The impact of improved traceability on the safety of food

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Contents

Executive summary

Traceability is a fundamental cornerstone of any robust food system, underpinning the claims and labelling on the product. In the context of food safety, traceability has been introduced to enable the food industry to meet regulatory requirements and provide food assurance, as well as having effective systems in place to enable prompt product recalls if required. Following major reputational issues involving food safety or adulteration, the requirement for traceability has increased significantly across all food groups.

'Traceability' is a very broad term. At the simplest level it can refer to the 'internal traceability' of a product within an organisation or 'external traceability' of products between businesses or across the whole value chain. Full chain traceability, which provides information for all the stages involved in the development of a product, addresses the growing interest from consumers in the environmental and social credentials associated with the products they buy.

This review first set out to map the different types of traceability techniques and the gaps, limitations, benefits, and risks associated with these different techniques. Four groups of traceability technologies were identified; software, Internet of Things (IoT), food sensing technologies, and physical testing. The particular focus was on the various types of software that are claiming to provide a full chain traceability solution, some of which are blockchain based.

The second part of the review focused on a number of different industries as case studies to explore how technology was being used. These industries (seafood, beef, dairy, baking, cereal, and spice) were selected as they provided a range of examples of food safety risks where traceability is seen as a key solution to reducing or avoiding those risks.

Key findings

From the case studies, only a limited number of supply chains were identified where full chain traceability have been demonstrated. These were all for high-value and premium products (e.g. grass-fed beef, line caught tuna).

In many examples where full chain traceability have been demonstrated the supply chains themselves are relatively simple and, because of this, present less risk. In addition, entities in a fully vertically integrated supply chain – with producers, processors, and retailer under the same ownership – crucially makes the co-operation and sharing of data between supply chain entities much easier, as there are no commercial incentives to restrict data access. Challenges exist with more complex supply chains, for example, those with many intermediaries or with a multi-ingredient nature (e.g. baking products) or where items are transported as a bulk commodity such as grains and cereals.

While small-scale producers have been shown to participate in some traceability initiatives this has often required facilitation by NGOs. One of the biggest obstacles in implementing digital sustainability tools in many ingredient-producing parts of the world is the limited infrastructure and lack of technology. A challenge for the industry is to develop traceability solutions that can be used in facilities where the work is seasonal and where workers may have low digital literacy. Small-scale producers will likely need training on how to use technology as well as support with upfront capital costs and ongoing operating costs.

All the separate stages of the food chain pay for traceability, regardless of whether it includes physical testing or investment in a technologically advanced system. Resource implications can be significant, depending on the scale of the system, and can be a barrier to further development, for example with introducing new solutions or for supplying into new markets or suppliers. Ultimately the consumer will have to pay in the price at point of sale.

Notwithstanding the costs of implementing new technology, including measures around cyber security, there are practical and logistical challenges that will need to be overcome so that the potential of new technologies can be properly realised. For example, traders and supply chain intermediaries can play a key role in linking small-scale producers with global markets, and it will often be in their own interest to keep their onward relationships with buyers separate from their suppliers. This means that full chain traceability will be difficult to realise in such circumstances. A technology roadmap tailored towards small-scale producers in different sectors might help facilitate dialogue on the unique traceability challenges experienced in the production of different types of products and help overcome existing barriers to achieving traceability in the first mile of the supply chain.

Most businesses cannot make improvements in full chain traceability without the collaboration of their wider supply chain. Standards, such as Global Standards (GS1) barcodes and the Global Dialogue on Seafood Traceability (GDST) seafood traceability standard, are critically important for traceability infrastructure and interoperability. They help ensure that data requirements for different markets are better harmonised, meaning the same data point has to be only input once into a standardised universally accepted format.

Improved traceability will certainly empower consumers to make buying-decisions that are based on their own needs and beliefs. Whether consumers are prepared to pay more for products with better information is unknown, and will be dependent on market factors e.g. ‘uniqueness’ of the traceability attributes, reduction of perceived risk (increasing trust), and whether traceability further bolsters a product claim (e.g. organic, Halal, etc).

Verification and third-party assurance will also still be required to underpin the veracity of the traceability claims being made. Data entry validation irrespective of the technology (blockchain or otherwise) will become increasingly important. Manual data entry will be susceptible to human error whether it has been entered into an online app or spreadsheet. Automating data-entry processes and developing foolproof ways of avoiding erroneous data entry will be key to ensure the adage of ‘garbage in = garbage out’ is minimised.

Recommendations

Based on the case study findings and review of traceability technologies, the following activities have been identified as a starting point for discussion with other organisations with an interest in food traceability. These recommendations are focused at building capacity into traceability methods and use, advocating and communicating, and strengthening the evidence base that traceability improves food safety.

Capacity building

- Ensure latest technical innovation in traceability informs any food safety activities planned.
- Provide guidance / support to low- and middle-income countries (LMICs) in ensuring food sectors can meet evolving regulatory and traceability demands of export markets.
- Collaborate / partner with existing traceability initiatives (e.g. GDST) or establish new initiatives in specific sectors of interest.

Advocacy and communications

- Develop a technology roadmap for businesses to better understand the opportunities, risks (data security) and cost implications around using new types of traceability technology (e.g. blockchain) in different food sector supply chains.
- Develop guidance for consumers to better understand the benefits of food traceability.

Evidence building

- Undertake market research to understand the needs and 'willingness to pay' by consumers for improved traceability information on the origin of food / drink products to generate trust / confidence.
- Assess the interoperability of new technologies with existing stock control traceability systems and accessibility of these new technologies to suppliers that operate in developing markets.

1. Introduction

Lloyd's Register Foundation published its Foresight Review of Food Safety in 2019, the findings of which are based on research involving interviews with over 100 industry experts[1] from around the world. The three core areas identified by the Foundation as the focus of its future efforts are:

- food safety education and training
- traceability; and
- safety and sustainability in the seafood sector.

This is one of three reports related to these topics and focuses on recent advancements in traceability technology that enable full chain traceability to the end-consumer. Supply chain context is key to fully understanding how technology is being used and its future potential. With this in mind, a number of different industry case studies have been captured to demonstrate how technology is being used to improve traceability in supply chains. The evidence in this report and supplementary spreadsheet has come from a desk-based review exercise and discussions with traceability experts and technology providers. The report's methods and research approach is set out in Section 3.

1.1 Context

Traceability is a fundamental cornerstone of any robust food system, underpinning the claims and labelling on the product. In the context of food safety, traceability allows product batches to be recalled and withdrawn where necessary.

'Traceability' is a very broad term. At the simplest level it can refer to the 'internal traceability' of a product within an organisation, or 'external traceability' of products between businesses or across the whole value chain. Given advances in digital technology, full chain traceability is a widely used concept that means the product, and some of the key information on its provenance and journey through the supply chain, is visible to the end-consumer. For the purpose of this report, specific traceability definitions and concepts are outlined in Section 2, to help explore the complexity of the landscape and some of the key challenges.

1 Experts interviewed include food safety specialists from global food brands, academics from several leading universities, representatives from Lloyd's Register's specialist food assurance team and several NGOs.

Over the past decade, food industry scandals such as 'horsegate'[2] and increasing reports of food fraud, coupled with the rise of electronic traceability software solutions, has led to increasing pressure on the food supply chain to implement full chain traceability from the following key drivers (also see Figure 1):

- government pressure: growing societal and regulatory demands for more information about product origin to prove legal sourcing and to prevent fraudulent claims
- NGO pressure: rising concerns about the marketing of food which is sourced from illegal, unsustainable, or socially irresponsible practices (including forced labour, uncontrolled antibiotic use, deforestation or disregard for animal welfare, etc.); and
- market pressure: increased consumer interest in product origin, sustainability, transparency and assurance that food safety fundamentals are met.

Leading businesses are looking to improve traceability within their supply chains due to the efficiency savings and risk reduction this provides, though generally speaking, full chain traceability is currently demonstrated in relatively simple supply chains or where the product is high-value. The UK Food Standards Agency has stated the following benefits of improved traceability[3]:

- to support food safety and / or quality objectives and meet customer specification
- to fulfil local, regional, or international regulations or standards, as applicable
- to communicate information to relevant stakeholders and consumers through the provision of reliable information to regulators, customers and consumers
- improved consumer protection through better targeted and more rapid recalls and / or withdrawals
- greater efficiency within businesses, with more information to assist in process control and management, e.g. in stock control and quality control
- to support authenticity claims about products, e.g. to authenticate origin and production claims.; and
- deterrence of fraud.

Photo by Daria Volkova on Unsplash

2 Horsegate was a food industry scandal in 2013 in parts of Europe in which foods advertised as containing beef were found to contain undeclared or improperly declared horse meat - as much as 100% of the meat content in some cases.

3 The benefits of traceability https://traceabilitytraining.food.gov.uk/module1/overview_2.html

Figure 1: Drivers for improved traceability in food supply chains[4]

For many supply chains, there currently is a gap between what is theoretically possible and what is practically achievable. Not least because many food supply chains are global, are incredibly complex involving multiple actors whose interests may not always align, and have multiple raw ingredients that are often mixed with different batches and transformed. Data capture, storage, and transfer can quickly become very complicated.

Fundamentally, improvements to traceability will depend on market need (both customer and regulatory requirements), the supply chain specific risks being addressed, and addressing the interoperability challenges with suppliers and customers in the supply chain. From an implementation perspective, there has to be sufficient consideration of costs and the key objectives of making improvements to traceability; is the focus on reducing risks in a food safety / fraud context, or telling the product story to the end-consumer? If the former, a full-chain solution may not be necessary and targeted interventions at Critical Tracking Events[5] may meet a supply chain's traceability requirement.

While food-chain solutions may look good from the point of view of the end-consumer, data being captured at all stages in the chain will need to verified through audits and product testing. Without this critical supporting infrastructure in place (Sections 4.3 and 4.4), claims being made on the product could still have the potential to be misleading or fraudulent.

4 *Traceability in a food supply chain: Safety and quality perspectives*. Aung, M.M., Chang, Y.S. 2014. Food Control 39: 172 - 184

5 Events, such as receiving, packing, shipping, transporting, that occur to the traceable object during its life cycle

At the time of writing this review, the world is still in the grip of the COVID-19 pandemic. This has been a great disrupter for global supply chains. An October 2020 survey by McKinsey found that the pandemic has speeded the adoption of digital technologies by several years and that many changes are here to stay[6].

1.2 Aims and objectives

This report looks to provide insights in the following technical areas in Section 4:

1. The full range of traceability techniques, both established and in development.
2. The gaps, limitations, benefits, and risks associated with different traceability techniques.

In Section 5, through a case-study approach of full chain traceability initiatives in different food sectors, insights to the following societal areas are provided and these are further discussed in Section 6:

3. The stakeholders involved in food traceability.
4. The challenges to food traceability resulting from global inequalities in access to, and skills in the use of, relevant technology.
5. The likely impact of food traceability initiatives resulting from different levels of access to, and skills in the use of, relevant technology.
6. The evidence that improved traceability of food makes food safe for each individual, based on their own needs and beliefs.

6 https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/how-covid-19-has-pushed-companies-over-the-technology-tipping-point-and-transformed-business-forever

2. Traceability concepts and definitions

Traceability in food manufacturing has been evolving since the 1970s when the first Global Standards (GS1) barcodes were scanned at a retail point of sale. Fundamentally, traceability necessitates that each batch or lot[7] of each food material is given a unique identifier which accompanies it and is recorded at all stages of its progress through the food chain. In this section we provide an overview of key terms that will help the reader understand the context (and future potential) in which different technologies can be used (Sections 4 and 5). Other definitions are supplied in the glossary in Annex 1.

Traceability standards: GS1

GS1 is a neutral, global collaboration platform that brings industry leaders, governments, regulators, academia, and associations together to develop standards-based solutions to address the challenges of data exchange and ensure a common language (e.g. the barcode). GS1 has local member organisations in 115 countries and over 2 million user companies covering 6 billion transactions every day[8]. The foundational principles at the heart of GS1 standards are Identify – Capture – Share. GS1 provides guidance for implementing traceability systems in different industries.

Interoperability[9] has been a major barrier to establishing full chain traceability in certain sectors. With advances in traceability technology GS1 has now developed Global Traceability Standard 2 (GTS2)[10], outlining key concepts for interoperable traceability: 1) Critical Tracking Events (CTEs), that are the actual events, such as receiving, packing, shipping, transporting, that occur to the traceable object during its life cycle, and 2) Key Data Elements (KDEs), the elements of data that describe the actual instances of the CTEs.

Unique identifiers

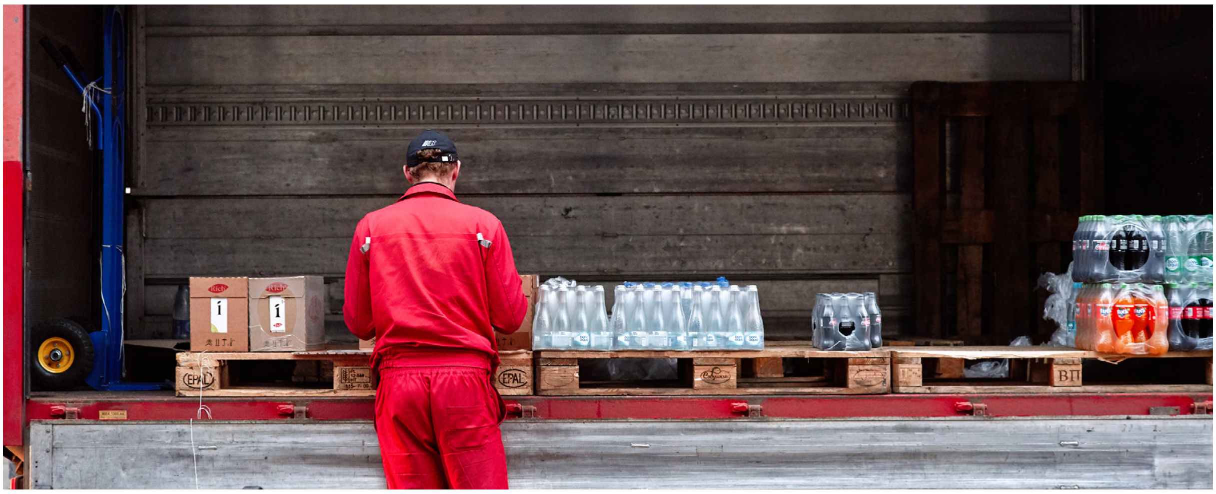
Central to the work of GS1 is the Global Trade Identification Number (GTIN). The GTIN is used by a company to uniquely identify all its trade items. GS1 defines trade items as products or services that are priced, ordered or invoiced at any point in the supply chain. This has been commonly addressed through GS1 product barcodes, and Electronic Product Codes (EPCs) or Radio Frequency Identification (RFID) tags. Increasingly, quick response (QR) codes are being used as they can store more data than a standard barcode. Until recently, QR code scanners were more expensive than those utilised for standard barcodes because of the need to cover two dimensions instead of one. However, the development of mobile warehouse management systems to facilitate inventory tracking and storage, means QR codes can be read by mobile devices.

7 Goods that were made together in the same production run, typically using the same sources of materials.

8 https://www.gs1.org/about

9 The ability of different information technology systems or software programs to communicate seamlessly for the purpose of exchanging, interpreting and using data is a critical component of full chain digital traceability.

10 See https://www.gs1.org/standards/traceability#gs1-traceability-standards for information.



Types of traceability

Food traceability is the ability to follow the movement of a food product and its ingredients through all steps in the supply chain, both backward and forward.

One up one down traceability

Traditionally, supply chains use the concept of 'one up one down' (OUOD) traceability. OUOD requires supply chain participants to have good 'internal traceability' (i.e. they can track products through their business from goods-in to onward customer) and be able to identify, through records, the immediate supplier and customer of an identified food material. Even with recent advances in digital technology, this approach is still very widely used. The drawback of OUOD is that, during product recall and food safety investigations, auditing such a trail of records is tedious and time consuming. This 'traceback' process starts with the review of documents in the last known supply chain node to identify the next node up the chain.

External traceability

External traceability requires all traceable items to be uniquely identified and information to be shared between all affected distribution channel participants. External traceability allows tracing back (supplier traceability) and tracking forward (client traceability).

Internal traceability

Internal traceability means processes must be maintained within an enterprise to link identities of raw materials to those of the finished goods. When one material is combined with others, and processed, reconfigured, or repacked, the new product must have its own unique product identifier. The linkage must be maintained between this new product and its original material inputs (such as batters, breading, seasonings, marinades, salt, packaging materials, and many other inputs) to maintain traceability.

Full chain traceability

Full chain traceability is a modern concept that uses technology to gain more visibility into a product's journey through the supply chain. Such insight can provide a complete view of the product from farm to fork (or sea to plate), greatly reducing the potential for safety breakdowns in food production.

Advanced Enterprise Resource Planning (ERP) systems[11] along with IoT allows the collection of massive amounts of data across all aspects of a products life cycle. Linking information from electronic freshness sensors, digital farming, logistics, etc. makes it possible for further development into consumer-friendly apps that provide in-depth information about the origin of food. It is becoming more feasible for consumers to have the capability to scan a product in the store, via a smartphone, and find out the geo coordinates of harvest, processing and distribution methods, temperature history, freshness data, and environmental impact records.

Transparency

Transparency relates to the visibility of data across a supply chain and that made available to the end-consumer. A supply chain could have full traceability but limited transparency if it was not in the commercial interest of supply chain entities to share data. Many retailers and brands are now disclosing details of their suppliers to provide assurance to consumers that they have nothing to hide, in terms of unethical / unsustainable practices.

Verification

Irrespective of the level of traceability, claims made on a product (e.g. protected designated origin, kosher, organic, Fairtrade etc.) still need to be substantiated. Often this is through third-party certification and assurance schemes that would require third-party auditors verifying production sites and chain of custody – the complete set of documents and mechanisms used to verify the traceability between the verified unit of production and the claim about the final product.

11 A type of software that organisations use to manage day-to-day business activities such as accounting, procurement, project management, risk management and compliance, and supply chain operations.

3. Methods and research approach

3.1 Information review

Using the World Economic Forum (WEF) report, Innovation with a Purpose: Improving Traceability in Food Value Chains through Technology Innovations[12], the various types of traceability technology were grouped into the following four categories:

- software - including blockchain and non-blockchain solutions, and Software as a Service
- Internet of Things (IoT)[13] - hardware devices linked to the internet to assist in data gathering
- food sensing technologies - part of the IoT, though specifically for analysing and measuring foods; and
- physical testing of food - sampling of food to authenticate certain attributes (e.g. animal species, origin, nutritional claims, etc.).

A detailed information review was then undertaken using the above terms in combination with search terms including food, traceability, food industry, supply chains. The searches were undertaken using Google over three days in February 2021.

The results of this search included a range of information covering briefing reports by key organisations, scientific papers, technology providers, opinion pieces, media articles etc. (The findings from the information review are presented in a supplementary excel file to this report entitled Traceability technologies library[14].)

We are confident the results reflect the general 'landscape' of technology available on the market. However, it is unlikely to be comprehensive and may have overlooked new novel technologies in development phase that are not being actively marketed yet and would not be picked up through an internet search.

A strengths, weaknesses, opportunities and threats (SWOT) analysis was carried out to identify the gaps, limitations, benefits, and risks associated with different traceability techniques at a general level for each technology category. It was beyond the scope of this review to determine the strengths and weaknesses of specific technology provider offerings; for example, in many cases, software offerings have been developed with a particular industry in mind. The results of the SWOT analyses are shown in Section 4 and discussed in Section 6.

3.2 Case studies

The purpose of the case studies was to illustrate how leading-edge technology is being used in different industries. Through consultation with the Foundation, staff from Lloyd's Register, and communications with traceability experts (see Annex 2 for details), initiatives in the following industries were profiled: seafood, beef, dairy, baking, cereal, and spice. These industries were identified as they were potential high-risk supply chains and could provide examples of leadership in traceability with initiatives that had involved small-scale producers who could find it hard to access the technologies used.

12 For WEF report, see https://www.weforum.org/reports/innovation-with-a-purpose-improving-traceability-in-food-value-chains-through-technology-innovations

13 See glossary Annex 1

14 https://www.lrfoundation.org.uk/en/news/impact-traceability-food-safety/ (link to spreadsheet at the bottom)

To address the aims and objectives of this report (section 1.2), for each case study, information is provided in the following categories:

- supply chain risk overview
- Critical Tracking Events
- key groups
- technology accessibility; and
- examples of full chain traceability used in the industry.

For some sectors (e.g. seafood and beef) additional examples of how blockchain technology is being in some supply chains is shown in Annex 4 and 5.

Some of the case studies (e.g. seafood) were also informed with conversations with technology providers (e.g. Provenance[15]).

15 https://www.provenance.org/

4. Traceability technologies overview

In this section, the results of the information review are summarised looking at the full range of traceability techniques, both established and in development. It also looks at the gaps, limitations, benefits, and risks associated with the different traceability techniques through the means of SWOT analyses. Further details can be found in the supplementary excel file entitled Traceability technologies library[16].

Barcode-reading technology on a sushi industrial production line.

4.1 Software

There are tens if not hundreds of different software providers, offering Enterprise Resource Planning (ERP) software, and some claiming full chain solutions. It was not possible to document each one for the purpose of this report. The offering of software companies can range from on-premise installation through to full cloud[17]-based Software as a Service (SaaS) (see Annex 3). While there is a growing interest in blockchain[17] solutions, many solutions are not blockchain based.

Given the range of software offerings on the market, it is important for users to define the specific traceability issues they want to solve and ensure that the software provider understands the specific traceability issues relevant to their business and supply chain. In many cases, expensive 'off the shelf' solutions might not be the best approach for a business.

16 https://www.lrfoundation.org.uk/en/news/impact-traceability-food-safety/ (link to spreadsheet at the bottom)
17 See glossary Annex 1.

Software			
Strengths	**Weaknesses**	**Opportunities**	**Threats**
• Customisable by the user. • Online systems enable wide use and easy access. • Multiple points of use / data entry. • Flexible pricing schemes available (low pricing for simple systems vs higher pricing for more complex systems). • Can be updated to make improvements, changes in supply chains. • Hardware to run the software varies from mobile phones to specialist readers / PCs, making it accessible to a range of budgets.	• Needs reliable access to internet for data entry which may be challenging for some regions / countries / foods. • Has to be customised by the user before use in specific supply chains (high resource requirement from outset). • The requirement for specialist hardware to run / use the software can be a significant initial investment. • Software as a Service (SaaS) model can lead to variable fees which are likely to escalate over time. • SaaS means a company is tied to one software provider for the duration. It can be difficult and expensive to change. • Any investment in customisation could be lost if a business wishes to migrate to another system. • A limiting factor is compatible hardware and ensuring this is up to the task of keeping up to date with new software developments. • The speed of change means software needs to be constantly developed, with new solutions all the time. Existing systems become dated quickly.	• Flexible to suit all potential uses and food groups. • Enables additional, off the shelf plug-ins, such as GPS, to build added functionality depending on the needs of the user. • Programs that link different solutions would allow the use of existing systems across the supply chain, reducing or negating the need for investment in all new software and hardware. • There are a myriad options for software development to track / trace products, people and services – the potential is limitless. • Linking to Internet of Things (IoT), software will enable wider utilisation of different solutions (hardware, information, etc.) that will enable traceability to be seamlessly embedded in time.	• Numerous different systems competing in the market, all offering similar solutions. • Current lack of integration between different software solutions means that there is no universal system for traceability. • Information requirements are developed for specific supply chains and applications rather than a universal language for traceability. • If different software applications cannot be integrated, there is a cost barrier to changing to a new software system (for example if suppliers insist on a specific software solution different to the one a company already uses). • SaaS can result in historical records being unavailable if a company moves from one system to another (not suitable for food traceability where records are legally required to be retained for a period of time, often several years). • Hidden costs to migrate between different systems e.g. paying for two systems during transition phases.

4.2 Internet of Things (IoT)

The Internet of Things (IoT) describes hardware linked to the internet that often involve sensors monitoring and capturing data. This can help a business improve its performance in different areas, for example, smart energy use, optimising production, reducing waste etc. In the context of food safety and traceability, sensors can be used to automatically capture shipping times and temperatures to ensuring effective cold chain management.

A key constraint in many regions is that IoT devices need to have regular access to the internet to upload data to the cloud. Power outages in many developing countries will also interfere with automated data capture.

For this group of techniques, and others that rely on internet connectivity, a growing threat is that cyber security management will not match the fast emergence of new security threats. Cyber security measures and staff training will also need to be costed into decisions around implementing traceability solutions that operate on the internet.

Internet of Things (IoT)			
Strengths	**Weaknesses**	**Opportunities**	**Threats**
• Large number of applications and uses across the whole food chain already. • Enables digitisation of all aspects of supply chain management and traceability, in real time. • Facilitates faster product recall if information is available on exactly who has purchased items. • Consumers have access to greater information on their food (the story of food). • Improved food safety by helping to avoid issues before they become a hazard. • Leaner inventory management can bring cost savings. • Reduction in food wastage through better control across all food production. • Can reduce / eliminate the risk of counterfeit food products. • Better control of food quality.	• It is a term that people misuse and implies something new or different (already exists). • The number of separate devices that do not or cannot connect would need replacing. • Ensuring any / all devices can connect or develop APIs (application programming interface) to enable data to be used from existing technologies. • Businesses are beholden to device manufacturers for updates. • If a device goes wrong, what can replace it if a food environment relies on it (contingency plans). • Requires permanent / regular access to the internet which can be problematic in specific regions, production points, etc.	• The potential for use of smartphones as an interface makes technology universally accessible. • The potential uses of sensors are endless (so long as they are backed up by investment in software, hardware). • Better understanding of consumer behaviour enables food production to better align to market demands. • Can provide access to cost effective solutions for traceability in time.	• The amount of data becomes overwhelming. • Reliance on technology can be problematic in the event of power or internet loss. • Companies promising something new / different with market leaders investing heavily in areas that may not be needed. • The need to keep devices up to date. • Security of devices (i.e. from internet hackers, malware, viruses) requires robust security systems. • The security of information needs to be managed in line with legal requirements and any privacy requirements.

4.3 Food sensing technologies

Food sensing technologies are crucial analytical tools in verifying the authenticity and safety of food. Some of these technologies may automatically upload data to the cloud and be classified as IoT devices.

Sensors are now being embedded in Radio Frequency Identification (RFID) tags for the in-situ monitoring of product deterioration. For example, RFIDs can be fitted with sensors capable of measuring temperature, humidity, and the presence of volatile amine compounds, to estimate cod fish freshness; and CO_2 and oxygen sensors can be fitted for monitoring the freshness of vegetables.

Spectroscopy[18] is suited to point of use and on-line applications; equipment can be small, portable, and give instantaneous results. Near infrared (NIR), particularly, is suitable for miniaturisation into handheld scanners and even smartphone applications. NIR light also passes through glass and thin plastic, meaning that products can be examined through packaging. All spectral imaging can be configured so that it is suited for unskilled operation, giving red light / green light results output.

Food sensing technologies			
Strengths	**Weaknesses**	**Opportunities**	**Threats**
• In-line systems with minimal interference in production systems. • Rapid results ensure efficient production processes with minimal downtime. • Non-destructive. • Offer continuous assurance for the parameters being tested. • Use of food screening meaning physical tests are required less frequently. • Verification of test parameters would identify infringements quickly. • Detection and identification of contaminants during the food manufacturing processes. • Help to ensure consistency of products (e.g. aroma, flavour). • Reduce wastage and losses in production.	• Expensive to install, manage and monitor. May only be accessible to large companies. • They need to be tailored for different food items with the relevant test parameters and acceptable ranges (not necessarily off the shelf). • False positives need investigation; sensing technology is not infallible. • If issues are identified they need to be rectified quickly, requiring investigation by people with the right skillset. • Have been used in food production processes, less so in other sectors. • Requirements for specialised skills to use / operate / understand.	• Linkage to software solutions enables additional information to be gathered in real time. • Whether used 'in-line' or 'stand-alone' sensors can be integrated in conjunction to Wi-Fi technologies and used for real-time transmission of contamination alarms and / or test results to remote servers. • The potential to extend use beyond food manufacturing along the whole supply chain.	• Applicability to different food types / supply chains requires broad spectrum technologies. • Security of devices (i.e. from internet hackers, malware, viruses) requires robust security systems particularly when they are linked to the internet. • The security of information needs to be managed in line with legal requirements and any privacy requirements.

18 See glossary Annex 1

4.4 Physical testing

Physical testing will still be required to verify the authenticity and safety of food products. Microbiological and DNA testing is a key requirement of many third-party food safety standards such as BRCGS[19].

Of particular relevance to traceability are those tests providing assurance on product authenticity. For example, following the horsegate scandal DNA testing has become more widely used to verify animal species in food. Quantitative and qualitative results (which are derived from different test methods) are used to assess the presence / absence of other species or to quantify the extent of contamination of other species. While DNA testing has been widely used for number of years to authenticate origin, issues remain around the use of standard methods, reference databases, and determining levels which indicate cross contamination versus deliberate adulteration.

Stable isotope ratios are used in considering the geographic origin, as the ratio is influenced by local conditions, or to differentiate between organic and non-organic variants. Stable isotopes in drinking water and feedstuffs are transferred into animal tissues. Measurement of these ratios by means of isotope ratio mass spectrometry (IRMS) can provide information on the geographical origin of meat and fish, and their products or the method of production.

Stable isotope ratios have been used for a number of years to authenticate origin. However, the cost of analysis was prohibitive so has typically been limited to where there have been suspicions of mislabelling.

Stable isotope testing has also been used in higher value differentiation, for example between a higher value species / product from a much lower value product. With analytical techniques rapidly developing, affordable test procedures mean it is becoming more widely used.

19 British Retail Consortium Global Standards

Physical testing			
Strengths	**Weaknesses**	**Opportunities**	**Threats**
• Provide definitive results for positive / negative tests. • Accredited and standardised test methods ensure quality assurance. • They provide unequivocal results. • They are widely available across the food industry, globally. • Long history of use has enabled databanks to be created to build up understanding of variables, e.g. seasonality effects, optimum harvest conditions. • Expertise in laboratories is widespread and is used to assist food companies to develop best testing schedules.	• Destructive. • Slow results turnaround may require food items to be held back until they receive the all clear. • The use of different test methods to test the same parameter can yield different results (e.g. nitrogen results, used for meat or fish content, can vary between Kjeldahl method and rapid method). • Requires an understanding of food technology / chemistry to ensure the right tests are being carried out and what the results mean. • Require the use of external laboratories for certain tests, particularly specialised tests, which has significant cost implications. • Often singular tests yield singular results so require multiple analyses. • It is expensive to create new validated test methods undertaken by all labs. • Often a need for a ‘reference’ sample for comparison and confirmation of ‘origin’ – given the vast and complex variety of foods this may not always be available.	• Small scale ‘lab on a chip’ methods. • Development of rapid test kits. • The use of databanks for reference material enables common agreement and standards.	• The rise of food sensing is reducing the need for physical testing, impacting on availability of commercial testing labs. • Companies have been looking to reduce operational costs in past decades as the requirements to test more parameters has increased. • The cost of testing becomes more competitive as it becomes more commonplace. • Loss of expertise / knowledge in food business to interpret test results.

5. Traceability case studies

Six case study industries were chosen to illustrate some key traceability initiatives. A summary and discussion of the key findings is provided in Section 6. A more detailed technical review of traceability in some of these industries can be found in a 2014 guidance document[20].

5.1 Seafood industry

SUMMARY

- Most seafood supply chains are complex, often involving intermediaries and traders making traceability particularly challenging.
- Full chain solutions have been demonstrated only in a few seafood supply chains, often for high value products (e.g. tuna, salmon, warm water prawns), and where the supply chain is already vertically integrated (i.e. under the same ownership).
- The Global Dialogue on Seafood Traceability (GDST) is a leading initiative that has developed the first ever global standards for seafood traceability, with the intention to improve interoperability of systems between businesses.

Supply chain risk overview

In the seafood industry, production of fish (including shellfish and aquatic plants) occurs through aquaculture (farmed seafood) or wild capture fisheries. As production often occurs in remote areas and, in the case of fishing vessels, often hundreds of miles offshore, detailed oversight of producers is challenging. Indeed, the seafood industry in many regions has been associated with illegal fishing practices and human rights abuses[21].

The complexity of seafood supply chains (perhaps more aptly described as 'webs'), and role of intermediaries and traders has meant, that compared with other industries, traceability has been lagging. Given the lack of supply chain oversight, and the fact that many types of seafood are a high-value commodity, this provides ample opportunity for fraudulent activities. Traceability has an important role to play in improving oversight and combatting fraud.

20 *A Guidance Document on the Best Practices in Food Traceability.* Zhang, J. & Bhatt, T. 2014. Comprehensive Reviews in Food Science and Food Safety. 13 (5) https://doi.org/10.1111/1541-4337.12103

21 https://reliefweb.int/report/world/blood-and-water-human-rights-abuse-global-seafood-industry

Critical Tracking Events

An example of some seafood CTEs (events that occur to the traceable object during its life cycle) are:

- catching
- on-vessel processing
- transhipment
- landing
- pack / unpack
- ship / receive; and
- processing.

Key groups

The Global Dialogue on Seafood Traceability (GDST) was launched in April 2017 as a seafood industry forum dedicated to drafting the first-ever global standards for seafood traceability. The GDST has grown into one of the largest and most diverse business-to-business forums in the seafood sector. In March 2020, after nearly three years of consensus-based work, the GDST launched the GDST Standards and Guidelines for Interoperable Seafood Traceability Systems, Version 1.0[22].

The Seafood Alliance for Legality and Traceability (SALT[23]) is a global community of governments, the seafood industry, and NGOs, working together to share ideas and collaborate on solutions for legal and sustainable seafood. It has a particular focus on traceability and ability to track the movement of seafood to prevent illegally caught fish entering supply chains.

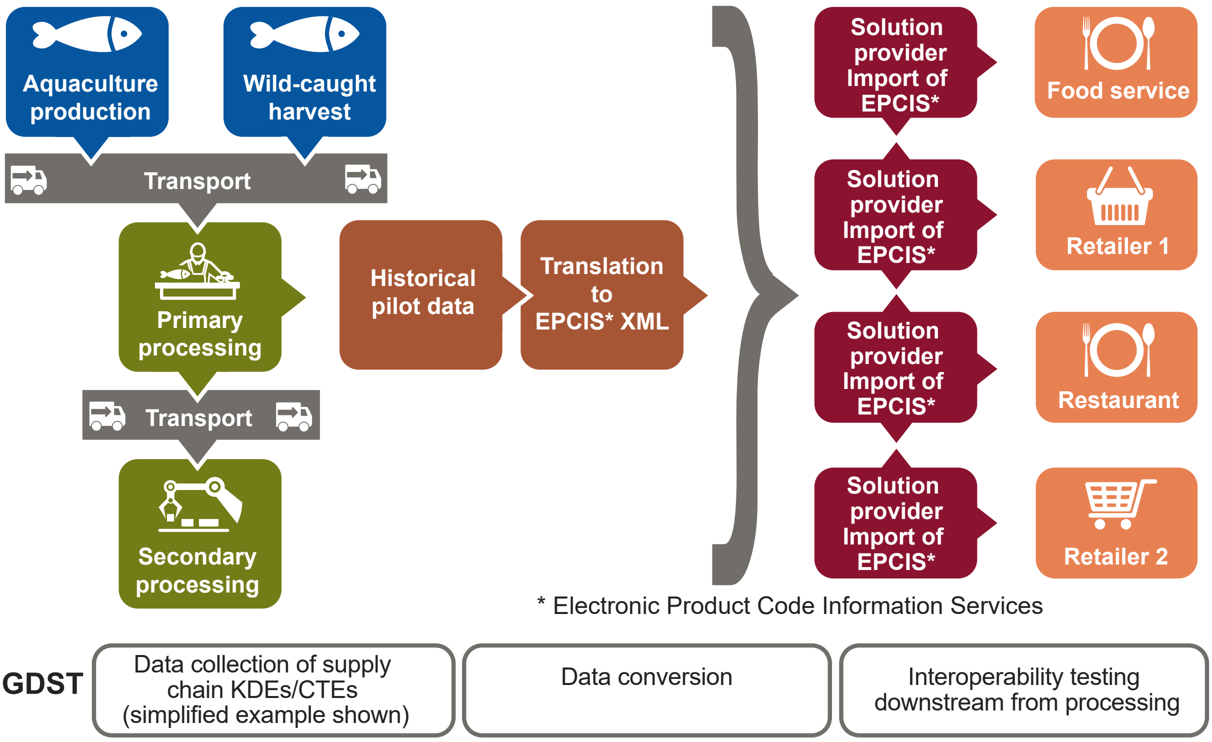


Figure 2: Summary of the work of the GDST[24].

22 https://traceability-dialogue.org/gdst-1-0-materials/
23 SALT https://www.salttraceability.org/
24 Source: GDST.

Technology accessibility

While internet coverage in more remote areas may be challenging, all that is required for most producers to upload data onto a software platform would be access to a smartphone. Generally speaking, the main barriers to achieving full chain traceability in seafood supply chains are:

- supply chains are fragmented, produce is consolidated from small-scale producers (e.g. farmed shrimp) and often there will be numerous traders in between production and processing
- actors with competing interests do not want complete visibility, as it could allow entities downstream in the supply chain (e.g. retailers) to circumvent traders and go straight to the producers; and
- there is a time (and verification) cost associated with the inputting of data, so incentives need to be in place for supply chain actors to upload data. Training and intuitive technology will also likely be needed to help facilitate producers entering data onto traceability software.

Examples of full chain traceability in the seafood industry

Since 2017, the Institute of Food Technologists' (IFT) Global Food Traceability Center (GFTC) has been working with the World Wildlife Fund for Nature (WWF) to advance a unified framework by convening seafood companies and other relevant stakeholders. From October 2018 – March 2020, the GFTC conducted end-to-end traceability pilots as a way of evaluating and interrogating real-world seafood supply chains for identification, data collection, and sharing relationship requirements. After the release of the GDST standards 1.0 in March 2020, GFTC with WWF are conducting early implementations grounded in the pilot methodology. A number of these pilot case studies are provided on the GDST website[25].

It should be noted that several of these seafood supply chains are vertically integrated, i.e. under the same ownership, and are dealing with relatively high value products (e.g. tuna, warm water prawn, and salmon). In terms of providing key information to the consumer, QR codes on tinned tuna, coupled with the use of blockchain technology have been used in some tuna supply chains, for example Provenance[26] (a diagram based on the Provenance model is shown in Annex 4).

25 For seafood case studies see https://traceability-dialogue.org/case_studies/

26 For example of blockchain technology being used in a tuna supply chain https://www.provenance.org/tracking-tuna-on-the-blockchain

5.2 Beef industry

SUMMARY

- The regulatory requirements for traceability in livestock production are comparatively strong compared to other sectors, not least due to the need to prevent the spread of livestock diseases and minimise any human health risks posed (e.g. BSE).
- GS1 has developed guidelines to help the beef industry implement the GS1 traceability standards.
- There are numerous technology providers and platforms catering for the beef industry and supporting services (e.g. product authentication).
- A blockchain solution (Beefchain™) is being used by a group of Wyoming beef ranchers to receive a premium on grass-fed beef.

Photo by Annie Spratt on Unsplash

Supply chain risk overview

The beef industry has been hit with some devastating bovine diseases over the last few decades that have seen whole farms destroyed, such as foot and mouth disease, BSE and TB[27]. BSE in particular was the catalyst for major reforms of food and feed safety regulation in the EU. There was also the horsegate scandal in the EU which left consumers demanding more insight into what is in their food and where it has come from.

Traceability is a crucial factor in preventing the spread of livestock diseases and there are strict controls on movement to ensure compliance with regulations. In the UK and EU there is a legal requirement for all livestock (excluding poultry) to be identified. In order to be traceable, all cattle need to have a passport which corresponds to its livestock identification or cattle id tag in accordance with EU legislation.

Traceability is also essential in ensuring premium meats such as Aberdeen Angus are not fraudulently substituted with inferior (less valuable) product.

27 BSE - bovine spongiform encephalopathy ‘mad cow disease’, TB - tuberculosis

Critical Tracking Events

An example of some livestock CTEs are:

- farm / field location
- transportation
- abattoir / slaughter
- distribution
- primary processing / butchers
- pack / unpack
- distribution; and
- secondary processing.

Key groups

There does not appear to be one single global umbrella group addressing traceability challenges in the beef industry (unlike the seafood industry). Industry-government partnership initiatives have been established in different countries to improve data capture and transfer. GS1 has developed guidelines to help the beef industry implement their traceability standards[28] (Figure 3).

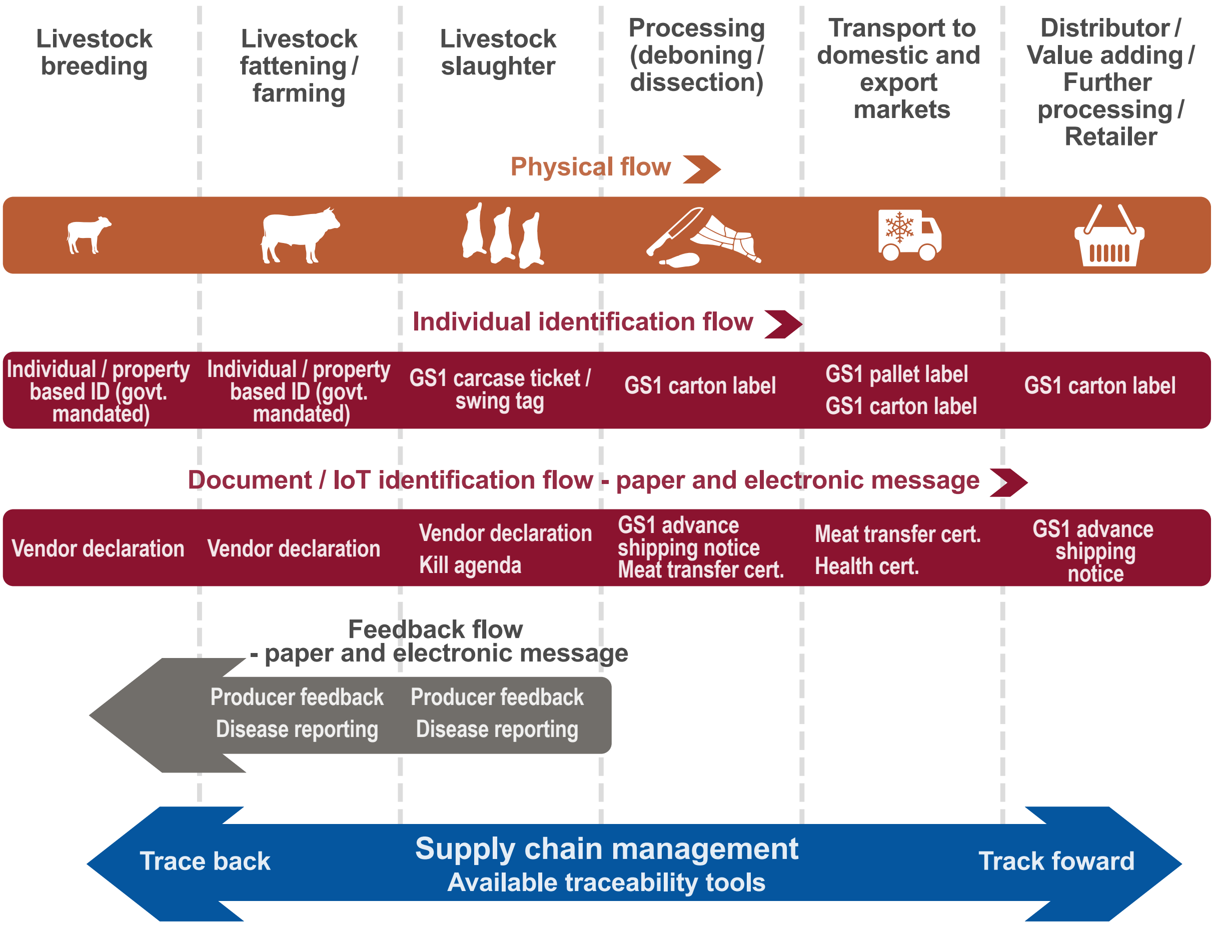


Figure 3: Beef supply chain traceability model, in one or more countries[28]

28 For GS1 beef industry guidance see: https://www.gs1.org/docs/traceability/GS1_Global_Meat_and_Poultry_Guideline_Part2_Beef_Supply_Chain.pdf

In the UK, the Livestock Information Programme[29] was launched in 2019 through the Agriculture and Horticulture Development Board (AHDB) and is a centralised, fully digital and near real-time system of data sharing that would be capable of integrating with the entire supply chain. Aside from helping improve food safety, animal welfare and proof of origin, the Livestock Information Programme will increase operating efficiency of the industry by allowing processors to see what animals are coming through the supply chain and plan production capacity accordingly.

Technology accessibility

The legal requirements for farms to be able to trace individual livestock (at least in wealthier countries or for export markets) means that the traceability system is fairly well developed for the global beef industry. There are numerous technology providers and platforms catering for the beef industry[30] and supporting services (e.g. product authentication).

Examples of full chain traceability in the beef industry

There are limited examples of full chain traceability in the beef industry, for example where consumers scan a QR code to see details of the product journey.

A blockchain solution (Beefchain™)[31] is being used by a group of Wyoming beef ranchers to receive a premium on grass-fed beef through providing consumers with greater confidence in the meat they consume. Typically, before this blockchain solution, the price premium was captured further up the supply chain when the feedlot operator / processor sells to the retail channel which passes it through as their markup; the rancher received the lower, functionally identical price at the sale lot – two steps removed from the end customer.

5.3 Dairy industry

SUMMARY

- Milk fraud is a reoccurring problem in developing countries, it is relatively straightforward for fraudsters to dilute milk through the addition of water, and then adding various chemicals and additives to increase its nutritional value.
- There are a number of different initiatives improving dairy traceability in different countries.
- In the UK, Red Tractor Dairy Standards provide assurance on the safety of farm produce, and products showing the red tractor logo can be traced back to certified farms.
- Some higher-end milk products, such as that from organic farms, allow the consumer to scan a QR code to find out details of the farm and product story.

Supply chain risk overview

Milk is a fragile substance and requires carefully controlled supply chains to maintain its quality. It has also been a common target for adulteration, for example, as highlighted by the melamine scandal in China[32].

29 The UK Livestock Information Programme https://ahdb.org.uk/livestock-information-programme

30 https://www.agrismart.co.uk/traceability/, https://animalcare.folio3.com/livestock-identification-traceability-systems/

31 Further information on Beefchain™ https://www.wyomingpublicmedia.org/post/blockchain-technology-could-make-wyoming-beef-premium-product#stream/0

32 https://www.bbc.co.uk/news/10565838

Milk fraud has become a reoccurring problem in developing countries due to the lack of awareness by food safety authorities. One of the easiest methods to commit fraud is by the addition of water to milk. If the water is contaminated with chemical or biological hazards this will further increase the risk to the consumer. Due to the dilution of various nutrients within milk, fraudsters will use various materials to increase the nutritional value, therefore making it harder to detect. Some of the most reported materials include milk powder, urea, cane sugar, melamine, formalin, caustic soda and detergents.

Critical Tracking Events

An example of some dairy CTEs are:

- farm location
- transportation
- processing plant (pasteurisation for liquid milk, and / or conversion into other dairy products)
- distribution; and
- retailer.

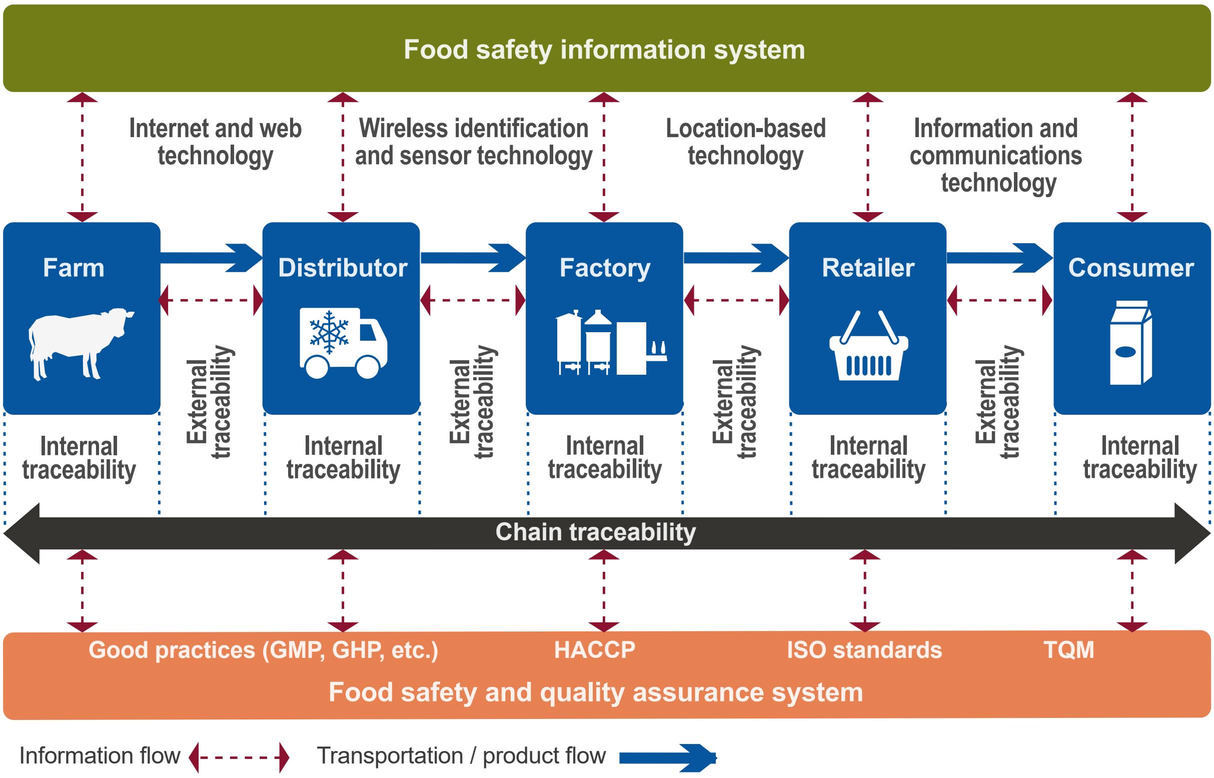


Figure 4: Conceptual framework for a dairy traceability system[33]

Key groups

There does not appear to be one single global umbrella group addressing traceability challenges in the dairy industry, however there are a number of different initiatives improving dairy traceability in different countries. For example, GS1 is working with Australian Dairy Farmers to support producers, processors and retailers with new ways of capturing and sharing data through the supply chain, some of which is involving the use of blockchain technology[34].

33 *Traceability in a food supply chain: Safety and quality perspectives*. Aung, M. M., & Chang, Y. S. (2014). Food Control, 39(1), 172–184. https://doi.org/10.1016/j.foodcont.2013.11.007

34 GS1 work with Australian dairy industry https://www.gs1au.org/for-your-industry/dairy

Software providers Ftrace[35] and soft-trace[36] have developed traceability products tailored for the dairy industry.

Technology accessibility

Resource requirements to introduce a blockchain based system can be extensive and a barrier to small-scale producers. However, some LMICs are exploring how it could be used in their dairy industries, for example in Vietnam[37].

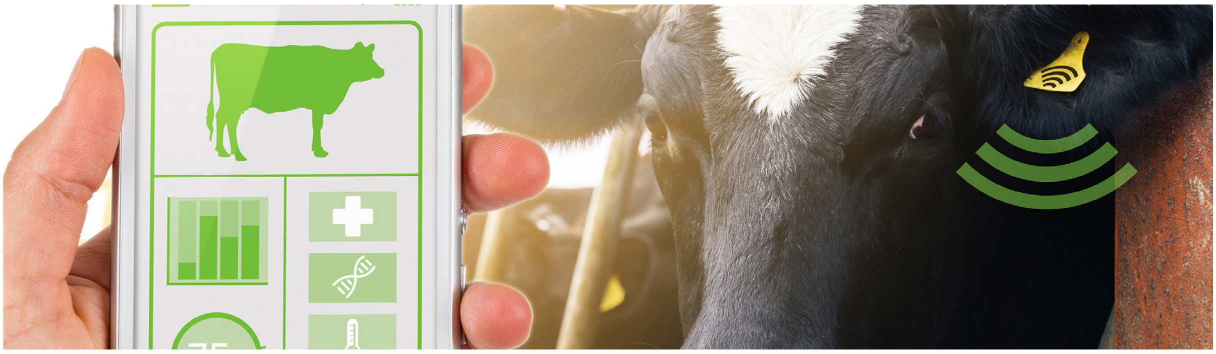
Theoretically, a smart contract combined with IoT sensors would reduce the transaction time between the dairy company and wholesalers / retailers. Before delivery, the sensor's logger ID, shipment details, and criteria such as temperature, humidity, tilt, shelf-life, and order deadline are updated and validated against the smart contract during transit. On arrival, the receiver confirms that the temperature and humidity levels have been followed and the shipment details such as order and shipment numbers, delivered volume and vehicle details are matched. If there are anomalies, an alert will be triggered for both sides to investigate and correct. Otherwise, payments will be made to the dairy company.

Consumers would be able to validate domestic dairy items using their smartphone. In the case of foodborne incidents, product recall will also be able to happen much more efficiently. For example, if a person suffers food poisoning after consuming a spoiled drinking yogurt produced by a domestic company, the manufacturer can use their interface of the application to scan the consumed bottle to see the original product from the QR code. This will show the raw milk batch used to produce it, the additives that went into it, the bottling / packaging material used to recall all the products of similar history that might have also been contaminated, also helping identify the root cause.

Examples of full chain traceability in the dairy industry

The first phase of a Blockchain and Traceability Framework for Australian Dairy Farmers is underway to reduce the threat of fraudulent product entering the supply chain.

In the UK, Red Tractor Dairy Standards[38] provide assurance on the safety of farm produce, and products showing the red tractor logo can be traced back to certified farms. Some higher-end milk products, such as that from organic farms, allow the consumer to scan a QR code to find out details of the farm and product story[39].



35 https://web.ftrace.com/en/industries/dairy-products

36 https://www.soft-trace.com/industries-dairy

37 *A proposed framework model for dairy supply chain traceability*. Tan, A., & Ngang, P. T. (2020). Sustainable Futures, 2, https://doi.org/10.1016/j.sftr.2020.100034

38 Red Tractor Dairy Standards https://assurance.redtractor.org.uk/standards/search?k=&c=9&o=relevance

39 QR codes on dairy products https://www.fwi.co.uk/livestock/dairy/qr-codes-lets-the-milk-do-the-talking

5.4 Baking industry

SUMMARY

- The multi-ingredient nature of baking products makes traceability challenging. However, recent deaths caused by lack of labelling of allergens has caused a renewed focus on traceability.
- Some higher value or differentiated ingredients (e.g. certified cocoa) will have a chain of custody to provide assurance on product claims.
- Given the complexity of baked goods, no examples of full chain traceability were found. The baking industry is moving towards lot traceability for its ingredients, to meet customer expectations.
- The Digital Sandwich project is a new initiative whereby a consortium of UK universities, technology, food and manufacturing firms are developing a platform to 'irrefutably' track all components of a sandwich with the help of IoT, blockchain, and artificial intelligence.

Supply chain risk overview

Bakery products are typically a combination of agricultural components, like flour, sugar, and eggs, and non-agricultural components, such as emulsifiers, leavening agents, salt, improvers, etc.

Recent tragedies, such as the death in 2016 of 15-year-old Natasha Laperouse, who died after an allergic reaction to a Pret A Manger baguette that lacked allergen labelling[40], has undermined confidence in food labels (note that foodservice operators were not legally required at that time to provide such allergen information on pack labels, however consumers expected to see such allergen labelling).

While traceability for the non-agricultural components may be quite straightforward and manageable, when it comes to the agricultural components, there are more complexities. Ideally, all agriculture components should be able to be traced back to the field, orchard, flock, or herd. However, that is rarely the case since most of these ingredients are first gathered in collecting locations, where they are commingled in a container, silo, or shipping vessel. Therefore it becomes quite impossible to maintain rigorous upstream traceability when dealing with bulk materials.

There may be exceptions for certain types of ingredient, for example third-party certified cocoa (e.g. by Fairtrade, Rainforest Alliance) will have a chain of custody, and some chocolate manufacturers have been establishing full chain traceability and associated metrics to communicate the product story to customers.

40 https://www.bbc.co.uk/news/uk-england-london-45623831

Critical Tracking Events

An example of some baking industry CTEs are:

- raw material harvesting and / or processing
- raw material receiving and storage
- processing raw materials into finished products
- finished product storage and shipping
- finished product receiving by customer; and
- finished product sale to consumers.

A further description of traceability at key stages in a typical bakery supply chain can be found on the Matrix Controls website[41].

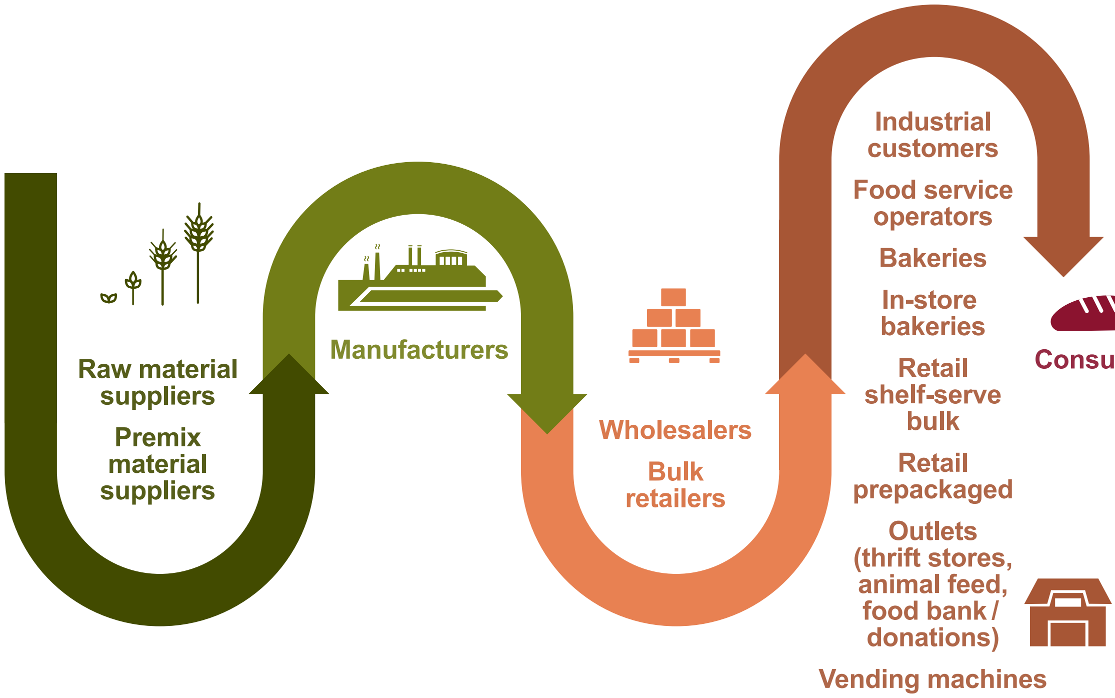


Figure 5: A simplified bakery supply chain[42]

Key groups

There does not appear to be one single global umbrella group addressing traceability challenges in the baking industry.

A consortium of UK universities, technology, food and manufacturing firms are developing a platform to 'irrefutably' track all components of a sandwich with the help of IoT, blockchain, and artificial intelligence – called the Digital Sandwich project[43]. IMS Evolve[44] is providing the IoT component of the project. Other consortium members include the University of Lincoln, and SME sandwich manufacturer Raynor Foods.

41 Traceability – the rising challenge for bakers http://www.matrixcontrols.net/traceability-rising-challenge-bakers/

42 *A Guidance Document on the Best Practices in Food Traceability*. Zhang, J. & Bhatt, T. 2014. Comprehensive Reviews in Food Science and Food Safety. 13 (5) https://doi.org/10.1111/1541-4337.12103

43 Further information on the 'Digital Sandwich' https://www.foodnavigator.com/Article/2020/11/27/Digital-sandwich-Next-gen-tech-traces-every-ingredient-in-and-between-the-bread

44 IMS Evolve https://www.ims-evolve.com/

FoodPro in Australia ran an exposition for food professionals in July 2021, with one event looking at certified organic bakery goods[45]. Aptean[46] and Ftrace[47] have developed software solutions tailored for bakery / multi-ingredient products.

Technology accessibility

One of the biggest obstacles in implementing digital sustainability tools in many ingredient-producing parts of the world is the limited infrastructure and lack of technology. A challenge for the industry is to develop traceability solutions that can be used in facilities where the work is seasonal and where workers may have low digital literacy. Many smallholder farmers may have never used a computer or smartphone; tools have to be accessible and producers need to be trained on how to use them.

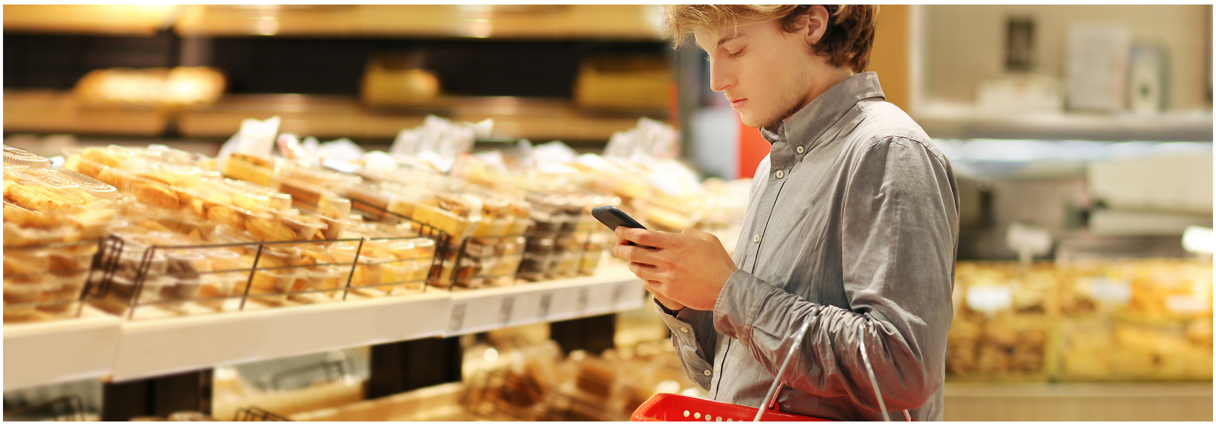
There are many generic software systems but these are not designed for bakers. For example, a system for warehouse management may not capture and deal with water loss in baking or a two-step recipe where, for example, a batch of icing is prepared separately and then used up over three different batches of buns. If the system cannot accommodate the specific baking process then achieving accurate traceability is impossible.

Examples of full chain traceability in the baking industry

Given the complexity of baked goods, no examples of full chain traceability were found. The baking industry is moving towards lot traceability for its ingredients to meet customer expectations[48].

There are examples of full chain traceability for particular ingredients. For example, Olam Cocoa's AtSource traceability platform[49] collects metrics on the social and environmental impact of products, to provide assurance that cocoa products have been responsibly sourced. Additionally, cocoa beans can be tracked from the farm to the factory through a barcode applied to every bag of cocoa beans.

In the context of providing the verification of organic claims, Etea Group has set-up Etea Organic[50], to monitor the different raw material production stages in order to guarantee full compliance with internationally established organic standards.



45 Foodpro Bakery & Baked Goods Industry https://foodproexh.com/industry-sector/bakery-baked-goods-industry/

46 https://www.aptean.com/en-US/industries/food-and-beverage/bakery

47 https://web.ftrace.com/en/industries/multi-ingredients-products

48 See https://www.perishablenews.com/bakery/how-lot-traceability-is-fast-becoming-the-2020-must-have-for-bakeries-as-consumers-drive-the-agenda/

49 AtSource https://www.atsource.io/atsource.html

50 Etea Organic https://www.eteagroup.com/en/organic.php

5.5 Cereal industry

SUMMARY

- The majority of grains and cereals are transported as a bulk commodity. There is limited traceability back to farms, and no examples of full chain traceability were found.
- The software provider Ftrace has developed a solution for cereal supply chains. For example, allowing the origin, production method, and absence of harmful substances (such as glyphosphate) of cereal products to be verified.
- IBM has developed the IBM Food Trust, engaging food and agriculture players on its blockchain-based traceability system.

Supply chain risk overview

Grains and cereals represent the largest agriproduct category by volume, with about 2.7 billion metric tons harvested each year. The majority of this is handled and transported in bulk form, from the farm all the way to the final food processing stages (see Figure 6). This presents unique challenges for traceability.

At the farm level, mandatory KDEs[51] could include the geolocation of the actual field where a specific grain crop was grown, and the types of seeds, fertilisers, insecticides and irrigation water that were used in growing it. This data should accompany the crop's journey post-harvest, while various CTEs are created as the grain is transported and transformed downstream. For instance, a transformation event could be a blending operation at the level of a terminal elevator facility, where grain from different origins and quality grades is being mixed to achieve a target grade. Additionally, insect infestation levels and pest control records (e.g. fumigation treatments) should be recorded and added to the digital tag, as these may relate to allergies and certification requirements for certain identity-preserved foods (e.g. organic).

Critical Tracking Events

An example of some agricultural industry CTEs are:

- seed production
- agricultural production
- storage in grain silos
- first transformation at milling industry
- storage; and
- secondary transformation at food mill.

51 Key Data Elements describe the actual instances of the CTEs

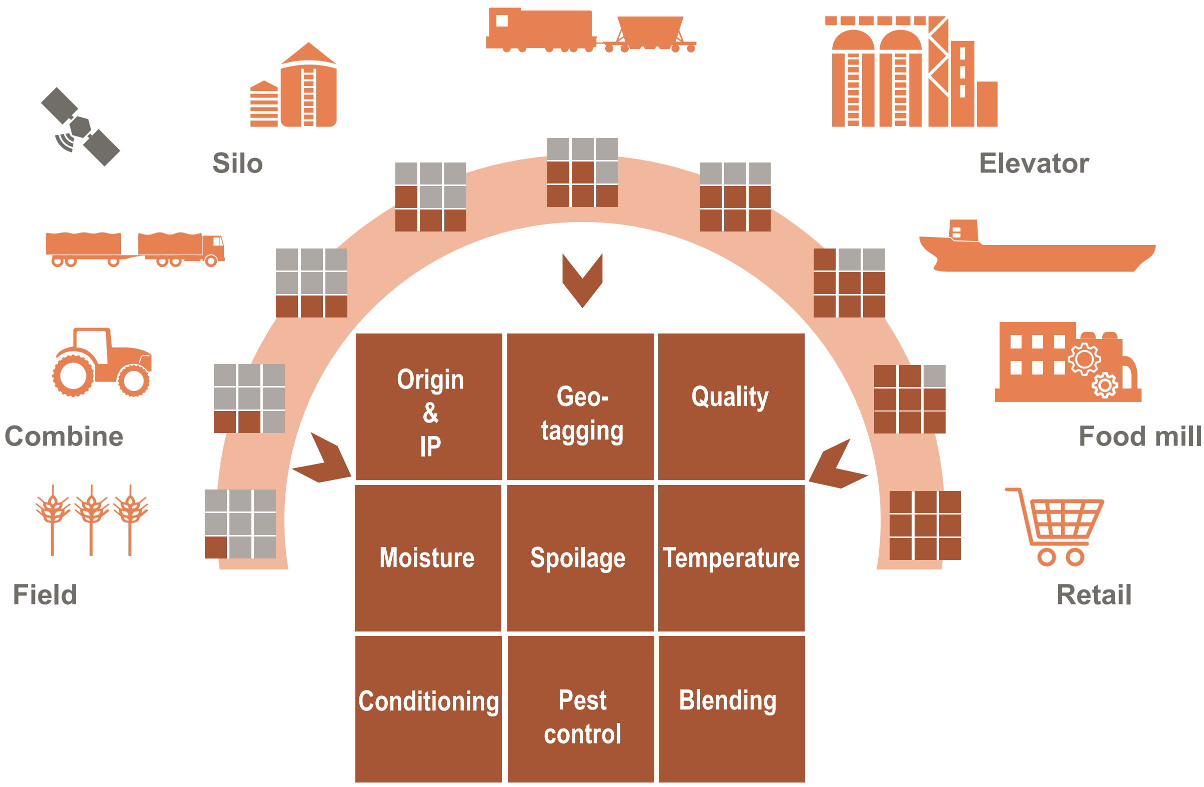


Figure 6: Farm-to-shelf traceability chain for grains and cereals[52]

Key groups

There does not appear to be one single global umbrella group addressing traceability challenges in the cereal industry, however there are different initiatives in progress.

Nestlé is working closely with Control Union and the Nature Conservancy to map their supply chains and identify and address key challenges, with a focus on good agricultural practices. Nestlé claim that 82% of their cereals and grains are traceable in 2020[53].

Centaur Analytics, Inc., a company creating the post-harvest quality chain for agricultural crops and food, is working jointly with the IFT's Global Food Traceability Center on digitising supply chains using blockchain. Centaur is working with OpenLedger ApS, a leading blockchain technology consultancy, to provide a version of its Internet-of-Crops™ platform coupled with blockchain technology[54].

The software provider Ftrace has developed a solution for cereal supply chains[55]. For example, allowing the origin, production method, and absence of harmful substances (such as glyphosate) of cereal products to be verified. IBM has developed the IBM Food Trust, engaging food and agriculture players on its blockchain-based traceability system, including Dole, Driscoll's, Golden State Foods, Kroger, McCormick & Company, McLane Company, Nestlé S.A., Tyson Foods, Unilever N.V. and Walmart.

52 Towards Traceable Flour: Digitizing the Grains & Cereals Supply Chain (https://cdn.newswire.com/files/x/61/52/ffe551be6dc73207a372c81c2df0.pdf)

53 Nestlé cereal grain traceability https://www.nestle.com/csv/raw-materials/cereals

54 https://www.perishablenews.com/bakery/centaur-and-ift-propose-ways-to-digitize-the-grains-cereals-supply-chain-to-bring-safety-and-traceability/

55 https://web.ftrace.com/en/industries/cereals

Technology accessibility

As with the previous case studies there is challenge around building capacity in small-scale producers to gain access to, and to be able to use, digital technology.

Example of full chain traceability in the cereal industry

While blockchain is being used in agriculture supply chains, no examples of full chain traceability were found (i.e. where consumers can trace grain ingredients back to source).

5.6 Spice industry

SUMMARY

- Spice and herb supply chains are incredibly diverse, ranging from wild harvesting, production by smallholders, to large-scale producers. There can also be many intermediaries in the supply chain between the farmer / collector through to the exporter.
- Given the high intrinsic value of many spices and herbs, they are very susceptible to adulteration and substitution.
- BRCGS, the Food and Drink Federation (FDF), and the Seasoning and Spice Association (SSA) have developed best practice guidance on assessing and protecting culinary dried herbs and spices.
- There are a few software offerings dedicated to improving traceability in spice supply chains, though no specific spice products were identified that currently have full chain traceability.

Supply chain risk overview

The global market for herbs and spices is complex with diverse supply chains and products being sourced from a variety of businesses ranging from large-scale producers to smallholders. Many herbs and spices grow wild or are farmed on a village or subsistence scale and there are often many intermediaries in the supply chain from farmer, collector, through to arrival at the origin processor / shipper. Protection against adulteration and substitution is of the upmost importance given that many herbs and spices have high intrinsic economic value. Food businesses need to ensure that they have appropriate controls and mitigation measures in place to prevent or detect product vulnerabilities.

Spices and herbs are present in almost every processed food, including ready-to-eat products, and are often used by the consumer for flavouring purposes without further processing. China is the major producer in the global spice trade. Similar to other agricultural products, spices and herbs may be subjected to chemical contamination within one or more stages of the supply chain. The chemical hazard most often notified is aflatoxins which are toxic secondary metabolites produced by a fungus, Aspergillus spp. Besides natural contaminants, spices and herbs may be subjected to deliberate contaminations. For example, dyes are added as colourants to make the spice look fresher. Sudan dyes have been added to chilli, curry and paprika powder to intensify and maintain the natural red colour of the spices. However, Sudan compounds are not authorised as food additives in the EU due to their carcinogenic properties. Besides the addition of artificial dyes, chemical residues from pesticides may be present. Various pesticide residues have been reported, sometimes exceeding the maximum residue levels.

Critical Tracking Events

The following table is a summary of a generic herb and spice supply chain, showing examples of potential vulnerabilities.

Table: CTEs of a general spice supply chain[56]

Supply chain stages	Examples of vulnerabilities
Grow	Adding non-functional parts of the plant
Collector	Loss of traceability
Primary processor	Adulteration at the grinding stage
Local traders	Deliberate misrepresentation
Secondary processor	Adulteration
Exporter	Purchase of low-grade material / mislabelling
Importer	Purchase of low-grade material / mislabelling
Trader	Purchase of low-grade material / mislabelling
Processor / packer	Substitution
Food manufacturer / retailer / wholesaler	Knowingly placing mislabelled product on the market

Key groups

There does not appear to be one single global umbrella group addressing traceability challenges in the spice industry. BRCGS, the UK's Food and Drink Federation (FDF), and the Seasoning and Spice Association (SSA) have developed best practice guidance on assessing and protecting culinary dried herbs and spices.

The Rainforest Alliance and the Union for Ethical BioTrade (UEBT) have developed the joint Herbs & Spices Programme. All ingredients certified under this new programme will be able to carry the Rainforest Alliance certified seal[57].

56 Guidance on Authenticity of Herbs and Spices. Industry best practice on assessing and protecting culinary dried herbs and spices. BRC, FDF, SSA https://www.fdf.org.uk/globalassets/resources/publications/guidance-herbsandspices.pdf

57 See https://www.rainforest-alliance.org/business/responsible-sourcing/supply-chain-certification/herbs-and-spices-program/

Technology accessibility

As with agriculture production in general, there is challenge around building capacity in small-scale producers to gain access to, and to be able to use, digital technology.

There are a few software offerings dedicated to spice supply chains, for example Cropin[58] is a Bangalore-based company developing Software as a Service for agriculture enterprises to drive efficiency in farming operations. Sourcetrace[59] is providing spice traceability right from farm to table, enabling the rural farmers to overcome the traditional quality control barriers using TraceNext, a food safety technology appropriate for spot quality testing of spices and capturing key information through the supply chain (Figure 7).

Example of full chain traceability in the spice industry

No specific spice products were identified that currently have full chain traceability, though Sourcetrace claims TraceNext has been developed as a full chain blockchain solution. Spices Board India agreed an MoU with UNDP India's Accelerator Lab in April 2021 to build a blockchain based traceability interface for Indian spices to enhance transparency in supply chain and trade[60].

Figure 7: Sourcetrace solution for spice supply chains[54]

58 Cropin https://www.cropin.com/investment-spice-traceability-customer-need-essential-sustainability-spice-industry/

59 Sourcetrace https://www.sourcetrace.com/blog/spice-traceability-a-complex-food-chain/

60 Spice blockchain https://www.nuffoodsspectrum.in/news/30/8089/govt-plans-blockchain-powered-traceability-interface-for-indian-spices.html

6. Key discussion points

SUMMARY

- High levels of assurance in the food industry are a pre-requisite for market access across the world.
- Increasing regulatory requirements and consumer interest are providing the incentives for businesses and supply chains to improve traceability.
- Traceability is a whole sector challenge. Most businesses cannot make improvements without relying on collaboration of their wider supply chain. In this regard, standards such as GS1 and forums (e.g. the GDST) are crucial to ensuring that businesses act in synergy with one another.
- Given the hundreds of different types of technology provider, it is important that businesses have a good understanding of their supply chain, and traceability challenges they want to address, before committing to a particular technology offering.
- It is also important that technology is future-proofed against any changing business environment to ensure ongoing interoperability with other systems.
- The majority of examples of full chain traceability are for high value products in relatively simple supply chains. From the case studies identified, the participation of small-scale producers in full chain traceability initiatives has required facilitation from NGOs.
- There are practical and logistical challenges that will need to be overcome so that the potential of new technologies can be properly realised. Traders and numerous other intermediaries often play a key role in linking small-scale producers with global markets, and it will often be in their own interest to keep their onward relationships with buyers separate from their suppliers, making full traceability difficult to realise.
- The current pace of change in cyber security management will not match the fast emergence of new security threats to digital environments. Current capabilities either do not scale, have not been tested, or simply do not exist yet.
- Cyber security measures and staff training will also need to be costed into decisions around implementing traceability solutions that rely on internet connectivity.

The food industry has been on a journey in the past 20 years, becoming heavily reliant on internal and external audits, constant checks (e.g. in-house quality control), and verification of food and hygiene through analytical testing. It has adapted to the introduction of new systems and technologies, particularly those supplying high risk foods or into global markets. High levels of assurance are a pre-requisite for market access across the world.

The number of food traceability systems, applications and approaches have proliferated in the past 20 years. These typically have been introduced to enable the food industry to meet regulatory requirements and provide food assurance, as well as having robust systems in place to enable prompt product recalls if required.

Following major reputational issues involving food safety or adulteration (such as product substitution, acrylamide in dairy, counterfeit alcohol plus many others), the requirement for traceability has increased significantly across all food groups. Regulations have tightened to ensure there are traceability measures in place. Third-party certification schemes, such as BRCGS have introduced an increasing number of verification requirements.

Some of the key findings from the technology and case study review are now discussed.

Technology as an 'enabler' rather than 'solution'

Various software platforms have been available for a number of years, providing a way to collect data at different points of the supply chain. There are almost too many to identify, with new platforms emerging on a continuous basis. Some are food chain generic, with others having been developed specifically tailored to particular supply chains (see Section 5).

Enterprise Resource Planning (ERP) systems are often used by retailers, large food producers and manufacturers, and many are now heavily marketing blockchain technology as a full chain solution. However, it is unclear the extent to which this technology is being used, therefore it is advisable that before businesses commit to a particular technology provider, that they have a good understanding of the traceability challenges they want to solve, and discuss options with several technology providers before coming to a decision. For example, buying into a Software as a Service (SaaS) package may restrict the scope of future options if supply chains change and there is a need for greater flexibility in terms of how data is transferred and managed. It is important that any technology is future-proofed against any changing business environment to ensure ongoing interoperability. There are many initiatives, big and small, looking to digitise data capture along the supply chain but few have presented a convincing approach for making that data truly interoperable without monopoly.

Blockchain is often being sold as if it is 'the solution' but it is just a platform that enables secure data sharing and access. Blockchain based traceability systems still require software, still require bespoke development and tailoring to supply chains, and specialised skills to set up. Also it requires high levels of investment in the platform, software and hardware to make it work.

The IoT is similar to some extent. Essentially it is a term being widely used to explain how the internet enables connectivity. IoT still requires hardware and software to make it happen and requires investment to make such things commonplace. It is inevitable that such systems / devices to facilitate traceability will become more common, easier to use and likely cost-effective in time. Indeed in a few of the seafood case studies (e.g. Provenance's tuna blockchain) it is evident that smartphone applications can allow key data to be captured, digitised, and uploaded onto a software platform by even small-scale producers.

The market and supply chain complexity determines what is feasible

There are two key factors that determine the feasibility of a supply chain implementing a full chain traceability solution:

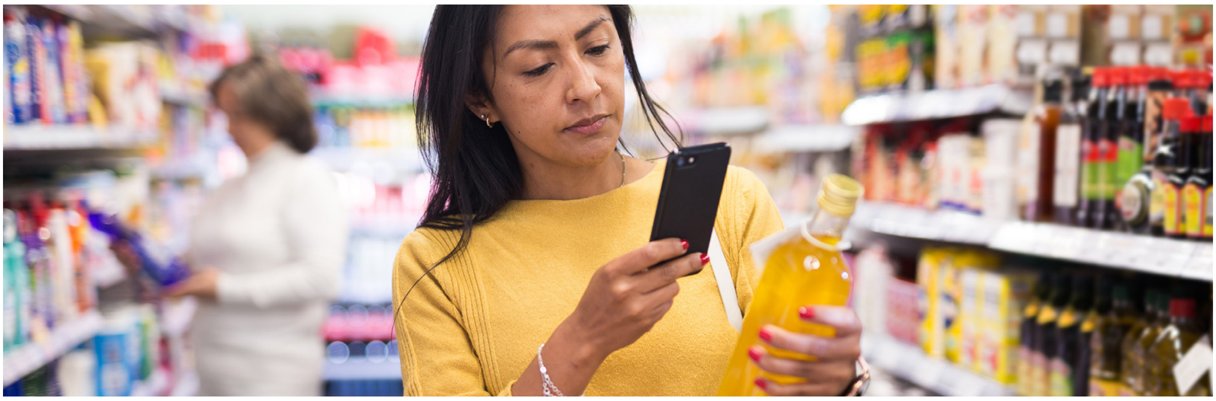
1) whether there is a market for key product information, this could be due to regulatory requirements or consumer preferences; and
2) more complex supply chains with several Critical Tracking Events will make full chain traceability more complicated.

First, there needs to be regulatory or market incentives for businesses to improve traceability. Many markets are requiring increasing information on product origin and associated documentation to ensure that key legal risks have been mitigated. Brand protection is also important, with traceability providing assurance to brand owners. Digitisation can help in this regard by automating processes and reducing the requirements for checking paperwork on shipping consignments. This makes things more cost-efficient in the long term for businesses despite the significant upfront capital costs associated with implementing technology to allow this.

Consumers are becoming increasingly proficient in the use of technology and socially aware of the impact of their buying decisions on the environment and human rights. QR codes can allow consumers to access a wealth of information on the provenance of a product and, potentially, key supply chain parameters (e.g. certificates, quality and safety parameters etc). Though the evidence of whether consumers are willing to pay a price premium for this information is not completely clear, hence why many examples of full chain traceability are limited to high-value and premium products (e.g. grass-fed beef, line caught tuna). However, a blockchain solution (Beefchain™) has been reported as enabling a group of Wyoming beef ranchers to receive a premium on grass-fed beef through providing consumers with greater confidence in the meat they consume. Therefore, digital technology can certainly be an enabler in allowing producers to realise the price premium consumers are willing to pay on certain products.

Second, in many of the examples where full chain traceability has been demonstrated, the supply chains themselves are relatively simple, and often may be vertically integrated. Entities in a fully integrated vertical supply chain (producers, processors, and retailer) are under the same ownership. This crucially makes the co-operation and sharing of data between supply chain entities much easier as there are no commercial incentives to restrict data access.

Standards, such as GS1 and the GDST's seafood traceability standard, are also critically important for traceability infrastructure and interoperability. They help ensure that data requirements for different markets are better harmonised, meaning the same data point has to be only inputted once into a standardised universally accepted format.



Engaging with small-scale producers

A few case studies have shown that it is possible for small-scale producers to participate in full chain traceability (for example the Provenance tuna blockchain) through mobile applications, provided there is reasonable Wi-Fi coverage.

Sourcetrace[61] is another software provider aimed at spice producers, enabling rural small-scale farmers to capture key data and overcome the traditional barriers around quality control. Its product, TraceNext, is a food safety technology appropriate for spot quality testing of spices and capturing key information through spice supply chains.

At least in some of these case studies, participation of small-scale producers in full chain traceability initiatives has required facilitation from NGOs. For example, the Provenance tuna blockchain pilot initiative was facilitated by the International Pole & Line Foundation (IPNLF) and Fairtrade. Such initiatives that bring small-scale producers together to improve working conditions and fair pay are perhaps one of the key things can be done to improve the accessibility and uptake of technology by small-scale producers. It should be also noted that small-scale producers will likely need training on how to use technology to ensure it is used correctly. Engagement with small-scale producers in full chain traceability initiatives will at the very least require an in-kind investment by the lead organisation, often a consumer facing organisation.

Notwithstanding these initiatives, for many small-scale producers, there are practical and logistical challenges that will need to be overcome so that the potential of new technologies can be properly realised. For example, produce from small-scale shrimp farms is often collected by traders that then sell on the product to seafood processors. It should be noted that traders and numerous other intermediaries often play a key role in linking small-scale producers with global markets, and it will often be in their own interest to keep their onward relationships with buyers separate from their suppliers, meaning that full chain traceability will be difficult to realise in such circumstances.

Full chain traceability does not replace verification

While digital technology can certainly be an enabler, making management of supply chains more efficient in the long run, there will always be a need for third-party certification and assurance. Industry scandals such as horsegate have meant the requirements for product authenticity testing have become more onerous in terms of meeting regulatory requirements for many markets and also the requirements of third-party food safety certification schemes, such as BRCGS.

61 Sourcetrace https://www.sourcetrace.com/blog/spice-traceability-a-complex-food-chain/

Additionally, as the demand for product data has grown to cover risks around food safety, sustainability, storage requirements, legal requirements etc., there has been an acceleration in the number of ways to provide assurance of the veracity of the data. The introduction of new technologies and solutions will require investment and skills development across the food industry.

As shown in Sections 4.3 and 4.4 there are several different types of testing method. Rapid screening methods through use of sensing technology has made testing easier and quicker and enables a higher degree of verification. If such screening identifies an issue then further detailed analysis would be undertaken. As technology grows in pace and becomes affordable it is likely that physical testing may be reduced. However, there would still be a need for testing in cases of complaints, recalls, confirming specifications, and for enforcement purposes.

Data entry validation irrespective of the technology (blockchain or otherwise) will also become increasingly important[62]. In the case of blockchain, just because there is better visibility of data uploaded onto the chain this is no guarantee of its veracity. The consensus algorithm in blockchain governing the writing of new data verifies who provided the data, but not the 'what' [the data itself]. Manual data entry will be susceptible to human error whether it has been entered into an online app or spreadsheet. Automating data-entry processes and developing foolproof ways of avoiding erroneous data entry will be key to ensure the adage of 'garbage in = garbage out' is avoided.

There are new risks with digitisation

Incidences of hacking and cyber crime are increasing globally, with data security issues and systems malfunction amongst the key risks for many organisations. A foresight review published by the Foundation[63], on the inherent risks around critical digital infrastructure and industrial IoT, concluded that the current pace of change in cyber security management will not match the fast emergence of new security threats to IoT environments. Current capabilities either do not scale, have not been tested, or simply do not exist yet.

While there are many challenges, the foresight review identified eight actions businesses could take to manage cyber security risks:

- always consider harm consequences when planning how to manage risks
- consider how security controls may fail with increasing use of IoT devices
- use techniques that can provide a continuous assessment of the business' position (near real-time) as opposed to periodic assessments
- consider how its supply chains are using IoT: consider their failure to maintain cyber security as risk to its own security risk management plans
- invest in forensic readiness processes
- include a consideration of future scenarios in risk assessments
- invest in training for staff on IoT standards and good practice; and
- collaborate to establish a device interface protocol for sharing security monitoring information.

While there are many benefits of digitisation in improving supply chain efficiencies, this serious downside needs to also be considered by businesses to ensure that cyber security measures and staff training are also costed into decisions around implementing traceability solutions that rely on internet connectivity.

62 Industry experts estimated 35% to 40% of all data in supply chain systems are faulty https://www.supplychaindive.com/news/blokchain-technology-trust-data-integrity-supply-chain/549139/

63 Foresight Review of Cyber Security for the Industrial IoT https://www.lrfoundation.org.uk/en/news/cybersecurity-foresight-review/

The benefits of improved traceability to the consumer

As of May 2021, a search of the term 'food AND traceability' in Web of Science returned over 2,800 publications. The evidence that improved traceability leads to safer food systems is unequivocal[64] and commonly accepted. For example, one study of European consumers' perceptions of traceability showed that they associate it with health, quality, safety and control, the latter associated with trust and confidence[65]. This is underpinned by evidence that traceability reduces the time taken to undertake product recalls and also enables recalls to be much more targeted, limiting their size and reputational impacts on the businesses affected[66].

There are countless numbers of website blogs on full chain traceability and benefits. Many of these are being published by technology providers promoting particular solutions. The costs versus benefits of implementing a full chain traceability solution have to be weighed up within the context of the attributes of the product (e.g. its uniqueness and value), complexity of the supply chain, and region of interest. For example, in China, a recent study of Chinese consumers found that willingness to pay for traceability is about 10% higher for detailed information than abbreviated information, with a particular interest in quality certificates and details of the chemical fertilisers / pesticides used in food production[67]. Interestingly in this study, males, married persons, and those with a relatively low educational level, placed a higher premium on traceability with detailed information, but consumers with good self-reported health did not want to pay a high premium for traceability with detailed information.

While the safety benefits of improved food traceability may be universal, consumer willingness to pay to pay for the costs associated with providing enhanced traceability information will be very dependent on market conditions and demographics. Having a good understanding of target markets will determine the main objectives for a traceability system, for example, building consumer trust on particular issues (e.g. the use of chemicals in production, that additives during processing are well managed), and / or ensuring that information on provenance is accurately reported, and that any product claims are underpinned by verifiable evidence.

64 For a review, see *Traceability in a food supply chain: Safety and quality perspectives*. Aung, M.M., Chang, Y.S. 2014. Food Control 39: 172 - 184

65 *Consumer perceptions of traceability: A cross-national comparison of the associated benefits*. van Rijswijka, W., Frewer, L.J., Menozzi, D., Faioli, G. 2008. Food Quality and Preference 19 (5) https://www.sciencedirect.com/science/article/pii/S0950329308000190

66 *Traceability, recalls, industry reputation and product safety*. Pouliot, S., Sumner, D.A. 2013. European Review of Agricultural Economics 40 (1): 121 - 142

67 *Amount of information and the willingness of consumers to pay for food traceability in China*. Jin, S., Zhang, Y., Xu, J. 2017. Food Control 77: 163 - 170

7. Conclusion and recommendations

This review was tasked with providing insights in six key areas.

1. The full range of traceability techniques, both established and in development

A desk-based review was undertaken of traceability software providers, Internet of Things (IoT), food sensing technologies, and physical testing technologies. Given the huge number of players and evolving nature of technology and 'solutions', it is impossible to envisage a truly global traceability system that covers foods in a consistent way. Certainly not all will use the same platform, have the same data requirements, etc. However, GS1 and sector specific standards will provide a much-needed framework for ensuring key information is recorded consistently to reduce interoperability issues. With examples from the seafood sector, it is evident that collaboration between different parts of the supply chain to agree core data requirements (Key Data Elements) is a vital first stage.

The ongoing development of a global standard for seafood traceability, the Global Dialogue on Seafood Traceability (GDST), could be mirrored in other sectors, where there is a definite need for improved traceability. though In sectors where the current supply chain is very fragmented, for example the spice industry. GDST could be a potential operating model; acknowledging that one size does not fit all but providing a useful framework that could be adapted for other sectors.

2. The gaps, limitations, benefits, and risks associated with different traceability techniques

A SWOT analysis was undertaken for each general technology category. These show that each type of traceability technology has its own uses and future opportunities. However, there are also issues, with no single technology application providing a solution that is easily introduced, without reliance on other factors e.g.. interaction with other technologies, manual processes and data input. Technology is an enabler of traceability, not 'the solution'.

It was beyond the scope of this project to analyse in detail the risks associated with specific types of technology / devices (for example, different types of software solution), and readers are cautioned to undertake their own research before committing to a particular technology provider / solution.

3. The stakeholders involved in food traceability

The case studies outlined in Section 5 were used to illustrate examples of the different initiatives and organisations involved in food traceability at present. The range of stakeholders with an interest in food traceability is vast, spanning government regulators, industries, standard and assurance schemes, technology providers, and consumers.

4. The challenges to food traceability resulting from global inequalities in access to, and skills in the use of, relevant technology

One focus of the case studies was to draw out initiatives that had involved small-scale producers, who typically are at a disadvantage in being able to access relevant technology (both in terms of cost and having the necessary skills). A few initiatives were identified that make it possible for small-scale producers to participate in full chain traceability. For example, the Provenance tuna blockchain allows pole and line fishermen to upload key data on their catch through a smartphone application. However, these initiatives often require a third-party NGO to help facilitate engagement from small-scale producers. There is a clear need to improve engagement with small-scale producers so that they can leverage new technology to their own advantage to build connections with consumers who are interested in differentiated versus mass produced products. A technology roadmap tailored towards small-scale producers in different sectors might help facilitate dialogue on the unique traceability challenges experienced in the production of different types of food product.

5. The likely impact of food traceability initiatives on existing global inequalities resulting from different levels of access to, and skills in the use of, relevant technology

Major markets (USA, EU, Canada, Australia) have well established food safety and traceability requirements, yet businesses are still using B2B based transfer of information, and it will take many years for LMICs to be able to be on a level playing field. With requirements expected to change and information demands expected to increase, it is important to consider that the technology roadmap for LMICs takes into account the language, operational and cultural challenges in these regions.

6. The evidence that improved traceability of food makes food safe for each individual, based on their own needs and beliefs

The evidence that improved traceability leads to safer food systems is unequivocal and commonly accepted. It could be assumed that improved traceability empowers discerning consumers to make better choices based on their own beliefs. However, verification and third-party assurance will still be required to underpin the veracity of the traceability claims being made. From an auditor and verification perspective a key challenge will be understanding the numerous systems and the data being gathered.

Recommendations

Based on the case study findings and review of traceability technologies, the following activities have been identified as a starting point for discussion with other organisations with an interest in food traceability. These recommendations are focused at building capacity into traceability methods and use, advocating and communicating, and strengthening the evidence base that traceability improves food safety.

Capacity building

- Ensure latest technical innovation in traceability informs any food safety activities.
- Provide guidance / support / training to LMICs in ensuring food sectors can meet evolving regulatory and traceability demands of export markets.
- Collaborate / partner with existing traceability initiatives (e.g. GDST) or establish new initiatives in specific sectors of interest.
- Provide training resources for food businesses (particularly in LMICs) to better understand traceability and its links to food safety, food sustainability, and environmental protection.

Advocacy and communications

- Develop a technology roadmap for businesses to better understand the opportunities, risks (data security) and cost implications around using new types of traceability technology (e.g. blockchain) in different food sector supply chains.
- Develop guidance for consumers to better understand the benefits of food traceability.

Evidence building

- Undertake market research to understand the needs and 'willingness to pay' by consumers for improved traceability information on the origin of food / drink products to generate trust / confidence.
- Assess the interoperability of new technologies with existing stock control traceability systems, and accessibility of these new technologies to suppliers that operate in developing markets.

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Annex 1 - Glossary

Blockchain

A shared record keeping system that eliminates the need to aggregate or reconcile across several separate systems (i.e. ledgers); once information is added, it cannot be deleted and requires a specific 'key' to view specific information or add to the system.

Blockchain technology in particular has been touted by many as a 'wonder solution' to enable full chain traceability and foolproof integrity, however key challenges remain, particularly around the verification of data being uploaded at the start of the chain, ownership of data, data security, and scaling and associated cost issues. Other cloud-based systems could be more practical and pragmatic in the short mid-term and use elements of blockchain technology where appropriate.

The 'cloud'

The cloud refers to software and services that run on the internet, instead of locally on a computer. Most cloud services can be accessed through a web browser.

EPCIS

Electronic Product Code Information Services (EPCIS) is a Global GS1 Standard for creating and sharing visibility event data, both within and across enterprises, to enable users to gain a shared view of physical or digital objects within a relevant business context.

Internet of Things (IoT)

Online / cloud-based systems for real-time data generation and collation. Collect comprehensive and consistent data about food products along the supply chain. Can be made visible / open to numerous operators.

Consumer and industrial devices are having chips inserted into them to collect and communicate data. Essentially objects that 'talk' to each other. The IoT is made up of devices – from simple sensors to smartphones and wearables – connected together.

Interoperability

The ability of different information technology systems and software applications to communicate, to exchange data accurately, effectively, and consistently, and to use the information that has been exchanged.

Spectroscopy

Spectroscopic methods measure the wavelength dependence of the interaction of light with matter. This interaction could be the amount of light absorbed by a sample, or the diffuse reflection of light off a sample, making spectroscopy a valuable tool for measuring a wide variety of liquids, solids and gases. Every compound is unique in its molecular composition and arrangement of atoms; therefore, each chemical will interact with light at different wavelengths. By incorporating certain types of measurement heads and probes, it is possible to measure food samples in-line without destroying any of the product and delaying the process.
https://www.photonics.com/Articles/Spectroscopy_Can_Head_Off_Food_Safety_Crises/a57942

TACCP

Threat Assessment and Critical Control Points. This protocol focuses on tampering, intentional adulteration of food, and food defence. TACCP generally requires a wider range of employee involvement than HACCP, as it covers issues such as manufacturing plant and transportation security, IT security, and employee background checks. Some points will overlap with HACCP, such as tamper-proof seals and various quality control checks.

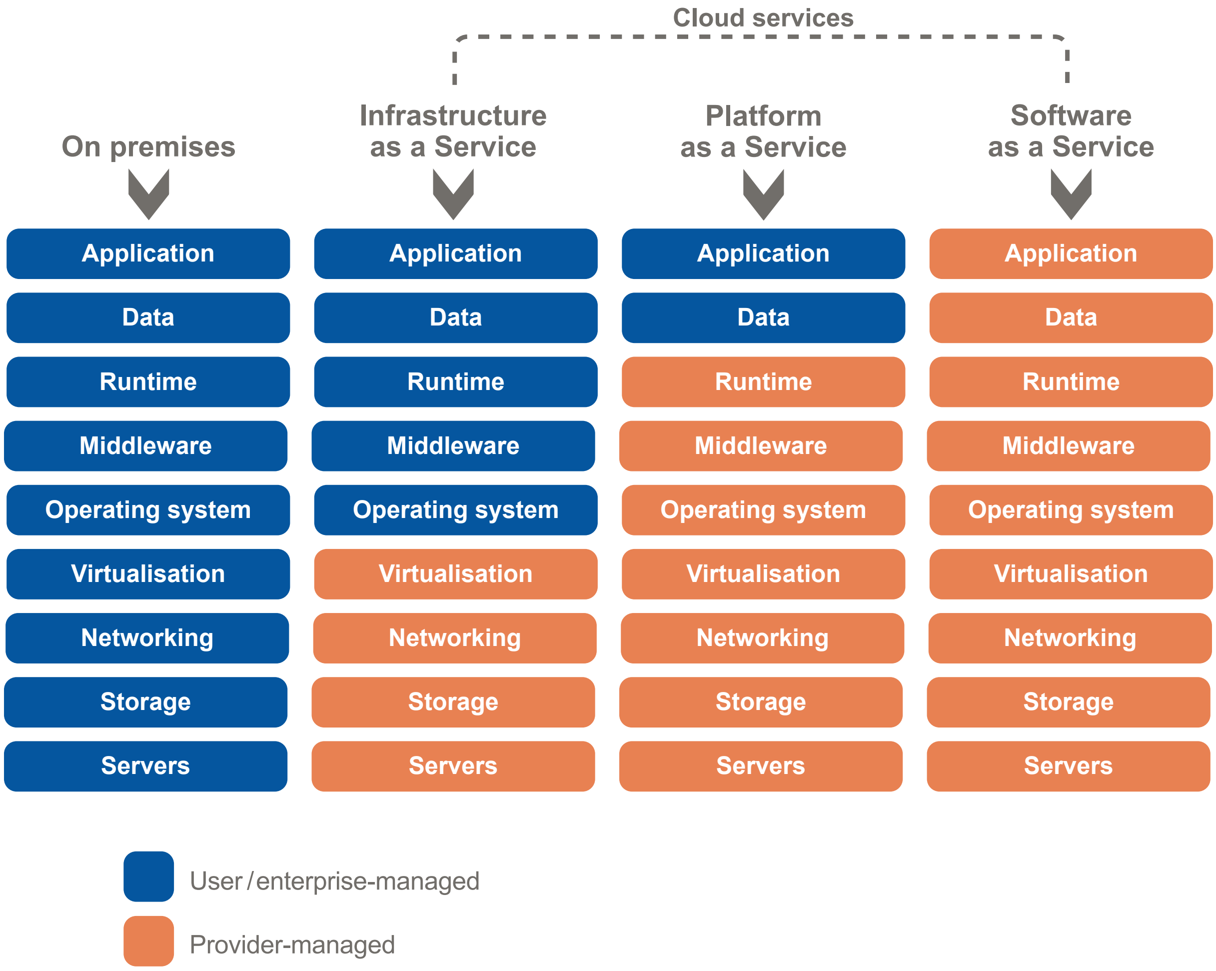
VACCP

Vulnerability Assessment and Critical Control Points. It focuses on food fraud as well and widens the scope to include systematic prevention of any potential adulteration of food, whether intentional or not, by identifying the vulnerable points in a supply chain. It is especially concerned with economically motivated adulteration (EMA). Examples include product substitutions, unapproved product enhancements, counterfeiting, stolen goods and others.

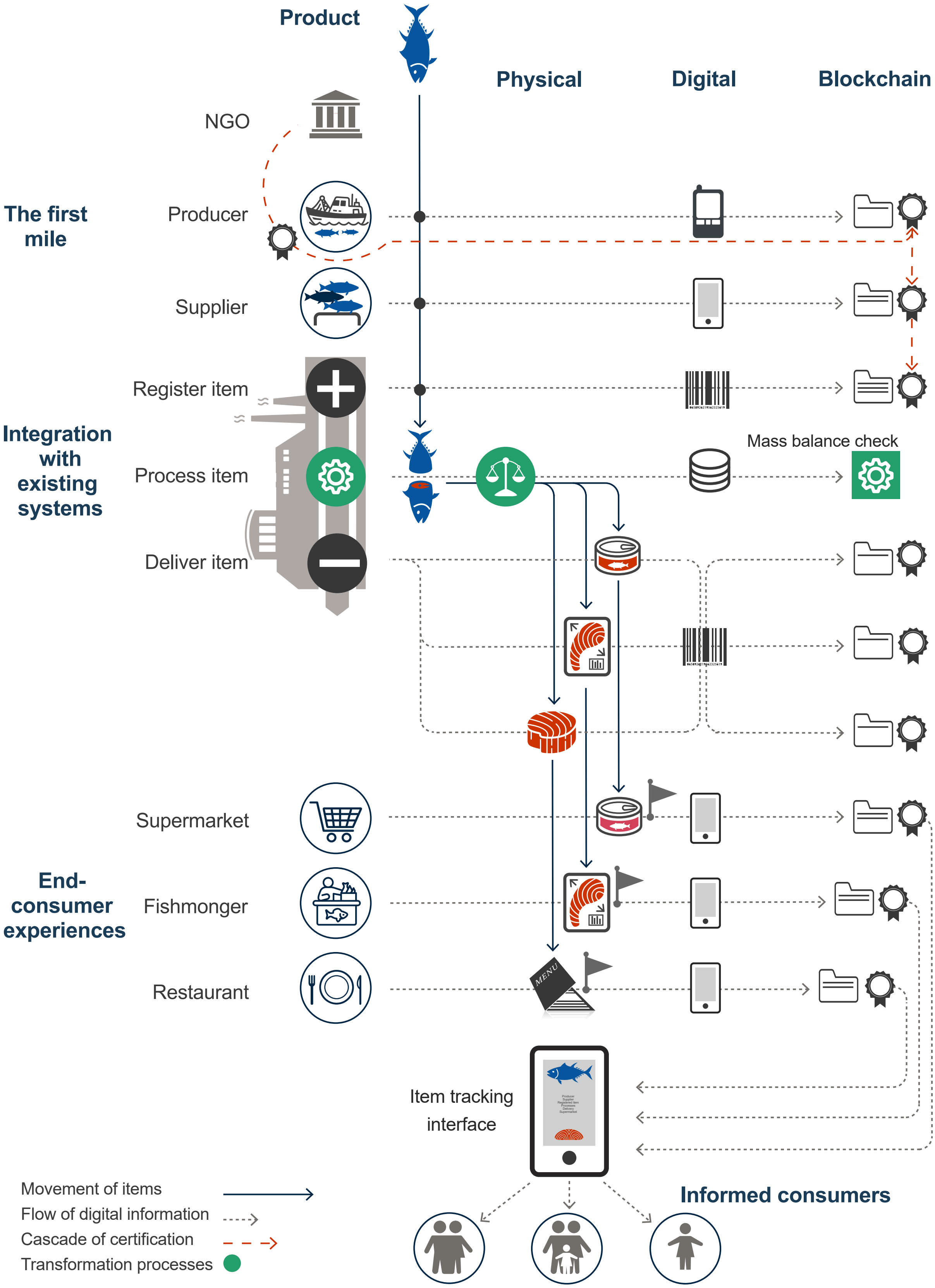
Annex 2 – List of stakeholders interviewed

Sector	Organisation	Contact	Correspondence
Consultancy	Alinea	Brian Bedard	Call
	Food Forensics	Rick Sanderson	Call
Technology provider	IBM	Espen Braathe	Webinar
Professional membership body	Institute of Food Science and Technology (IFST)	Prof Chris Elliot	Webinar
		Clare Menezes	
		Hayley Ward-Ivan	
Technology provider	Provenance	Erika Starke	Call

Annex 3 – Software options



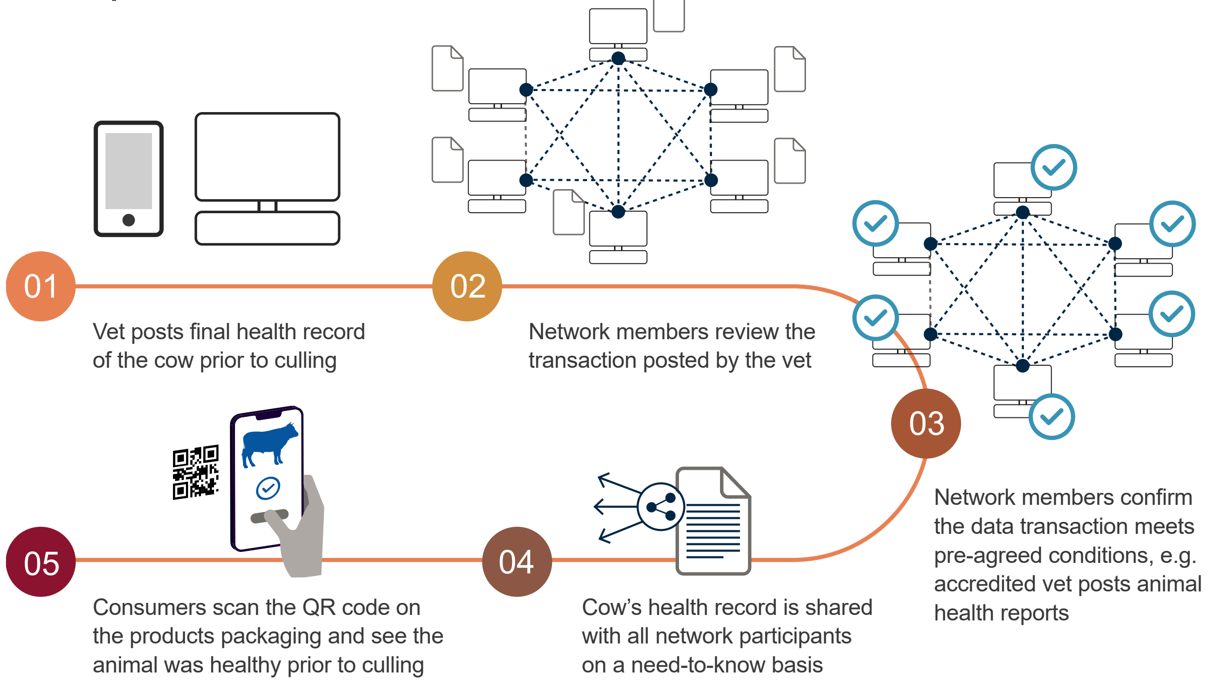
Annex 4 – Blockchain in a tuna supply chain



Source: https://www.provenance.org/tracking-tuna-on-the-blockchain

Annex 5 – Blockchain in the beef industry

An example of how a blockchain works



Consumer engagement

Current model

Current labelling practices share product information with the consumer, such as:

- product description
- best before dates
- origin of the beef product; and
- quality standards.

Blockchain model

QR codes located on product packaging give the consumer access to the information stored on the blockchain through an augmented reality experience. This provides consumers with product information that aligns with evolving purchase drivers and consumer trends.

The consumer will be able to use their smart mobile device to scan a QR code which will provide them with detailed information about the product's journey to the shelf.

To align with the growth of online retail a hyperlink can be added to webpages. This will enable consumer access to the information stored on the blockchain to enable informed purchase decisions.

Source: https://www2.deloitte.com/content/dam/Deloitte/de/Documents/Innovation/Beefing-up-Blockchain-Meat-Supply-Chain-Transformation-Deloitte-2018.pdf

The impact of improved traceability on the safety of food

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