC, and; 3) different cultures in the agricultural industry of each country, and even each region, have a significant impact on the acceptability of traceability maps (*Cheraghi Saray and Hosseinkhani*, 2013; *Cheraghi Saray and Rafat*, 2016).

5.1.9 Costs and benefits of traceability systems

The main costs of companies or institutions that initially launch and design tracking systems are: 1) hardware costs, such as providing computers and scanners; 2) software costs, including purchasing applications tailored to each tracking system, such as the Abaserve; 3) costs of obtaining relevant licensing from national and international organizations; 4) costs of designing labels suitable for the type of meat sources; 5) costs of staff salaries, and; 6) costs of designing and maintaining central databases (*Vander-Merwe and Kirsten*, 2015). The main advantages of designing traceability systems are: 1) increased trust between meat producers (livestock owners and farmers), slaughterhouses, and consumers of meat products; 2) better control regarding the origin of meat through the use of electronic than paper-based documentation; 3) inventory control, online and accurate statistics, and limiting product theft; 4) improved control of illegal and fraudulent cases; 5) correct identification of an incident problem at any stage from production to sale; 6) improved management and accounting units in relevant companies and institutions; 7) easy and accurate access to retail markets, and; 8) potentially increased health and safety of consumers (*Probst et al*., 2013; *Vander-Merwe and Kirsten*, 2015; *Galvez et al.*, 2018; *Zhang et al*., 2020).

6. Conclusion

This review has shown that for those involved in the meat SC, the implementation of modern electronics based on communication and information technology, such as electronic barcodes, DNA markers, RFID, GPS, EPCIS, and other biometric sensors, plays critical roles in monitoring and detecting problems and providing consumers with information to support their purchasing decisions. An important result of this review is the description of the implementation of different information systems and traceability in the meat product sector. Since the expected result of the current review was to explain the necessity, efficiency, and economic reasons for implementing tracking systems and provide guidance for future research, such studies are advised to examine consumer trends regarding meat SC traceability. Proper, full traceability would enable meat SC companies to limit their legal and financial burdens, would support production decisions, enhance consumer health and purchase decisions, and would create public confidence in meat chain security. Consequently, traceability in the meat SC can bring both commercial and regulatory benefits for any country.

Određivanje i primena alata za sledljivost u lancu snabdevanja mesom i proizvodima od mesa sa ciljem podizanja svesti potrošača i jačanja poverenja javnosti

Sadegh Cheraghi Saray, Ali Hosseinkhani, Seyed Abbas Rafat, Hamed Hamishehkar i Peyman Zare

INFORMACIJE O RADU

Ključne reči:
Sledljivost
Izvori mesa
Proizvodi životinjskog porekla
Zdravlje životinja
Javno zdravlje

APSTRAKT

Zbog zabrinutosti za bezbednost uvezenih prehrambenih proizvoda i prevenciju zoonotskih bolesti vlade su se usmerile na dizajn sistema za praćenje. U ovoj studiji pregledana je i predstavljena potrebna infrastruktura, metode prikupljanja podataka, kao i zdravstvene koristi i komponente koje se postižu primenom sledljivosti na međunarodnom nivou. Pregled je pokazao da implementacija svakog elektronskog sistema za praćenje omogućava identifikaciju konzumiranog mesa od farme do trpeze. Međutim, sistemi za identifikaciju putem radio-frekvencije (RFID), DNK markeri i bežične senzorske mreže (WSN) označeni su kao najprikladnije i najtačnije metode za praćenje porekla konzumiranog mesa. Prema rezultatima istraživanja u ovom radu, regulatorna tela i donosioci odluka treba ozbiljno da obrate pažnju na ovo pitanje kako bi se sprečila pojava falsifikovanih proizvoda od mesa i očuvalo javno zdravlje.

Disclosure Statement: No potential conflict of interest was reported by authors.

Acknowledgements: The authors gratefully acknowledge Dr. Amir-Mahdi Elahi, Dr. Mohammad Cheraghi, and Prof. Sarah Mohammad-Panah for help and advice.

References

Alfian, G., Rhee, J., Ahn, H., Lee, J., Farooq, U., Ijaz, M. F. and Syaekhoni, M. A., (2017). Integration of RFID, wireless sensor networks, and data mining in an e-pedigree food traceability system. *Journal of Food Engineering,* 212, 65–75. https://doi.org/ 10.1016/j.jfoodeng.2017.05.008

Alfian, G., Syafrudin, M., Farooq, U., Maarif, M. R., Syaekhoni, M. A., Fitriyani, N. L., Rhee, J., (2020). Improving efficiency of RFID-based traceability system for perishable food by utilizing IoT sensors and machine learning model. *Food Control,* 110, 107016. https://doi.org/10.1016/j.foodcont.2019.107016

Aung, M. M., & Chang, Y. S., (2014). Temperature management for the quality assurance of a perishable food supply chain. *Food Control*, 40, 198–207. http://doi.org/10.1016/j.foodcont.2013.11.016.

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. http://doi.org/10.1016/j.foodcont.2017.02.040.

Barragan, W., Aalhus, J. L., Penner, G., Dugan, M. E. R., Juarez, M., Lopez-Campos, O., & Prieto, N., (2021). Authentication of barley-finished beef using visible and near infrared spectroscopy (Vis-NIRS) and different discrimination approaches. *Meat Science*, 172, 108342. https://doi.org/10.1016/j.meatsci.2020.108342.

Bougdira, A., Akharraz, I., & Ahaitouf, A., (2019). A traceability proposal for industry 4.0. *Journal of Ambient Intelligence and Humanized Computing*, 11, 3355–3369. https://doi.org/10.1007/s12652-019-01532-7.

Buhr, B. L., (2003). Traceability and information technology in the meat supply chain: implications for firm organization and market structure. *Journal of Food Distribution Research,* 34, 13–26. https://doi.org/10.22004/ag.econ.27057.

Buskirk, D., Schweihofer, J., Rowntree, J., Clarke, R., Grooms, D., & Fowler, T., (2013). A traceability model for beef product origin within a local institutional value chain. *Journal of Agriculture, Food Systems, and Community Development*, 3, 33–43. http://doi.org/10.5304/jafscd.2013.032.007.

Cao, S., Powell, W., Foth, M., Natanelov, V., Miller, T., & Dulleck, U., (2021). Strengthening consumer trust in beef supply chain traceability with a blockchain-based human-machine reconcile mechanism. *Computers and Electronics in Agriculture,* 180, 105886. https://doi.org/10.1016/j.compag.2020.105886.

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.

Cheraghi Saray, S., & Hosseinkhani, A., (2013). Selection indices in poultry breeding programs. *Kowsar Agricultural Research and Development Company*, 22, 93–105. In Persian.

Cheraghi Saray, S., & Rafat, S. A., (2012). Traceability of meat and livestock products. *Journal of Damparvaran,* 123, 35–38. In Persian.

Cheraghi Saray, S., & Rafat, S. A., (2016). Livestock identification and meat traceability. *Iranian Journal of Damdaran,* 191, 13–17. In Persian.

Cheraghi Saray, S., Hosseinkhani, A., Janmohammadi, H., Zare, P., & Daghighkia, H., (2014). Thermal and probiotic treatment effects on restaurant waste for incorporation into poultry diet. *International Journal of Recycling of Organic Waste in Agriculture*, 3, 1–7. https://doi.org/10.1007/s40093-014-0071-1.

Cheraghi Saray, S., Hosseinkhani, A., Taghizadeh, A., & Mohammadzadeh, H., (2019). Evaluation of co-aggregation and anti-adhesive effects of selenium nanoparticles and selected probiotic strains on clinical and standard strains of index pathogens. *Jundishapur Scientific Medical Journal*, 17, 583–595. https://doi.org/10.22118/jsmj.2019.85286.

Davoudi, S., Stasinopoulos, P., & Shiwakoti, N., (2024). Two Decades of Advancements in Cold Supply Chain Logistics for Reducing Food Waste: A Review with Focus on the Meat Industry. *Sustainability*, 16(16), 6986. https://doi.org/10.3390/su16166986.

De-Camargo, G. M. F., (2018). The role of molecular genetics in livestock production. *Animal Production Science*, 59, 201–206. https://doi.org/10.1071/AN18013.

Deng, M., & Feng, P., (2021). Research on a Traceability Scheme for a Grain Supply Chain. *Journal of Sensors,* 8860487, 1–9. https://doi.org/10.1155/2021/8860487.

Dumalisile, P., Manley, M., Hoffman, L., & Williams, P. J., (2020). Discriminating muscle type of selected game species using near infrared (NIR) spectroscopy. *Food Control*, 110, 106981. https://doi.org/10.1016/j.foodcont.2019.106981.

Ellahi, R. M., Wood, L. C., Khan, M., & Bekhit, A. E. D. A., (2025). Integrity Challenges in Halal Meat Supply Chain: Potential Industry 4.0 Technologies as Catalysts for Resolution. *Foods*, 14(7), 1135. https://doi.org/10.3390/foods14071135.

El-Sayed, A., El-Shannat, S., Kamel, M., Castaneda-Vazquez, M. A., & Castaneda-Vazquez, H., (2016). Molecular epidemiology of *Mycobacterium bovis* in humans and cattle. *Zoonoses and Public Health*, 63, 251–264. https://doi.org/10.1111/zph.12242.

Fan, L., Chen, Y., Zeng, Y., Yu, Z., Dong, Y., Li, D., Zhang, Ch., & Ye, Ch., (2024). Application of visual intelligent labels in the assessment of meat freshness. *Food Chemistry*, 140562. https://doi.org/10.1016/j.foodchem.2024.140562.

Fang, Z., Zhao, Y., Warner, R. D., & Johnson, S. K., (2017). Active and intelligent packaging in meat industry. *Trends in Food Science and Technology,* 61, 60–71. http://doi.org/10.1016/j.tifs.2017.01.002.

Farooq, U., Tao, W., Alfian, G., Kang, Y. S., & Rhee, J., (2016). ePedigree traceability system for the agricultural food supply chain to ensure consumer health. *Sustainability*, 8, 839. https://doi.org/10.3390/su8090839.

Focardi, R., Luccio, F. L., & Wahsheh, H. A., (2018). Security threats and solutions for two-dimensional barcodes: A comparative study. Computer and Network Security Essentials. Chapter 12, 207–219. https://doi.org/10.1007/978-3-319-58424-9_12.

Foster, T. P., Schweihofer, J. P., Grooms, D. L., Clarke, R. H., & Buskirk, D. D., (2018). Comparison of beef traceability in serial and parallel fabrication systems using RFID and two-dimensional barcodes. *Translational Animal Science*, 2, 101–110. https://doi.org/10.1093/tas/txx007.

Galvez, J. F., Mejuto, J. C., & Simal-Gandara, J., (2018). Future challenges on the use of blockchain for food traceability analysis. *Trends in Analytical Chemistry*, 107, 222–232. https://doi.org/10.1016/j.trac.2018.08.011.

Gao, J., Kulkarni, V., Ranavat, H., Chang, L., & Mei, H., (2009). A 2D barcode-based mobile payment system. 2009 Third International Conference on Multimedia and Ubiquitous Engineering. 320–329. https://doi.org/10.1109/MUE.2009.62.

Ghag, N., & Shedage, S., (2025). From farm to fork: Blockchain's impact on agri-food distribution, sourcing, and safety. *Journal of Foodservice Business Research*, 1–25. https://doi.org/10.1080/15378020.2025.2473175.

Ghosh, M., Sharma, N., Singh, A. K., Gera, M., Pulicherla, K. K., & Jeong, D. K., (2018). Transformation of animal genomics by next-generation sequencing technologies: a decade of challenges and their impact on genetic architecture. *Critical Reviews in Biotechnology,* 38, 1157–1175. https://doi.org/10.1080/07388551.2018.1451819.

Gil, M., Rudy, M., Duma-Kocan, P., & Stanisławczyk, R., (2025). Electronic Sensing Technologies in Food Quality Assessment: A Comprehensive Literature Review. *Applied Sciences*, 15(3), 1530. https://doi.org/10.3390/app15031530.

Hamishehkar, H., Ghasemzadeh, B., Naseri, A., Salehi, R., & Rasoulzadeh, F., (2015). Carbon dots preparation as a fluorescent sensing platform for highly efficient detection of Fe (III) ions in biological systems. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 150, 934–939. http://doi.org/10.1016/j.saa.2015.06.061.

Hamishehkar, H., Khani, S., Kashanian, S., Ezzati Nazhad Dolatabadi, J., & Eskandani, M., (2014). Geno-and cytotoxicity of propyl gallate food additive. Drug and Chemical Toxicology. 37, 241–246. https://doi.org/10.3109/01480545.2013.838776.

Han, J.W., Ruiz-Garcia, L., Qian, J. P., & Yang, X. T., (2018). Food packaging: A comprehensive review and future trends. *Comprehensive Reviews in Food Science and Food Safety,* 17, 860–877. https://doi.org/10.1111/1541-4337.12343.

Heaton, M. P., Keen, J.E., Clawson, M. L., Harhay, G. P., Bauer, N., Shultz, C., & Laegreid, W.W., (2005). Use of bovine single nucleotide polymorphism markers to verify sample tracking in beef processing. *Journal of the American Veterinary Medical Association*, 226, 1311–1314. https://doi.org/10.2460/javma.2005.226.1311.

Horcada, A., Valera, M., Juarez, M., & Fernandez-Cabanas, V. M., (2020). Authentication of Iberian pork official quality categories using a portable near infrared spectroscopy (NIRS) instrument. *Food Chemistry,* 318, 126471. https://doi.org/10.1016/j.foodchem.2020.126471.

Hosseinkhani, A., Valizadeh, R., Naserian, A., Mesgharan, M. D., & Shahroodi, F. E., (2007). Effect of alfalfa hay particle size and water addition to barely base diets on dairy cows performance in early lactation. *Journal of Animal and Veterinary Advances*, 6, 1482–1488.

Hrbek, V., Zdenkova, K., Jilkova, D., Cermakova, E., Jiru, M., Demnerova, K., & Hajslova, J., (2020). Authentication of meat and meat products using triacylglycerols profiling and by DNA analysis. *Foods*, 9, 1269. https://doi.org/10.3390/foods9091269.

Ismail, I., & Huda, N., (2024). Current Techniques and Technologies of Meat Quality Evaluation. In Hand Book of Processed Functional Meat Products (pp. 437–512). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-69868-2_17.

Jansen, W., Grabowski, N., Gerulat, B., & Klein, G., (2016). Food safety hazards and microbiological zoonoses in European meat imports detected in border inspection in the period 2008–2013. *Zoonoses and Public Health*, 63, 53–61. https://doi.org/10.1111/zph.12204.

Kademi, H. I., Ulusoy, B. H., & Hecer, C., (2019). Applications of miniaturized and portable near infrared spectroscopy (NIRS) for inspection and control of meat and meat products. *Food Reviews International*, 35, 201–220. https://doi.org/10.1080/87559129.2018.1514624.

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.

Levings, R. L., (2012). Emerging and exotic zoonotic disease preparedness and response in the United States–coordination of the animal health component. *Zoonoses and Public Health,* 59, 80–94. https://doi.org/10.1111/j.1863-2378.2012.01495.x.

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. https://doi.org/10.1016/j.tifs.2024.104384.

Li, T.T., Jalbani, Y. M., Zhang, G. L., Zhao, Z. Y., Wang, Z. Y., Zhao, X. Y., & Chen, A. L., (2019). Detection of goat meat adulteration by real-time PCR based on a reference primer. *Food Chemistry,* 277, 554–557. https://doi.org/10.1016/j.foodchem.2018.11.009.

Monahan, F. J., Schmidt, O. & Moloney, A. P., (2018). Meat provenance: Authentication of geographical origin and dietary background of meat. *Meat Science,* 144, 2–14. https://doi.org/10.1016/j.meatsci.2018.05.008.

Morcia, C., Tumino, G., Ghizzoni, R., & Terzi, V., (2016). Effective use of food traceability in animal feed. *Advances in Food Traceability Techniques and Technologies,* 353–363. https://doi.org/10.1016/B978-0-08-100310-7.00019-3.

Nastasijevic, I., Kundacina, I., Jaric, S., Pavlovic, Z., Radovic, M. & Radonic, V., (2025). Recent Advances in Biosensor Technologies for Meat Production Chain. *Foods*, 14(5), 744. https://doi.org/10.3390/foods14050744.

Naveena, B. M., Jagadeesh, D. S., Kamuni, V., Muthukumar, M., Kulkarni, V. V., Kiran, M., & Rapole, S., (2018). In-gel and OFFGEL-based proteomic approach for authentication of meat species from minced meat and meat products. *Journal of the Science of Food and Agriculture,* 98, 1188–1196. https://doi.org/10.1002/jsfa.8572.

Odeyemi, O. A., Alegbeleye, O. O., Strateva, M. & Stratev, D., (2020). Understanding spoilage microbial community and spoilage mechanisms in foods of animal origin. *Comprehensive Reviews in Food Science and Food Safety*, 19, 311–331. https://doi.org/10.1111/1541-4337.12526.

Prache, S., Cornu, A., Berdague, J. L. & Priolo, A., (2005). Traceability of animal feeding diet in the meat and milk of small ruminants. *Small Ruminant Research,* 59, 157–168. https://doi.org/10.1016/j.smallrumres.2005.05.004.

Prache, S., Martin, B. & Coppa, M., (2020). Authentication of grass-fed meat and dairy products from cattle and sheep. *Animal*, 14, 854–863. https://doi.org/10.1017/S1751731119002568.

Probst, C., Gethmann, J. M., Heuser, R., Niemann, H. & Conraths, F. J., (2013). Direct costs of bovine spongiform encephalopathy control measures in Germany. *Zoonoses and Public Health*, 60, 577–595. https://doi.org/10.1111/zph.12032.

Qian, J., Dai, B., Wang, B., Zha, Y. & Song, Q., (2020a). Traceability in food processing: problems, methods, and performance evaluations—a review. *Critical Reviews in Food Science and Nutrition,* 1–14. https://doi.org/10.1080/10408398.2020.1825925.

Qian, J., Ruiz-Garcia, L., Fan, B., Villalba, J. I. R., McCarthy, U., Zhang, B. & Wu, W., (2020b). Food traceability system from governmental, corporate, and consumer perspectives in the European Union and China: A comparative review. *Trends in Food Science and Technology*, 99, 402–412. https://doi.org/10.1016/j.tifs.2020.03.025.

Qiao, J., Hao, M. & Guo, M., (2023). Design of meat product safety information chain traceability system based on UHF RFID. *Sensors*, 23, 3372. https://doi.org/10.3390/s23073372.

Romanenko, G. A., (2017). Genetic resources of plants, animals, and microorganisms as the basis for basic agricultural research. *Herald of the Russian Academy of Sciences*, 87, 101–103. https://doi.org/10.1134/S1019331617020149

Salih, S. M., (2017). Authenticity and quality of muscle foods: Assessing consumer trust and fraud detection approaches. Doctoral dissertation, University of Plymouth.

Sargeant, J. M., Ramsingh, B., Wilkins, A., Travis, R.G., Gavrus, D. & Snelgrove, J. W., (2007). Constraints to microbial food safety policy: opinions from stakeholder groups along the farm to fork continuum. *Zoonoses and Public Health,* 54, 177–184. https://doi.org/10.1111/j.1863-2378.2007.01042.x.

Shackell, G. H., (2008). Traceability in the meat industry–the farm to plate continuum. *International Journal of Food Science and Technology,* 43, 2134–2142. https://doi.org/10.1111/j.1365-2621.2008.01812.x.

Singh, P. K., Agrawal, N. & Suman, S., (2025). Practices for Healthier Meat and Meat Products. In: Kumar Pathera, A., Kumar, H., Yadav, S. (eds) Healthier Meat Products. Springer, Cham. https://doi.org/10.1007/978-3-031-78215-2_2.

Smith, G. C., Pendell, D. L., Tatum, J. D., Belk, K. E. & Sofos, J. N., (2008). Post-slaughter traceability. *Meat Science*, 80, 66–74. https://doi.org/10.1016/j.meatsci.2008.05.024.

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.

Thakur, M. & Foras, E., (2015). EPCIS based online temperature monitoring and traceability in a cold meat chain. *Computers and Electronics in Agriculture*, 117, 22–30. http://doi.org/10.1016/j.compag.2015.07.006.

Thakur, M., Tveit, G. M., Vevle, G. & Yurt, T., (2020). A framework for traceability of hides for improved supply chain coordination. *Computers and Electronics in Agriculture*, 174, 105478. https://doi.org/10.1016/j.compag.2020.105478.

Thesmar, H. S. & Stevens, S. K., (2019). Meat and poultry traceability–its history and continuing challenges. Food Traceability, Food Microbiology and Food Safety, Chapter 6, 71–80. https://doi.org/10.1007/978-3-030-10902-8_6.

Urbano, O., Perles, A., Pedraza, C., Rubio-Arraez, S., Castello, M. L., Ortola, M. D. & Mercado, R., (2020). Cost-effective implementation of a temperature traceability system based on smart RFID Tags and IoT services. Sensors. 20, 1163. https://doi.org/10.3390/s20041163.

Vander-Merwe, M. & Kirsten, J. F., (2015). Traceability systems and originbased meat products in the South African sheep meat industry. *Agrekon*, 54, 53–69. https://doi.org/10.1080/03031853.2015.1019524.

Velandia, D. M. S., Kaur, N., Whittow, W. G., Conway, P. P. & West, A. A., (2016). Towards industrial internet of things: Crankshaft monitoring, traceability and tracking using RFID. *Robotics and Computer-Integrated Manufacturing,* 41, 66–77. http://doi.org/10.1016/j.rcim.2016.02.004.

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, 2764. http://doi.org/10.3390/ijerph15122764.

Wang, J., Zhang, M., Gao, Z. & Adhikari, B., (2017). Smart storage technologies applied to fresh foods: A review. *Critical Reviews in Food Science and Nutrition*, 58, 2689–2699. http://doi.org/10.1080/10408398.2017.1323722.

Yan, C., Huanhuan, F., Ablikim, B., Zheng, G., Xiaoshuan, Z. & Jun, L., (2018). Traceability information modeling and system implementation in Chinese domestic sheep meat supply chains. *Journal of Food Process Engineering,* 41, e12864. http://doi.org/10.1111/jfpe.12864.

Yiying, Z., Yuanlong, R., Fei, L., Jing, S. & Song, L., (2019). Research on meat food traceability system based on RFID technology. 2019 IEEE 3rd Information Technology, Networking, Electronic and Automation Control Conference (ITNEC). 2172–2175. http://doi.org/10.1109/ITNEC.2019.8729408.

Zare, P., Choboghlo H.G., Jaberi S., Razzaghi S., Mirzae M. & Mafuni, K., (2014). Occurrence and antimicrobial resistance of *Salmonella spp* and *Escherichia coli* isolates in apparently healthy slaughtered cattle, sheep and goats in East Azarbaijan province. *International Journal of Enteric Pathogens*, 2, e15451. http://doi.org/10.17795/ijep15451.

Zare, P., Choboghlo, H.G., Tolouei, M. & Hadavi, J., (2016). Evaluation of the occurrence of Salmonella serovars and its Antibiotic Susceptibility in Apparently Healthy domestic animals in rural areas of East Azerbaijan province. *Iranian Journal of Medical Microbiology,* 10, 88–92.

Zhang, A., Mankad, A. & Ariyawardana, A., (2020). Establishing confidence in food safety: is traceability a solution in consumers' eyes. *Journal of Consumer Protection and Food Safety*, 15, 99–107. http://doi.org/10.1007/s00003-020-01277-y.

Zhang, J., Tian, G. Y., Marindra, A. M., Sunny, A. I., & Zhao, A. B., (2017). A review of passive RFID tag antenna-based sensors and systems for structural health monitoring applications. *Sensors,* 17, 265. http://doi.org/10.3390/s17020265.

Zhao, J., Li, A., Jin, X. & Pan, L., (2020). Technologies in individual animal identification and meat products traceability. *Biotechnology and Biotechnological Equipment,* 34, 48–57. https://doi.org/10.1080/13102818.2019.1711185.

Zhao, J., Xu, Z., You, X., Zhao, Y., He, W., Zhao, L. & Yang, S., (2019). Genetic traceability practices in a large-size beef company in China. *Food Chemistry*, 277, 222–228. https://doi.org/10.1016/j.foodchem.2018.10.007.

Zhao, J., Zhu, C., Xu, Z., Jiang, X., Yang, S. & Chen, A., (2017). Microsatellite markers for animal identification and meat traceability of six beef cattle breeds in the Chinese market. *Food Control*, 78, 469–475. http://doi.org/10.1016/j.foodcont.2017.03.017.

Zhao, Y. & Cao, N., (2017). Research on traceability of agricultural products based on internet of things. 2017 IEEE International Conference on Computational Science and Engineering (CSE) and IEEE International Conference on Embedded and Ubiquitous Computing (EUC). 414–417. http://doi.org/10.1109/CSE-EUC.2017.264.

Zhen, Y. A. N., Huang, Z. H., Yu, W. A. N. G. & Zhou, J. H., (2019). Are social embeddedness associated with food risk perception under media coverage? *Journal of Integrative Agriculture,* 18, 1804–1819, https://doi.org/10.1016/S2095-3119(19)62586-4.

Authors info

Sadegh Cheraghi Saray https://orcid.org/0000-0001-5924-1544
Ali Hosseinkhani https://orcid.org/0000-0001-5553-8404
Seyed Abbas Rafat https://orcid.org/0000-0003-0231-1331
Hamed Hamishehkar https://orcid.org/0000-0001-9905-0662
Peyman Zare https://orcid.org/0000-0003-1291-1808