Review of use of Distributed Ledger Technology (Blockchain) in Food Systems relevant to Scotland.

A report for RESAS project RI-B5-05: Novel Multi-Sector Approaches to Provenance and Food Tracking for use in Distributed Ledger Protocols.

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Introduction

This report reviews the potential application of blockchain technologies to the monitoring of Food Systems generally and Food Systems in Scotland specifically. It is produced as part of RESAS project RI-B5-05 (Novel Multi-Sector Approaches to Provenance and Food Tracking for use in Distributed Ledger Protocols).[1]

Blockchain technology offers transformative potential for the Food System. By enhancing traceability, improving food safety, increasing supply chain efficiency, combating food fraud, and supporting sustainability efforts, blockchain addresses many of the critical challenges facing the food industry today. International bodies such as the Food and Agriculture Organisation of the United Nations have highlighted the value of blockchain in tracing food chains[2] and there is increasing interest in applying this technology to Food Systems.[3]

RESAS project RI-B5-05

Project RI-B5-05 is designed to develop generic technologies – based on novel approaches to DNA (epigenetic) and chemical analysis – that can be used to track Food Systems and provenance across a wide range of produce and sectors in Distributed Ledger Technology systems, often referred to as 'blockchain'. It focuses on key Scottish produce – meat and fish (including salmon) – and is aimed at; 1) consumers seeking to make informed choices about food, 2) food producers processors and retailers seeking to protect and trade on their reputation for quality, safety, and provenance, 3) regulators tasked with ensuring safety and regulatory compliance within the Food System, 4) government and policy makers seeking to better understand food chains and their implications for public health and the economy. Significant changes to international trade following Brexit magnify the scale of the challenge in these areas and make the development of reliable technologies more urgent.

[1] This review was produced based on expert knowledge augmented by online searches using Web of Science, Google and ChatGPT (results verified manually).
[2] Blockchain Application in Seafood Value Chains: https://openknowledge.fao.org/server/api/core/bitstreams/e7401fd1-ee65-4523-9f42-abf874605427/content
[3] Ismail S, Reza H, Salameh K, Kashani Zadeh H, Vasefi F. Toward an Intelligent Blockchain IoT-Enabled Fish Supply Chain: A Review and Conceptual Framework. Sensors (Basel). 2023 May 28;23(11):5136. doi: 10.3390/s23115136. PMID: 37299864; PMCID: PMC10255790.

Blockchain and its application to Food Systems

Blockchain technologies were originally developed for cryptocurrencies but their decentralized, transparent, and immutable characteristics also make them useful for traceability, safety, supply chain efficiency, and regulatory enforcement, relevant to Food Systems.

Traceability:

One of the most significant applications of blockchain in the Food System is enhancing traceability. The food supply chain is complex and involves multiple stakeholders including farmers, processors, distributors, and retailers. This complexity often makes it challenging to trace the origin of food products and verify their journey from farm to table. Blockchain provides a decentralized ledger where every transaction is recorded and visible to all parties involved. This ensures that the entire supply chain is transparent, and each stakeholder can easily trace the history of a food product.

Consumers can scan a QR code on a food package and access detailed information about the product’s journey, including the farm where it was produced, the processing methods used, and the logistics involved in its transportation. This level of transparency builds trust among consumers and helps them make informed purchasing decisions.

Improving Food Safety:

Foodborne illnesses can have severe public health implications and adversely affect public confidence in the Food System. Blockchain technology can significantly improve food safety by enabling rapid response to contamination incidents. In the event of a foodborne disease outbreak, the source of contamination can be quickly identified by tracing the product's journey through the blockchain. This swift identification allows for targeted recalls, minimizing the impact of the contamination and reducing the risk to consumers.

Moreover, blockchain ensures the integrity of food safety records. Once data is recorded on the blockchain, in theory it cannot be altered or tampered with, ensuring that all information regarding food safety protocols, inspections, and certifications is accurate and trustworthy.

Enhancing Supply Chain Efficiency

Blockchain also enhances supply chain efficiency by streamlining operations and reducing administrative overhead. Traditional supply chain management relies heavily on paper-based records and manual processes, which are prone to errors and delays. Blockchain automates and digitizes these processes, providing a single, immutable record of all transactions.

Smart contracts, a feature of blockchain technology, can automate various aspects of the supply chain. For example, payments can be automatically released when certain conditions are met, such as the delivery of goods or the verification of quality standards. This automation reduces the need for intermediaries, speeds up transactions, and lowers costs.

Combating Food Fraud

Food fraud, including mis-labeling and adulteration, is a significant issue in the food industry. Blockchain can combat food fraud by providing a secure and transparent record of a product's journey through the supply chain. Each stakeholder, from the farmer to the retailer, records their transactions on the blockchain, creating a verifiable history of the product. This makes it difficult for fraudulent products to enter the supply chain without detection. However blockchain technology on its own cannot completely ensure against deliberate or inadvertent misrepresentation. This requires physical verification methods which are the subject of project RI-B5-05.[4]

Sustainability and Ethical Sourcing

Consumers are increasingly concerned about the sustainability and ethical sourcing of their food. Blockchain can verify and authenticate claims about sustainability practices and ethical sourcing. For example, certifications for organic farming or fair trade can be recorded on the blockchain, allowing consumers to verify these claims.

Conclusion

Blockchain technology offers transformative potential for the Food System. By enhancing traceability, improving food safety, increasing supply chain efficiency, combating food fraud, and supporting sustainability efforts, blockchain addresses many of the critical challenges facing the food industry today. Its ability to provide a transparent, immutable, and decentralized record of transactions makes it an invaluable tool for building a more resilient and trustworthy Food System.

Many automated logistic systems have been developed to implement blockchain technology and a number have already been applied to food chains. A good example is provided by the IBM system[5] but other proprietary systems and approaches are available. Examples of applications to Food Systems internationally and in Scotland are provided below.

[4] See section below on; "The importance of physical verification in blockchain applications to Food Systems"

[5] *https://www.ibm.com/topics/blockchain*

Examples of blockchain technology applications in the food chain internationally

Walmart and IBM's Food Trust

Walmart, in collaboration with IBM, has implemented blockchain technology through the IBM Food Trust platform. This initiative aims to improve food traceability from farm to table. For example, Walmart has used blockchain to track mangoes in the U.S. and pork in China. By scanning a QR code on a mango package, consumers can access detailed information about its origin, including the farm it came from, the harvesting process, and the transportation details. This enhanced traceability reduces the time needed to trace the source of food contamination from days or weeks to just a few seconds.

Carrefour

French retail giant Carrefour has also adopted blockchain technology to track and trace its food products. Carrefour's blockchain platform provides consumers with detailed information about various products, such as free-range chickens, eggs, and tomatoes. By scanning a QR code on the product's packaging, consumers can see data about the product's journey, including the location of the farm, the date of production, and the methods used. This initiative has increased consumer trust and allowed Carrefour to market its products as transparent and trustworthy.

Provenance and Tuna Fishing

Provenance, a UK-based company, has utilized blockchain to bring transparency to the tuna supply chain in Southeast Asia. By using blockchain technology, Provenance ensures that tuna fish are sustainably sourced and ethically caught. Fishermen register their catch on the blockchain, providing data on the time and location of the catch. This information is then accessible to consumers and retailers, helping to prevent illegal fishing practices and ensuring that the tuna they purchase is sustainably sourced.

Bumble Bee Foods and SAP

Bumble Bee Foods, a leading seafood company, has partnered with SAP to use blockchain technology for tracking its yellowfin tuna. This blockchain solution allows consumers to trace the journey of their tuna from the ocean to the table. By scanning a QR code on the product package, consumers can access information about the tuna's origin, including the fishing vessel, the location of the catch, and the processing methods. This transparency helps to ensure sustainable fishing practices and builds consumer trust in Bumble Bee's products.

Nestlé and IBM

Nestlé has also joined IBM's Food Trust network to enhance the traceability of its products. One of the pilot projects involved tracing the journey of mashed potatoes from the farm to the consumer. By leveraging blockchain technology, Nestlé can provide detailed information about the production process, ensuring transparency and accountability at every step of the supply chain. This initiative helps to improve food safety and build consumer confidence in Nestlé's products.

TE-FOOD

TE-FOOD is a blockchain-based solution that focuses on the traceability of fresh food. It has been implemented in various countries to track livestock, vegetables, and fruits. For example, in Vietnam, TE-FOOD has been used to track pigs from farms to slaughterhouses, ensuring that all relevant data, such as vaccination records and transportation details, are recorded on the blockchain. This system helps to improve food safety and reduce the risk of foodborne illnesses.

GrainChain

GrainChain is a blockchain-based platform that aims to streamline the supply chain for grains and other agricultural products. By using smart contracts, GrainChain automates transactions and ensures transparency and accuracy in the supply chain. Farmers can record their harvests on the blockchain, and buyers can verify the quality and origin of the grains. This system helps to reduce fraud, improve efficiency, and ensure fair payments to farmers.

Salmon

IBM has developed a blockchain platform with several food production companies, where a QR code is used to show data on the product. It is in use by French retailer Carrefour for its Atlantic salmon products from Norwegian producer Lerøy.[6]

Examples of blockchain technology applications in the food chain in Scotland

Scottish Enterprise "Blockchain in Scotland, Landscape Overview" review

A 2023 Scottish Enterprise report on "**Blockchain in Scotland, Landscape Overview**"[7] highlighted the importance and potential of blockchain for the Scottish Food sector. The report highlighted the example of Scottish farmers working with SAC Consulting and a data company to develop distributed ledger, or blockchain, technology to allow shoppers to trace oat products back along the supply chain ensure that they were they

[6] https://www.bestfishes.org.uk/wp-content/uploads/Summary-of-Fidra-farmed-salmon-consumer-survey-results-full-length-final.pdf
[7] https://www.scottish-enterprise.com/media/4bcdhunr/blockchain-in-scotland-landscape-overview.pdf

were gluten-free. The paucity of other specific examples highlighted the fact that the Scottish food sector has not yet realised the potential of blockchain in relation to Food Systems.

Aberdeen-Angus Cattle Society

The Aberdeen-Angus Cattle Society reported plans to use IdentiGEN's DNA TraceBack® technology to generate a reference DNA databank of animals eligible to enter the Certified Aberdeen Angus Beef programme. The databank can be used in the routine DNA monitoring of beef to confirm its Aberdeen-Angus origins, confirming its authenticity and quality. The aspiration is to allow farmers, processors, and retailers can record data, providing a comprehensive and immutable record of the product's journey. This approach is suitable for blockchain applications.

Scottish Salmon

Progress in this area has recently been documented by Fidra (an environmental charity supporting sustainability & preventing pollution).[8] Many projects are in development to enhance the traceability of Scottish salmon, ensuring that consumers and retailers can verify the origin and quality of the fish. By recording different stages of the salmon's journey on the blockchain, from hatchery to processing and distribution, the project aims to build consumer trust and ensure the sustainability of the product. This allows retailers to display the name of farm on product packaging, with corresponding data available on Scotland Aquaculture database and Scotland Environment website. Such approaches are blockchain compatible.

The importance of physical verification in blockchain applications to Food Systems

The value of blockchain depends on its immutability and applications to the Food System rely on the integrity of the link between the food identifier (often represented in a QR code or barcode) and the physical food itself. The weakness of many blockchain systems is that this link can potentially be compromised by tampering with the digital identifier (QR/barcode) on the food itself or misrepresenting the nature of the food when the digital identifier is generated.

In order to provide that final level of verification it is necessary to link the identifier to the physical fabric of the food itself in a way that it cannot be compromised and which can be checked at any part of the product journey to the consumer. This potential weakness in Food System blockchain applications is often overlooked and it requires

[8] https://www.bestfishes.org.uk/wp-content/uploads/Summary-of-Fidra-farmed-salmon-consumer-survey-results-full-length-final.pdf

the availability of physical detection methods to establish the authenticity and origin of foods and food products.

A number of verification methods have been developed to detect food adulteration, verify geographical origin, and authenticate food products but they each have strengths and weaknesses and they have often been developed for a specific application rather than for generic use in blockchain. Below are some of the primary physical detection methods.

Physical verification methods

Spectroscopy Techniques

a Infrared Spectroscopy (IR)

Infrared spectroscopy, including Near-Infrared (NIR) and Fourier-Transform Infrared (FTIR) spectroscopy, is widely used to determine the composition of food products. These methods can identify specific chemical bonds and functional groups, helping to detect adulteration and confirm the authenticity of food products.

b Raman Spectroscopy

Raman spectroscopy is used to identify molecular composition based on the scattering of monochromatic light. It is effective in detecting food fraud and verifying the authenticity of high-value products like honey, olive oil, and wine.

Chromatography Techniques

a Gas Chromatography (GC)

Gas chromatography, often coupled with mass spectrometry (GC-MS), is used to analyze volatile compounds in food products. It is commonly used for flavor and fragrance analysis and to detect adulterants in essential oils, spirits, and other food products.

b Liquid Chromatography (LC)

Liquid chromatography, including High-Performance Liquid Chromatography (HPLC), is used to separate and identify compounds in food products. It is particularly useful for analyzing vitamins, organic acids, and other non-volatile compounds.

Mass Spectrometry (MS)

Mass spectrometry, when combined with chromatography techniques (GC-MS, LC-MS), provides precise molecular information about the components of food products. It is extensively used for detecting contaminants, verifying authenticity, and identifying geographic origin through isotope ratio mass spectrometry (IRMS).

Stable Isotope Analysis

Stable isotope analysis involves measuring the ratios of stable isotopes, such as carbon-13 (13C), nitrogen-15 (15N), and oxygen-18 (18O), in food products. These ratios can provide information about the geographical origin and production methods of the food, as they vary with environmental and climatic conditions.

Nuclear Magnetic Resonance (NMR) Spectroscopy

NMR spectroscopy provides detailed information about the molecular structure and composition of food products. It is used for authenticity testing, detecting adulteration, and determining the geographical origin of products like wine, olive oil, and fruit juices.

DNA-Based Methods

a Polymerase Chain Reaction (PCR)

PCR is used to amplify specific DNA sequences, allowing for the identification of species and the detection of genetically modified organisms (GMOs) in food products. It is crucial for verifying the authenticity of meat, fish, and plant-based products.

b DNA Barcoding

DNA barcoding involves sequencing a short, standardized region of DNA to identify species. It is used for species identification in seafood, meat, and plant products, helping to prevent food fraud and mislabeling.

Electrophoresis

Electrophoresis, including gel electrophoresis and capillary electrophoresis, is used to separate and identify proteins and nucleic acids in food products. It is effective in verifying species authenticity and detecting adulteration in meat and dairy products.

Elemental Analysis

Elemental analysis involves measuring the concentrations of elements, such as trace metals, in food products. Techniques like Inductively Coupled Plasma Mass Spectrometry (ICP-MS) are used to determine the geographic origin and detect contamination.

Sensory Analysis

Sensory analysis involves human sensory evaluation to assess the taste, aroma, texture, and appearance of food products. While subjective, it is often used in combination with other methods to verify product quality and authenticity.

Microscopy

Microscopy techniques, including light microscopy and electron microscopy, are used to examine the microstructure and morphology of food products. They can help detect adulteration, identify contaminants, and verify the authenticity of products like spices and dairy.

Combining Methods

Often, a combination of these physical detection methods is used to provide a comprehensive analysis of food authenticity and origin. For example, combining spectroscopy, chromatography, and DNA-based methods can offer a robust approach to verifying the authenticity and traceability of complex food products.

Conclusions

Blockchain technology offers transformative potential for the Scottish Food System but uptake thus far has been limited to a few large sectors with the capacity and sophistication to understand the approach and the resources to implement it. Blockchain is a holistic approach which is potentially generalisable across the whole of the Scottish Food sector. It lends itself to the development of core generic technologies and approaches that can be modified in relatively minor ways for each sector.

An important limitation to the uptake of this powerful approach is a lack of understanding of its potential across the food sector in Scotland. There is a need to educate and inform the sector of the potential of blockchain in parallel with the development of generic approaches that can be applied at different scales, from niche producers to large industrial concerns.

Project RI-B5-05 is designed to contribute to these goals.