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How does traceability support stakeholders in food recall management? A case study of the beef chain

Como a rastreabilidade auxilia os stakeholders na gestão de um recall de alimentos? Um estudo de caso da cadeia da carne bovina

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Abstract: Complex food supply chains face increasing risks that can affect product quality and safety, which can all lead to recalls. This paper analyzes the role that traceability plays in the different stages of beef recall management. A case study was conducted in two beef supply chains and stakeholders from these chains were interviewed. Content analysis was performed using QDA Miner software. The results are summarized into a framework that describes the role of traceability before, during, and after a recall. In total, 18 roles were identified, including reevaluating partnerships with suppliers. Some of these results had not previously been discussed in the literature. The findings indicate that both the target market segment and company size are key factors influencing the level of investment in traceability. Traceability is an increasingly essential aspect of the beef supply chain, yet empirical studies exploring this from various levels and stakeholder perspectives are limited. This study provides insights for professionals in the food supply chain helping them understand the various roles that food traceability plays in managing potential recalls.

Keywords: Traceability; Recall; Food supply chain; Beef Industry.

Resumo: *As cadeias de suprimento de alimentos têm se tornado cada vez mais complexas e enfrentam riscos crescentes que podem afetar a qualidade e a segurança do produto, o que pode levar a recalls. Este artigo analisa o papel que a rastreabilidade desempenha nos diferentes estágios da gestão de recalls de carne bovina. Foi realizado um estudo de caso em duas cadeias de suprimentos de carne bovina, e stakeholders de ambas as cadeias foram entrevistados. A análise de conteúdo foi realizada usando o software QDA Miner. Os resultados estão sintetizados em um framework que descreve o papel da rastreabilidade antes, durante e depois de um recall. No total, foram identificados 18 papéis, incluindo a reavaliação de parcerias com fornecedores. Alguns destes resultados não haviam sido discutidos anteriormente na literatura. As descobertas indicam que tanto o segmento de mercado-alvo quanto o tamanho da empresa são fatores-chave que influenciam o nível de investimento das empresas em rastreabilidade. A rastreabilidade é*

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um aspecto cada vez mais essencial da cadeia de suprimentos de carne bovina, mas os estudos empíricos que exploram esse aspecto a partir de vários níveis e perspectivas dos stakeholders são limitados. Este estudo fornece insights para profissionais da cadeia de suprimentos de alimentos, ajudando-os a entender os vários papéis que a rastreabilidade de alimentos desempenha na gestão de possíveis recalls.

Palavras-chave: *Rastreabilidade*; *Recall*; *Cadeia de suprimentos de alimentos*; *Indústria de carne bovina.*

1 Introduction

The increasing globalization of the food supply chain presents challenges in ensuring the safety and quality of products sent to market. One of these challenges is related to the need to transport raw or processed food over long distances, which increases the likelihood of contamination (Rodrigues et al., 2019) and introduces risks and vulnerabilities in the supply chain. Furthermore, managing this is challenging due to the complex network of suppliers, processors, distributors, retailers, and other key players (Kumar et al., 2022). Consequently, these risks, which can be propagated throughout the supply chain by different stakeholders, may result in failures in food quality standards and could mean product recalls may be necessary (Chaudhuri et al., 2016).

A recall is when a specific lot of products is taken off the market to protect consumers from potential health risks (Bernon et al., 2018), and it is a fundamental procedure in risk management for cases of food safety failures (FAO, 2012). A recall can either be voluntary (when a company itself identifies a problem, whereby a food processor will actively take defective products off the market) or mandatory (recalls given external pressure from the public, media, or government) (Yu et al., 2023). The effects of a recall can be significantly detrimental to companies that experience it, as well as to their supply chain partners (Bernon et al., 2018). For instance, when consumers identify a potential health risk from food of questionable quality, they can lose trust in the company, which can, in turn, lead to reduced sales and profits (Kumar et al., 2015).

Given this context, food traceability is crucial in ensuring food safety throughout the supply chain (Yu et al., 2022). Traceability, as defined by the *Codex Alimentarius*, is "[…] the ability to follow the movement of a food through specified stage(s) of production, processing and distribution […] " (FAO, 2006, p. 1). It aids in pinpointing when and where failures occur (Kumar, 2014). Moreover, it is a proactive strategy for managing product safety (Kumar et al., 2015) and promoting transparency within the supply chain. In food supply chains, this transparency not only influences product acceptance but also builds trust among consumers (Kodan et al., 2019) as stakeholders gain insights into the flow of goods via shared access to information about products and processes (Aung & Chang, 2014).

In the context of the Brazilian beef industry, traceability is a mandatory requirement for meat exporting companies, particularly for those exporting to the European Union (Klein et al., 2014). To fulfill these requirements, the Ministry of Agriculture, Livestock, and Supply (MAPA) established the Brazilian System for Identifying and Certifying Products of Animal Origin (SISBOV). This system sets standards and procedures for cattle and buffalo production in Brazil. Adoption is voluntary for cattle sold in the Brazilian domestic market, but is mandatory when products are sold in external markets that demand traceability (Brasil, 2023).

It has been observed that food chains often lack traceability and transparency (Yu et al., 2022). With the recent increase in deforestation and forest fires in Brazil, traceability has become increasingly relevant for stakeholders in the beef industry, particularly for end consumers (Burnier et al., 2021). Consumers are increasingly concerned about consuming sustainable products and the possibility of track and trace product origin is highlighted. Brazil is the world's second-largest producer and the largest beef exporter (ABIEC, 2022). Yet, there is a lack of comprehensive research on traceability within this sector that also considers various stakeholder levels in the supply chain. Most of the recent research on recalls tends to omit specific stakeholders, e.g., suppliers, and pays less attention to phases before and during recalls, compared to the post-recall phase (Li et al., 2022). Furthermore, there is a gap in the literature regarding empirical research on the role of traceability in different phases of food recalls. For these reasons, this study has set forth the following research question:

What is the role of traceability in the different phases of beef recall management?

2 Literature review

2.1 *The role of traceability in food recall management*

To address the role of traceability in food recall management, this paper sought to examine the effectiveness of traceability across three phases, as outlined by Li et al. (2022), i.e., before, during, and after recalls (see Table 1). This study served as the foundation for coding the gathered data.

Table 1. The role of traceability in food recall phases.

Recall Phases	The role of traceability	Authors
Before the recall	▪ Recording information related to originating, raw material sourcing, processing, storing, and lot	Hu et al. (2009), Thakur et al. (2011), Bosona & Gebresenbet (2013)
	▪ Identifying non-conformities	Charlebois & Haratifar (2015), Tang et al. (2015)
	▪ Reducing food fraud	Charlebois & Haratifar (2015)
	▪ Containing problems before they enter the distribution channel	Zhou et al. (2022)
	▪ Controlling and assuring quality	Wang et al. (2017), Tsang et al. (2019)
	▪ Simulating recalls	Stanisławek et al. (2021)
During the recall	▪ Identifying affected lots	Kelepouris et al. (2007), Klein et al. (2014), Mededjel et al. (2017)
	▪ Minimizing the scope of recalls	Klein et al. (2014), Lin et al. (2020)
	▪ Recalling quickly	Ringsberg & Mirzabeiki (2014), Hall & Johnson-Hall (2021)
	▪ Reducing costs	Kelepouris et al. (2007)
	▪ Limiting consumer exposure to hazardous foods	Adam et al. (2016)
After the recall	▪ Identifying the source of contamination	Bhatt et al. (2013), Yu et al. (2022)
	▪ Identifying the root cause of recall	Bhatt et al. (2013)
	▪ Gathering information to enhance processes and liability	Skilton & Robinson (2009), Piramuthu et al. (2013)

Author’s compilation.

2.1.1 Before the recall

According to Tsang et al. (2019), the purpose of a traceability system goes beyond monitoring and tracking items along the supply chain, as it also enhances the proactive functions of quality controls and assurances. This aids in identifying risks and exposes vulnerabilities in the chain that might have previously gone unnoticed (Hall & Johnson-Hall, 2021). Documenting and establishing information systems related to processed, repackaged, or distributed products can allow companies to assess food safety risks more effectively (Hall & Johnson-Hall, 2021). By embracing traceability, the food processing industry can promptly address quality issues before products enter the distribution chain, thus preventing recalls and minimizing associated economic losses (Zhou et al., 2022).

Charlebois & Haratifar (2015) state that traceability, when viewed from the perspective of the entire food chain, contributes to reducing food fraud and counterfeits. Traceability tools can help prevent or eliminate illegal, undeclared, and unregulated products by tracking their history, processing, and locations using authentication technologies, often combined with identification methods throughout the supply chain. Additionally, Stanisławek et al. (2021) highlight the manufacturer's responsibility in carrying out product traceability and recall tests to ensure that personnel are trained and prepared for emergencies, thereby improving internal processes.

The traceability system proposed by Wang et al. (2017), which is based on fuzzy logic and neural networks, can assess food quality at each stage of the chain, and support quality management, thereby enhancing transparency within the chain. The early detection of quality risks can aid in preventing food-safety-related incidents, preserving reputations, and identifying those responsible for failures.

In a study of a Chinese food factory, Hu et al. (2009) found that, to swiftly and accurately recall defective products, recorded information on raw materials and processes must be error-free. Thakur et al. (2011) also emphasize the need to link information from outgoing lots (shipments) to incoming lots to address emergency food safety situations promptly. Other pertinent details that traceability systems should document to assist in recall management includes the origins and types of food/feed, ingredients, authenticity, species, and age (for animal origin products); processes at all stages of the supply chain (primary production, processing, testing, storage, distribution, retail, and consumption); and any resources used (people, machinery, and transportation equipment) (Bosona & Gebresenbet, 2013).

2.1.2 During the recall

In the event of a food recall, a robust traceability system can allow managers to identify the distribution path taken by the contaminated products, track delivery trucks, and even pinpoint the stores and shelves where they are displayed (Mededjel et al., 2017). For instance, Klein et al. (2014) reported that during an "mad cow disease outbreak," traceability played a crucial role in identifying the specific lot and farm of the contaminated products, allowing them to isolate the problem. This highlights how traceability facilitates effective product recalls and provides precise information to stakeholders (Tang et al., 2015).

A comprehensive traceability system throughout the entire supply chain can, therefore, mitigate consumer exposure to potentially hazardous food (Adam et al., 2016). A study by Hall & Johnson-Hall (2021) showed that companies with downstream traceability carry out recall procedures 55% faster, reducing the aforementioned risks associated with consumer exposure. The reduction in the time it takes for contaminated food to be identified during recalls was also observed by stakeholders in a study by Ringsberg & Mirzabeiki (2014), who developed a traceability system based on RFID and Electronic Product Code Information Services (EPCIS). Lin et al. (2020) further emphasized that Blockchain can allow purchasing managers to monitor all online information in real-time, pinpointing individual contaminated products without the need to recall all the associated products. Kelepouris et al. (2007) add that a traceability information system can reduce recall costs since precise identification of recalled product lots reduces expenses related to lost sales, product disposals, and damage to the company's reputation.

2.1.3 After the recall

Bhatt et al. (2013) emphasize that an investigation based on upstream traceability involves documenting the distribution paths of products from different locations to ascertain if there is a point of convergence in the chain, e.g., an expected date and location of the harvest or processing. This is a crucial factor in conducting a source investigation to determine the cause of contamination and to prevent future illnesses.

For those involved in producing and processing goods, traceability serves as a cost-effective quality management system that can aid in continuous improvements and reduce the impacts of safety-related risks (Aung & Chang, 2014). According to Kumar (2014), after a recall has been completed, companies should evaluate the process and seek out solutions to mitigate future recalls. To this end, as defects or adverse events occur in processes, traceability is used to uncover the underlying causes of these variations, potentially leading to the development of improved controls or processes (Skilton & Robinson, 2009).

Additionally, as stated by Piramuthu et al. (2013), the choice of the level of traceability and the technology involved not only entails costs but also affects the division of responsibility among different members of the supply chain. In this regard, the authors also define "responsibility" as a cost incurred when contamination is detected. Therefore, identifying the source of contamination facilitates isolating it and correcting the cause of the failure. Once it has been identified, the party responsible for the contamination can cover the costs of recalling the product.

Lastly, Adam et al. (2016) argue that Big Data Analytics, which spans the entire supply chain and is applied to traceability systems, can link data from various production and processing stages to consumer data, thereby creating a vast repository. Analytical algorithms can leverage this data to establish an early detection system for animal diseases, food safety issues, and bioterrorism. Furthermore, it can be employed to predict, group, associate, correlate, classify, and optimize food-related diseases. This leads to more informed and faster decision-making.

3 Method

3.1 Design and approach of the study

This study is exploratory since we observed that the literature has not fully explored the role of traceability relative to a recall event within a specific chain. Additionally, the results of the structured literature review have allowed us to identify the primary roles of traceability in the various phases of food recall management. Consequently, the case study method was selected since it emphasizes the timeliness of the study concerning traceability and recalls, while also incorporating various sources of evidence, including interviews, site visits, and documentation (Barratt et al., 2011).

3.2 Case selection

The meat sector is a relevant industry for study, given that its products and derivatives are widely consumed both in Brazil and internationally. Moreover, Brazil is the world's second-largest meat producer, accounting for 13.66% of global production, behind only the United States, with a 17.87% share of global production. Brazil is also the largest beef exporter, with China serving as the primary destination for fresh meat, with the United States, the United Kingdom, and the European Union all importing processed meat to a lesser extent (ABIEC, 2022).

In Brazil, Resolution RDC 655/2022 is currently in effect, which governs food recalls in the country. Recalls must be communicated to the National Health Surveillance Agency (Brasil, 2022). The regulations outline food sector companies' actions when identifying a risk that may necessitate a recall. All companies must publish their Product Recall Plans to employees and health authorities. Additionally, the resolution mandates that food companies keep traceability records on the origins and destinations of their products throughout the entire supply chain, to ensure efficient food recalls when necessary. These parameters align with the traceability objectives outlined for recall management by FAO/WHO (FAO, 2012). Finally, both ANVISA and consumers must be immediately notified in the event of any threat that may pose a risk to consumer health, thus warranting a recall. The agency also holds full authority over ordering mandatory recalls (Brasil, 2022).

Much like other food supply chains, the beef chain has faced challenges related to traceability for reasons concerning quality, health, and more recently, concerns regarding environmental and social sustainability risks (OECD, 2020). We recognized an opportunity to deepen our understanding of recalls, with a focus on the role of traceability, and therefore sought to examine the perspectives of various stakeholders within the beef food chain, starting with beef processors (as the primary companies of interest) that have undergone recall incidents, and to connect them with their raw material suppliers and retail customers.

To do this, we selected a company (B1) that underwent a voluntary recall of its products. Since we could not access a second company that had also undergone a recall, we sought out a company that was recognized for its beef exports and made use of traceability technology (B2). The unit of analysis was the tracking processes (including collections, storage, and information exchanges) that occur before, during, or after a food recall, in processing industries that have:

1) undergone a mandatory or voluntary recall; and
2) have implemented activities and traceability processes to prevent future recall events.

B1 is a Brazilian-national family-owned company that started its operations in 2013, specializing in cattle breeding and genetic development. This company exclusively serves the domestic Brazilian market, with its primary customers consisting of supermarket chains, restaurants, and third-party brands. B1 experienced a voluntary recall due to the discovery of allergens in its products, brought to light by adverse reactions reported by several customers. Upon investigation, they determined that the issue stemmed from an antioxidant formulation used in the sausage line. The company successfully recalled approximately 85% of the affected products within three months of identifying the problem.

B1 employs a logistics operator located in the capital of São Paulo. With over 20 years of experience in the market, this logistics company operates within a cross-docking system. All products manufactured at B1 are sent to this central hub, from which all customer deliveries originate. We contacted them to gain insights into the communication processes between B1 and the logistics operator to better understand the operator's involvement in the B1 recall case.

By contrast, B2 is one of the largest meat exporters in all of South America. It markets products to over one hundred countries and operates multiple units spread across Brazil. The specific plant we analyzed is one of a dozen operations in Brazil, with more than another dozen distribution centers and slaughterhouses operating throughout South America to export markets worldwide.

Following interviews conducted at both companies, we sought out contact with suppliers, distributors, and retailers. To do this, we employed the snowball technique by requesting recommendations and additional contacts for data collection, furthering the research process. We decided to interview beef suppliers of both companies, i.e., two cattle suppliers. Cattle Farmer A also happens to be the owner of B1, exclusively supplying meat to this beef processor. Their company specializes in a specific cattle breed with a higher market value. By contrast, Cattle Farmer B supplies beef to both B1 and B2. The retailer we interviewed ranks among the top ten largest food retail chains, operating in various regions of Brazil and offering multiple store formats. These stores sell beef and other meats. At their points of sale, the retailer offers pre-packaged products of either the manufacturer's brand or its own, along with products that can be custom-cut in front of consumers.

In addition to speaking with livestock farmers, beef processors, logistics operators, and retailers, we also conducted interviews with companies specializing in Information Technology across various segments of the meat supply chain and also interviewed certifiers, government agency representatives, and researchers within the beef industry. It's worth noting that both beef processors serve the retail sector, while Cattle Farmer B supplies meat to both B1 and B2. Figure 1 summarizes the structure and arrangement of these cases.

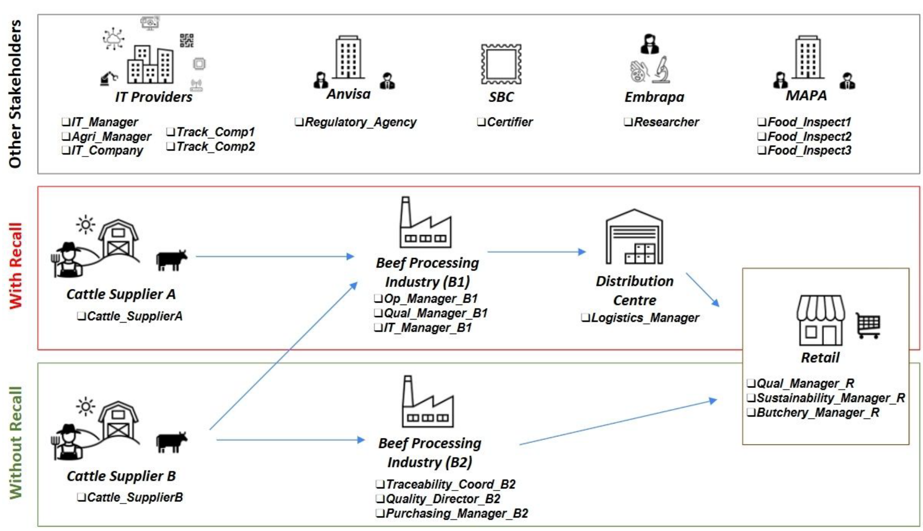

Figure 1. Case structure and arrangement between agents in the chain and interviewees. Authors' work.

3.3 Data collection and analysis

Due to the health restrictions imposed by the COVID-19 pandemic during the data collection phase of this study, the interviews were conducted via videoconference. We sought to gather data from multiple sources, following a strategy of data triangulation. Three primary sources of evidence were used: on-site visits, semi-structured interviews, and document/report analysis obtained from government agencies and websites of the selected companies. We also examined internal documents and reports provided by these companies. In total, 23 interviews were conducted (see Figure 1 for further details).

Building upon the literature from the initial review, the empirical research data were subjected to content analysis using the QDA Miner software. This analysis involved creating mutually exclusive and exhaustive categories, following the approach outlined by Krippendorff (2013). Co-occurrence analysis, also performed in QDA Miner (2023), was employed to identify instances where codes were in close proximity to each other, or occurred together. This analysis allowed us to identify the relationships between the codes and cases, ultimately facilitating the grouping of the traceability roles observed in the case study (see Figure 2).

4 Results and discussion

Figure 2 shows the relationships for traceability roles in the various phases of recall management. It is important to note that the size of the bubbles corresponds to the frequency of coding for each role (i.e., how often it was mentioned in interviews), while the color of the bubbles represents groupings generated by the software itself, guided by similarities and the collective discussion of these themes. In total, the case study identified 18 traceability roles in recall management, which were categorized into five groups.

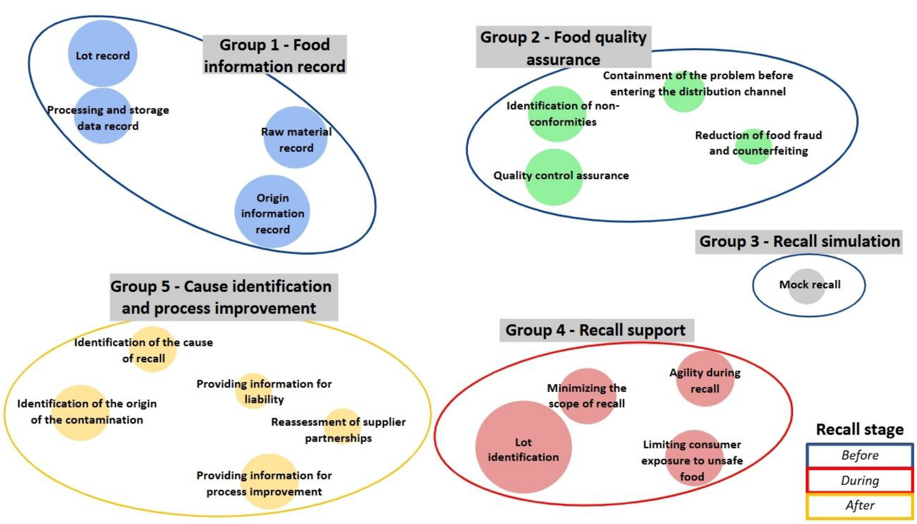

Figure 2. Traceability co-occurrence analysis in the recall phases.
Author’s analyses based on the interviewees' opinions.

In the upper portion of Figure 2, one can see the first three groupings, which pertain to the role of traceability **before** a recall event takes place. Regarding the cattle chain studied here, **the food information record** (Group 1) encompasses all details provided by the livestock farmer, including names, addresses, type of food provided, slaughter information, health records, and medication usage. From the perspective of food processing companies, "*it is crucial to have information about the animal, slaughter date, carcass expiration date, and other essential details to ensure proper processing before receiving the carcasses*" [Qual_Manager_B1].

Information recording within companies B1 and B2 is facilitated using an ERP system, which correlates data with product lots. As discussed in the literature (Ringsberg, 2014), it is evident that employees at these processing companies are already aware of the need to trace their products to mitigate potential impacts stemming from recalls. "*Prior to a recall, significant effort is given to building a database to ensure traceability. This means that, if we need to locate an item to address any issues, this database is readily accessible*" [IT_Manager_B1].

Group 2 focuses on the role of traceability in **quality control and assurance**, specifically for preventing recalls. During this phase, traceability aids quality assurance teams at meat processing companies in monitoring various parameters, e.g., temperature and other food-related information. As a result, "*prior to a recall, I check what the control actions carried out by the quality personnel are, as they continuously monitor temperature, water quality, carcass pH, and sanitary conditions*" [IT_Manager_B1]. This is also emphasized by government regulatory bodies, which scrutinize and request information from the traceability systems of meat processors. During inspections, a range of factors is assessed, including "*water supply, pH levels, chlorine content, adherence to good manufacturing practices, and compliance with Standard Operating Hygiene Procedures..."* [Food_Inspect2], following established protocols.

At B1, the receiving team is responsible for scrutinizing incoming carcasses and verifying the requisite traceability information for **cases of non-conformities**. For instance, if a carcass lacks essential details e.g., "*slaughter date, expiration date, and SIF mark, the product will not be accepted, and we assume responsibility for it. While our ERP system provides support for traceability, there is still room for improvement*" [Qual_Manager_B1]. Moreover, regulatory bodies may randomly select food companies for inspections, collecting samples for chemical, physical, and microbiological analyses. Consequently, "*if any deviations or non-conformities are detected, it triggers a recall of products from the sampled lot*" [Food_Inspect1]. Traceability can also **contain issues before contaminated food enters distribution channels**, to "*prevent deviations from spreading to other parts of the chain and reaching consumers*" [Food_Inspect1].

In instances where inspections uncover deviations or signs of fraud, inspectors initiate product collection procedures to prevent these issues from propagating further down the supply chain. At this stage, the need to "*ensure that the company can provide a comprehensive history of the product*" [Regulatory_Agency]. It's worth noting that Brazilian food processing companies are required to develop Self-Control Programs (PACs) that encompass traceability and recall program specifications. Consequently, traceability plays a crucial role in **reducing food fraud and counterfeiting** by tracking these products throughout the supply chain (Charlebois & Haratifar, 2015).

Group 3 focuses on the role of traceability in conducting **recall simulations**. B2 conducts product recall simulations every six months as part of its self-control procedures. Initially, the simulated recall's class is determined (Grade I, II, or III). Subsequently, the B2 risk management committee is informed, and they coordinate with the commercial department to initiate actions for identifying the affected merchandise and initiating collections from sales points. Traceability plays a crucial role in tracking these products across the distribution chain during recall simulations, aimed at testing the company's traceability systems. This practice helps ensure preparedness in the event of an actual recall, emphasizing personnel training and readiness (Stanisławek et al., 2021). After a simulation is concluded, its effectiveness is assessed. Unlike B2, B1 does not conduct recall simulations, despite experiencing recurrent recalls. This underscores the varying maturity levels of quality and recall prevention systems between the two companies.

As shown in Group 4, traceability plays a vital role in facilitating a more efficient recall process in the event of an actual recall. Special attention is given to **identifying** affected lots, with support from ERP and cloud computing software, as was the case for B1's recall. Upon receiving reports of recurring customer complaints about specific sausage lots, B1 promptly alerted the logistics operator and retailers to separate the affected lots, preventing them from being sold. Since many of these products were still being held by the logistics operator, they were separated after B1 informed them of the situation via telephone and email.

Traceability also plays a crucial role in speeding up the recall process. According to some retailers, when they have the product in their possession, the focus shifts to "*promptly identifying non-conforming lots in their inventory systems, so they can issue recall alerts quickly and accurately*" [Purchasing_Manager_B2]. Certain technologies, like QR Codes on shipping boxes, assist retailers in identifying the units where food was distributed. As mentioned in the interviews, some retailers employ product barcode blocking, preventing recalled items from being sold.

Group 5 deals with **post-recall** traceability functions, centered on identifying contamination sources and supporting improvement measures. In the case of B1, which conducted a voluntary recall, traceability played a crucial role in pinpointing product lots, facilitating investigations into the suppliers of its ingredients. During this process, they were able to identify the supplier responsible for the antioxidant used in the sausages. Subsequent discussions with the supplier revealed that the lot of raw materials had a formulation error that had led to allergic reactions. By using its traceability system to **identify the cause of the recall**, B1 revamped its operations and ingredients, opting for a line of more natural ingredients.

Regarding the role of traceability in **process improvements** at B1, it is worth highlighting that once the recalled food is retrieved and returned to the facility, it is placed in a warehouse with a non-conformity registration number. At this stage, the quality department conducts inspections on the products, and each new non-conformity code triggers the creation of new action plans. These plans seek to minimize the likelihood of similar situations in the future. In the post-recall phase, the traceability system is once again employed to analyze the root causes of the failures and generate non-conformity reports (Skilton & Robinson, 2009). This practice exemplifies traceability used to enhance processes in the event of a recall.

The investigation conducted by B1 held the condiment supplier **accountable for the financial losses incurred due to the recall**. Compensation was determined based on lost sales stemming from discarded product volumes. However, this compensation amount was paid for as a credit towards future purchases, which was not the preferred outcome for B1. As a result, the company reevaluated its partnership with this supplier and began importing natural chemical-free condiments to mitigate the risk of another recall. Similarly, following a recall incident, retailers must also pay close attention to the traceability standards offered by their suppliers. This vigilance is essential for safeguarding both consumer health and the brand's reputation. Up to now, the existing literature base has not identified this perspective within the retail vs. industry dynamic, underscoring the importance of understanding stakeholders from a multilevel perspective within the chain.

In addition to the insights offered by the retail and beef processing companies, Cattle Farmer B provided an example of a recall event that occurred several years ago. This recall resulted from incorrect animal vaccination, leading to abscesses in cuts of sirloin.

When the recall was started, they were able to "*identify the issue, and using traceability, we traced it back to the producer who had incorrectly administered the vaccinations*" [Cattle_SupplierB]. Thus, traceability serves as a vital tool for **identifying the root causes of problems**, or in extreme cases, potential food contaminations, and serves as the foundation for decision-making aimed at process improvements. In this particular case, it led to enhanced training to ensure that vaccinations were correctly administered.

5 Cross-case analysis and proposed framework

A comparative analysis of B1 and B2 shows that the market segment they serve and their respective company sizes play a crucial role in determining their level of investment in traceability and food quality processes. B1, as a smaller company with a focus on the domestic market, experiences recurrent recalls. By contrast, B2, a large company and a leading beef exporter in South America, shows no recurrent history of recalls.

Unlike B1, B2 relies on more automated processes that require fewer manual data entry, thereby minimizing human errors and optimizing operations. Moreover, B2 maintains closer contact with its livestock suppliers, by purchasing animals from georeferenced areas. B2 conducts recall simulations every six months, while B1 does not. Implementing recall simulations could benefit B1 by training and preparing its personnel for emergencies, leading to internal process improvements, as emphasized by Stanisławek et al. (2021). Table 2 summarizes the comparison between traceability aspects related to B1 and B2 cases.

Table 2. Comparison between B1 and B2 cases.

Aspect	Case 1 (B1)	Case 2 (B2)
Target Market	▪ Domestic market	▪ International market
Recall experience	▪ Voluntary recall registered in 2022, with 3 months length and 85% effectiveness	▪ No recall registered
Internal traceability	▪ Based on ERP systems	▪ Based on ERP systems
	▪ Lot identification	▪ Lot identification
Supplier traceability	▪ Focus on tracing direct suppliers and complying with national legislation around food traceability	▪ Focus on tracing direct and indirect suppliers
		▪ Monitoring suppliers from areas undergoing deforestation or involved in illegal labor
Traceability before recall	▪ Food information record (type of food provided, slaughter information, health records, medication usage)	▪ Food information record (type of food provided, slaughter information, health records, medication usage)
	▪ Monitoring quality aspects (temperature, water quality, carcass pH, and sanitary conditions)	▪ Monitoring quality aspects (temperature, water quality, carcass pH, and sanitary conditions)
	▪ Manual carcass inspection	▪ Automated carcass inspection
	▪ No recall simulation registered	▪ Recall simulation every six months
Traceability during recall	▪ Identification and segregation of the affected lots with agility	▪ Did not undergo recall
	▪ Reduced scope of recall (less affected consumers)	
Traceability after recall	▪ Identification of recall cause	▪ Did not undergo recall
	▪ Providing information for recall liability	

Authors' compilation.

It is worth noting that, the role of traceability in reducing costs related to damage to a company's market reputation, as suggested by Kelepouris et al. (2007), was not explicitly mentioned by the interviewees. However, B2 and retailers do share concerns about sourcing animals from illegal areas to protect their brand's image. While this measure can help reduce lost sales, it was not seen as being directly linked to recalls. Lastly, both processing companies showed no evidence of practices connecting traceability data with early detection systems for animal diseases, food safety issues, or bioterrorism, not even with Big Data Analytics, as cited by Adam et al. (2016).

Furthermore, Blockchain-based traceability systems have not yet been widely adopted by beef chains in Brazil, unlike the North American pork chain, which implemented this technology to ensure food safety within the Walmart retail chain (George et al., 2019). Several factors contribute to this, including the perception that automatic data capture technologies are generally expensive and challenging to implement (Galvez et al., 2018). Similar to the findings from Magalhaes et al. (2022), there is a lack of interest among Brazilian consumers in traceability information. Additionally, Wang & Scrimgeour (2023), point out that consumers prefer that Blockchain technology be applied to imported foods rather than domestic food, further discouraging investment in new information technologies in the domestic market.

Figure 3 gives a summary of the primary contribution of this study, which is the role of traceability in each stage of a recall. In **Phase 1 (pre-recall)**, there is a focus on roles related to recording food information, creating a repository to facilitate data retrieval if needed, and working on recall prevention to identify problems and non-conformities in products and processes. This phase also involves monitoring food in transit to ensure food quality and conducting recall simulations to gain a better understanding of the chain and its variables, ultimately enhancing the effectiveness of the traceability system in the event of a recall. It's during this stage that traceability plays a pivotal role, allowing the other phases to function smoothly in the event of a recall.

Phase 1	**Pre-Recall** (before the recall)	
1.1 Recording Food Information - Registering lot information - Recording origin information - Documenting raw material usage - Logging storage and processing details	**1.2 Preventing Recalls** - Identifying non-conformities - Preventing problems from reaching the distribution channel - Reducing fraud and counterfeit risks - Providing support for quality control and guarantees	**1.3 Simulating and Testing** - Simulating recalls
Phase 2	**During Recall** (actions taken after identifying the risk)	
2. Supporting Recall - Identifying non-conformities in affected lots and enhancing recall accuracy - Minimizing consumer exposure to hazardous foods - Reacting quickly during recalls (reducing response time) - Implementing cost-saving measures		
Phase 3	**Post-Recall** (dealing with the aftermath of the recall)	
3.1 Investigating the cause - Identifying the recall's root cause - Tracing the source of contamination - Sharing information to hold responsible parties accountable	**3.2 Continuous Improvement** - Sharing information to enhance processes	**3.3 Reevaluating Relationships with Other Supply Chain Members** - Reassessing partnerships with suppliers

Figure 3. Framework on the role of traceability in the food recall phases.
Author's analyses based on interviewees' opinions.

In **Phase 2 (during the recall)**, the primary role of traceability is to assist in the recall process by accurately and swiftly identifying the products that need to be recalled. In this way, traceability indirectly acts as a safeguard for consumers, reducing the risk of consuming contaminated and potentially harmful food. This, in turn, leads to a reduction in the high costs associated with interventions on behalf of the company. Finally, in **Phase 3 (post-recall)**, the availability of traceability information is beneficial for developing corrective actions. This includes identifying the root cause of the recall, determining those responsible for it, proposing improvements to processes, and reevaluating relationships with other stakeholders, such as suppliers. This phase can be extensive, as reassessing suppliers is crucial for continuously enhancing their processes and providing support for the first phase to prevent future recalls.

6 Conclusion

The increasing number of problems and incidents highlights the significant need for supply chain participants to embrace product traceability (Zhou et al., 2022). This is crucial for preventing recalls and, subsequently, reducing risks to consumer health, along with intervention costs, and the overall reputation of a company or the entire supply chain. Recent studies on the beef industry in Brazil have primarily focused on understanding consumer perceptions and traceability-related demands (Burnier et al., 2021; Magalhaes et al., 2022), without providing a comprehensive view of the entire chain. This study explores a different perspective, as it empirically characterizes the role of traceability in managing food recalls within Brazilian chains. It contributes to the literature by highlighting the various phases of a recall, as presented by Li et al. (2022), with a specific focus on food traceability.

The study identified 18 traceability roles in food recall management, categorized as follows:

- **pre-recall** (including recording food information, recall prevention, and simulation/testing);
- **during the recall** (recall support); and
- **post-recall** (encompassing the investigation of the root cause, continuous improvements, and reevaluating relationships with other chain members).

These categories were not previously identified in the literature. Furthermore, interviewees did not mention practices for early incident detection of food quality using Big Data, despite the potential benefits it offers for enhancing food chains (Adam et al., 2016).

A notable trend started to emerge upon conducting this study, showing an increasing concern among retailers and the B2 meat processor (a large company) regarding environmental sustainability and the source of the animals they purchase and distribute. This emerging concern suggests a potential driving force for enhancing traceability in the early stages of the beef supply chain. The significance of enhancing transparency by integrating data from georeferencing systems and production areas is clear.

The findings of this study provide valuable insights for professionals in the food supply chain at a managerial level, helping them understand the various roles that food traceability plays in managing potential recalls (refer to Figure 3). Given that end-to-end traceability in the chain is still voluntary in Brazil, the results can serve as a guide for decision-makers when assessing the need for traceability in recall management. It is important to note that, despite the specific focus of this study, recalls are not exclusive to the food sector. Thus, the findings of this study could also be extrapolated to analyze other sectors, e.g., the pharmaceutical industry or consumer goods in general.

This study was limited in that it only analyzed two beef processors in Brazil, where end-to-end traceability in the chain is not yet mandatory. Future research could explore the application of the proposed framework to other food chains (e.g., dairy or fresh produce) that have experienced recall incidents, or in countries where traceability is compulsory. Additionally, this study did not delve into the roles played by each player in the food chain or different technologies used during various phases of a recall process, which could be investigated in subsequent studies. It would also be beneficial for future research to explore the motivations and obstacles related to adopting traceability-supporting technologies in Brazil, e.g., Blockchain, Artificial Intelligence, and other related technologies, as well as support devices, since these were not identified in the cases examined. Finally, future studies could benefit from looking into how the identified actions and assigned phases might vary, especially when it comes to mandatory recalls.

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Data availability statement

The authors certify that all the data collected during the study is presented in this manuscript and no data from the study has been or will be published separately. The authors attest that, if requested by the editors, they will provide the data/information or will cooperate fully in obtaining and providing the data/information on which the manuscript is based for examination by the editors or their assignees.

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Authors contribution

João Guilherme Pulita, Carla Roberta Pereira and Andrea Lago da Silva worked on the conceptualization and theoretical-methodological approach. The theoretical review was conducted by João Guilherme Pulita, supervised by Carla Roberta Pereira and Andrea Lago da Silva. Data collection was coordinated by Andrea Lago da Silva and conducted by herself and João Guilherme Pulita. Data analysis included all authors, who also worked together in the writing and final revision of the manuscript.