Heliyon 9 (2023) e16526

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Review article

"Blockchain technology in food safety and traceability concern to livestock products"

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ARTICLE INFO

Keywords:
Food traceability
Blockchain technology
Food supply chain
Livestock products

ABSTRACT

Livestock products share more than fifteen percent of total agri-foods traded worldwide. A global increase in food demand has increased the risk to food safety. Improvements in food quality, cold chain transit, and preservation are required for safe livestock products. Though, the food safety and regulation authorities demand complete food traceability from farm to fork, but in traditional supply chain it is ignored by fiddling with the transit paperwork and bill invoices. The process of supply chain reformation and activities linked to food recalls during food safety issues are insanely expensive and challenging. Traceability-driven food supply chain management is likely to implement novel technologies like the Internet of Things (IoT). The capability of the Blockchain era within the food sector is emerging with use cases across different regions, as shown via the growing number of studies. Credibility, efficiency, and safety are all improved when food products can be instantly traced from their point of origin through all points of contact on their way to the consumer. Blockchain assures a tamper-proof and transparent system that allows an innovative business solution, together with smart contracts. However, there are significant difficulties with the implementation of blockchain technology for food traceability. It necessitates more and more training platforms as well as trainers, who can make understanding and operability of this technology easy among ground-level participants and food entities. For the tactical application of this technology, it is essential to comprehend the legal and regulatory framework.

1. Introduction

Animal product industrialization has grown speedily, which also leads to development in the scale and scope of animal husbandry and breeding. The world's trade in animal products accounted for sixteen percent of the whole agri-food market. The value of animal products that were traded internationally went from €56 billion in 2000 to €152 billion (in current currency) in 2018 [1]. Animal products are becoming more and more popular, so large-scale livestock farming and the food chains that support it have become very important. Research have been carried out to analyse a range of manufacturing factors that affect the quality of livestock products, as well as attempts, were made to optimize and boost the quality from all facets. As seen over the previous decade, following food

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https://doi.org/10.1016/j.heliyon.2023.e16526
Received 7 November 2022; Received in revised form 20 April 2023; Accepted 18 May 2023
Available online 21 May 2023
2405-8440/

security, it is mandatory to produce adequate safe food. With the increase in the demand for food needed, the threat to food safety is growing and wants extra attention [2,3]. World Health Organization [4] stated that the safeguarding of food quality and safety continuously poses new challenges for the food sector and science and millions of people suffer every year due to contaminated foods. The manufacturing of quality products is one of the features of food security, which dictate methodical research aimed at monitoring the existing quality regulations and standards, initially from grass and fodder production, their processing, animal feeding, animal products manufacturing, transportation, and up to the purchaser's basket. In industrialized countries, food safety is of major concern where consumers are more and more demanding superior quality and safer foods [5]. The livestock products processing necessitates improvements in food quality and taste, cold chain transportation, and preservation. However, it is complicated to manage the quality of animal products in the traditional supply chain.

At the same time, the nuisances raised include various types of food frauds, because fraudsters usually have a high level of cleverness and scientific knowledge, which makes it complicated to blame the perpetrators. Inadvertent contamination and residues in the end products occur repeatedly regardless of established high standards of hygiene and measures for quality assurance [6]. The global economy faces massive social and economic loss due to mislabelled, misbranded, contaminated, and adulterated food products. The food supply chain, including on-farm rearing, processing, storage, shipping, and retail chain, can be contaminated by microorganisms due to improper management and pose a threat to the contamination of foods [7]. An expected 600 million humans or nearly one of 10 people on the earth, fall unwell after consuming contaminated food products [8]. Genomic testing and analysis are appropriate for the detection of meat speciation as well as a genetically modified ingredient or product [9]. Based on Proteomics, animal species, technological processes or storage-dependent changes can be well understood. Metabolomics analyses, which are generally done by mass spectrometry (MS) or nuclear magnetic resonance (NMR) spectroscopy and iso-topolomics techniques are pertinent for indication of origin or means of manufacture [10]. However, comparatively huge instrumentation and laboratory infrastructure is mandatory in these testing methods and is usually time-consuming as well as expensive even though some parameters can be rapidly tested on-site with the use of rapid test kits. Such defined analytical procedures are followed in the food industry in addition to that, implement by food regulations authorities [11]. Additionally, the food regulation and safety standards authorities insist on complete traceability of foods from farm to fork. So far, the intermediates/supervisors can find a way to escape from these claims by manipulating transport documentation and bill invoices. In the international food trade system, the food recall-related work and supply chain reformation process during the food safety issues are shown to be expensive, time-ingesting, and very difficult.

The food traceability system assembles, stores and transmits adequate history of livestock products, from the rearing of livestock on a farm up to the final product in the consumer's basket, at all stages inside the Food Supply Chain (FSC) in order to check the product for quality control as well as safety and can be traced forward and backward direction whenever required [12]. Traceability is well thought-out as a new quality indicator in the food sector. Case-sensitive information storage and handling becomes mandatory in the food industry. Regulations are imposed by food authorities to allow monitoring and identification of all raw materials and substances utilized in food product preparation [13]. These types of necessities have been incorporated by many FSC participants but a number of them still rely on a non-automated paper-based system. The food sector makes use of a traceability system for the enhancement of FSC and facilitates the traceback for food quality and safety [12]. Traditional technologies for record-keeping can offer some solutions to the above issues, but that can't clear up all the issues. Therefore, it is strongly desired to introduce a new edge think tank as well as advanced technologies that create possibilities to solve product quality and supply chain problems.

Traceability-driven FSC management in the food sector is likely to implement novel technology like the Internet of Things (IoT). IoT-associated applications provide up-to-date info about products as well as contamination facts in the course of production and distribution [14]. IoT-enabled programs and applicable technology such as Radio Frequency Identification (RFID) possibly will revolutionize the food sector by digitizing facts to be queried and managed in real-time [15]. The application of blockchain technology has recently experienced a remarkable boom. The capability of the blockchain era within the food sector is only starting to emerge with use cases across different regions, as shown via the growing number of studies, trials, research initiatives, and projects [16]. Early researchers indicated that blockchain technology has to be used in the food sector for two reasons: a greater efficient food tracing system, which may promptly recognize a source of food infection while a food safety crisis happens; the second is to construct purchaser's faith in food safety via blockchain technology [17]. Blockchain assures a tamper-proof, transparent, shared, and protected system that can allow an innovative business solution, in particular together with smart contracts [18]. Blockchain is a virtual and distributed transaction ledger, maintained with the aid of multiple peer-to-peer computing machines that are not depending upon a trusted third party. Every transaction information file (block) is controlled thru unique software program systems that permit the records to be transmitted, processed, saved, and represented in human-readable form [19]. This article explains blockchain technology, how it works with food safety and traceability systems, and how it has recently been included in the initiatives related to the livestock products sector.

1.1. Concept of blockchain technology (BCT)

In 1982, David Chaum first time proposed a cryptographic concept similar to Blockchain technology [20]. Haber and Stornetta [21] further described tamper-proof time-stamping of digital documents or information on a cryptographically secured chain of blocks. Bayer et al. [22] integrated Merkle trees in this design to improve efficiency by permitting numerous document certifications to be composed into one block.

The concept of BCT was imagined by a person (or group of people) in 2008 using the name Satoshi Nakamoto to provide a digital and decentralized public transaction ledger of the crypto-currency: Bitcoin. Nakamoto stepped forward the layout by employing a Hash cash-like technique to timestamp blocks without the involvement of trusted central authorities or the financial sector. More than ten years have passed ever since the release of the virtual currency "Bitcoin: A Peer-to-Peer Electronic Cash System" by using the pseudonymous creator [23]. Blockchain Technology is coming into recognition as the underlying digital infrastructure on which cryptocurrencies work. A cryptocurrency (e.g. Bitcoin) is a digital currency that can be used in the same way as international or national currency like the USD or Indian rupee. Throughout the last decade, Blockchain has passed through extensive progress, which is a digital currency (Blockchain 1.0), digital economy (Blockchain 2.0), and digital society (Blockchain 3.0).

1.2. Blockchain generation

Blockchain is a distributed, decentralized, and jointly verifiable ledger technology consisting of digital records called a *block*. Blockchain technology (BCT) particularly connects blocks thru cryptographic strategies (Fig. 1). Each data block consists of information regarding a particular system and creates virtual signatures to authenticate the validity of facts and links to the subsequent data block to form the main chain that is referred to as Blockchain [24]. The information on a blockchain is immutable, which makes it a justifiable technology for industries like finance, cybersecurity, healthcare, food supply chain, and public services [25]. The BCT makes use of a hash algorithm. The first block will act as the genesis block, additionally known as the block header. The beginner (genesis) block mainly includes the Hash, Mine difficulty; Nonce (number only used once) for mining data, Timestamp, and Merkle tree root records [26]. Through this, the individual blocks are linked together and protected against manipulations. The blockchain is distributed on the computers of all subscribers (which act as a node) so that a "peer-to-peer network" is obtained. All participants (stakeholders) keep eye on the data and verify the data (consensus principle) to be added to the block at the same time by the addition of a timestamp to the document/information [27]. The data on the block become tamperproof by the addition of a hash algorithm of the previous block and finally a new hash algorithm generated for that block. In this way, it forms a chain between block to block by hash algorithm. The hash procedure is a one-way code word technique and guarantees that the transaction data/information becomes tamperproof [28]. If someone changes data/information on the block, it will automatically change the timestamp of the block so that the created hash value will change and data/information turns out to be invalid [29]. The Merkle tree root on the blockchain accumulates the values of all nodes and these nodes contain the hash value for data/information present on blocks [30].

1.3. Blockchain classification based on governance

It refers to the regulation of permission to the digital register (ledger) and associated services. Based on reads and write control allowed to participants over block data, it is classified into three types.

1) Public Blockchain: It enables everyone to access the network. Energy usage is high. Access to the block information is permitted for each node (Participant) on the blockchain network. These digital ledgers are distributed and freely accessible. The contract or transaction can be validated by any node, and information is made publicly available. The public blockchain is very anonymous when it comes to the participant's identity [31]. The majority of cryptocurrencies commonly use it.
2) Private Blockchain: A genuine invitation is a sole way for a participant to function as a node. Data privacy is ensured since only specific nodes on the system could access block data. It is not a completely decentralized system. The controller permits the nodes to view the data. It functions as a centralised, cryptographic-based organisational network, e.g. Multichain [32]. It is applicable to sectors like the banking system, securities foundations, etc …

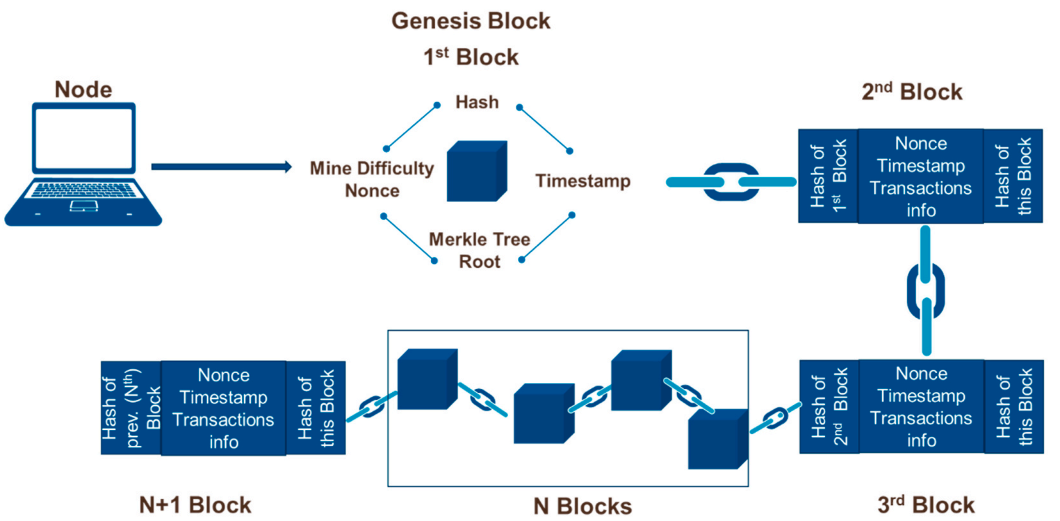

Fig. 1. Blockchain formation.

3) Permissioned Blockchain: Access to over-block data is only permitted by the system's verified and trusted nodes who meet the required standards. The blockchain network is controlled by authorized members, each of whom has a specific role and defined authorization. It combines elements of both public and private blockchains. The likelihood of a Sybil attack is very low [33]. Most of the industrial sectors like the health-care sector, food sector, education sector, real-estate sector, agricultural sector, etc … can have applicability of permissioned Blockchain [16].

1.4. Consensus algorithm in blockchain technology

Almost every transaction is distributed via the network of computing machinery that runs a blockchain procedure and is required to be authenticated by all computer nodes [34]. The consensus algorithm (consensus mechanism) allows a network of computers (nodes) to work together aiming that all contributors obtain identical copies of the distributed database files. The "Proof of Work" (PoW) and "Proof of Stakes" (PoS) are mainly used consensus algorithms in blockchain technology.

The well-known cryptocurrency: "Bitcoin" uses a "Proof of Work" (PoW) and it requires computer nodes (miners) to solve the difficulty level of mining before authenticating transactions and adding data/information to block in Blockchain [35]. The first computer that is able to solve difficulty level (mathematical algorithm) as well as determine the hash and values authenticated by others, receives a number of bitcoins. This practice is repeated every 10 min [36] (Bohme et al., 2015). The probability to solve mathematical algorithm increases with an increase in numbers and networks of computers (miners) and at the same time, miners guarantee the network's inaccessibility against hackers. The miners compete continuously for computer power that springing up a race between individual miners. So in the PoW mechanism, the requirement of hardware, computer power and energy is very high that making it costly [37].

As an alternative to this, another mechanism that got momentum is "Proof of Stake" (PoS) with the emergence of the Ethereum system in 2015, which is established on a different algorithm that does not necessitate special hardware equipment and higher computing power [6]. In this mechanism, the validating power is given to individuals/bodies who possess coins within the system and place them "on stake" during transaction authorization. The computing nodes are identified as "validators" rather than "miners" [35]. To validate blocks and generate hashes, participants are chosen at random, and the stake volume maintained determines the likelihood of the random selection. So this mechanism is resource-saving and secure [38].

Other consensus mechanism includes Proof of Elapsed Time (PoET), Byzantine Fault Tolerance (BFT), Proof of Authority (PoA) [19] Delegated Proof of Stakes, Steller Consensus Protocol, Ripple, Raft, Proof of Burn, Proof of Personhood, etc … as described in details by Mingxiao et al. [39], Zubaydi et al. [40] and Cachin and Vukolic [41].

There are numerous blockchain platforms (i.e Bitcoin, Ethereum, Hyperledger, Agnostic, BigChainDB, Corda, Credits, Multichain, Openchain, Quorum, Stellar and Symbiont Assembly, etc …) working on any one of the consensus mechanisms as described in detail by Cachin and Vukolic [41]. Ethereum and Hyperledger are the most popular blockchain platforms experimented with or deployed in the groceries/agri-food supply chain and among these two, as time passed from the year 2015 to the year 2020, the Hyperledger blockchain took the lead over Ethereum [42].

1.5. Application of blockchain technology

Since the inception of blockchain technology, it has increased interest in its application to various sectors because of building up trust among stakeholders [43]. In the start-up, it was intended to maintain and record financial transactions among participants, and with the technological improvements, the application area for BCT has been broad up internationally [30]. Globally, more and more attention is given to research in this area by various organizations and countries. The revolutionizing changes applied in this technology have increased its application in digital data authentication and signature, controlling and storing organizational records, IPR and patent tracking and verification, tracing patient health records, enabling smart contracts, real estate management and record of ownership transfer, tracing products through the supply chain from producers to consumers [19]. Szabo [44] introduced the concept of smart contracts and now a day, it is vastly applied in this technology under the term Blockchain 2.0, which made tempering or censoring of data impossible. A contract is an agreement having a legal object entered into willingly by two or more bodies/parties. Each of them takes part to create one or more authorized obligations between them. A smart contract is a digitalized computer protocol that allows an agreement to be automatically executed with predefined conditions and authenticates as well as administers the performance of a contract or averts the need for a contractual clause [45]. A frequently used example for simple understanding is the task of drinks vending machine, which dispense a predefined volume of drink after the required money is entered into the machine [6]. The application of smart contracts in blockchain technology could be widely used in food supply chain (FSC) management systems to solve various food safety and traceability-related problems. The data interoperability, auditability, transparency, cost-reduction, tracing of products, authenticity and integrity are the important benefits of BCT application with smart contracts in the FSC traceability system [15].

1.6. Blockchain technology in food sector

The main area of application of BCT in the food sector concern to traceability system in the supply chain but along with this it can be also valuable for tracking and identification of the point of food fraud and authentication of food safety in the FSC management system from farm to fork. The BCT effectively promotes food safety and purchaser's reliance by timely and tamperproof sharing of data of product just like batch number, location and date of production, food safety certification, real-time hygienic and sanitary condition of production site [17]. In FSC the food passes through multiple locations starting from production, processing, transportation, distribution, and retail store up to the consumer. The involvement of intermediators can make the food transactions vulnerable to food fraud and costly in above said supply chain [46] because of improper maintenance of all records about food products from farm to fork. So till date, the current system of FSC is inefficient and unreliable [47]. The use of various kinds of sensors and digital technologies (i.e. RFID tags, NFC, Automatic Identification and Data Capture (AIDC) systems, mechanical and biological sensors, time-temperature indicators, smartphones, digital signatures, etc …) [48,49] can produce real-time information about environmental, production, processing, packaging, storage, transportation and distribution condition of food products. All real-time data records can be transferred to blocks using BCT and smart contracts after being verified and validated by all participants using a consensus process. This serves as an immutable way to deposit data records that are accepted by all participant parties [19]. The smart contracts in this system can be executed for management of food safety standards, food quality certifications, application of HACCP, Good Agricultural Practices and Good Manufacturing Practices and other standards as and when required at various stages of food transactions [15,50and51]. If the required procedure and standards from production to the consumer's basket do not meet, the smart contract will automatically dismiss the food supply process and information is not allowed to enter in Blockchain [52]. At last, all the information about the product from production to retail store can be available to the consumer by scanning a QR code labelled on the product which increases the consumer's trust and is also useful to manage food quality and safety from farm to fork. The participant parties of the food chain include producers, processors, logistic suppliers, retailers and purchasers. Each one act as a node and every node can see the information on the public service platform without knowing the private details of the parties/bodies [53]. Each participant's private details can be stored in a permissioned chain whereas the data which should be released is stored in a public chain. This permit parties to access, write and confirm with each other and safeguard participants' privacy to the maximum level possible [43].

1.6.1. Blockchain technology for food safety

The production, processing and handling of foods in a hygienic way to safeguard human health is known as food safety. The growing international trade of foods increases the difficulty to maintain food quality assurance and safety [6]. Globally, animal food safety and quality are of main concern. The safety issues in animal products are mainly due to the use of hormones, antibiotic residues, adulteration, zoonosis, microbial contamination as well as from animal feed with pesticides or herbicides residues, heavy metals and other contamination [54]. Drinking contaminated water can cause illness in animals which require veterinary medicines to treat their illness so along with the safety of animal feed, the provision of safe and potable drinking water is also necessary.

The handling of animals and temperature directly affect the safety of animal products mainly meat products. Stress due to fluctuation in environmental temperature during the transportation of animals to the slaughterhouse can cause quality problems in meat products after slaughter [55]. Illness in animals before slaughter, Improper handling of carcass or meat products during processing and packaging leads to microbial contamination and temperature fluctuation increases the microbial load, which causes abnormality in meat products quality [54]. In the same way, the production, collection, transportation, and processing of milk and milk products also require proper attention. Therefore, real-time monitoring and recording of temperature handling of animals and relative humidity

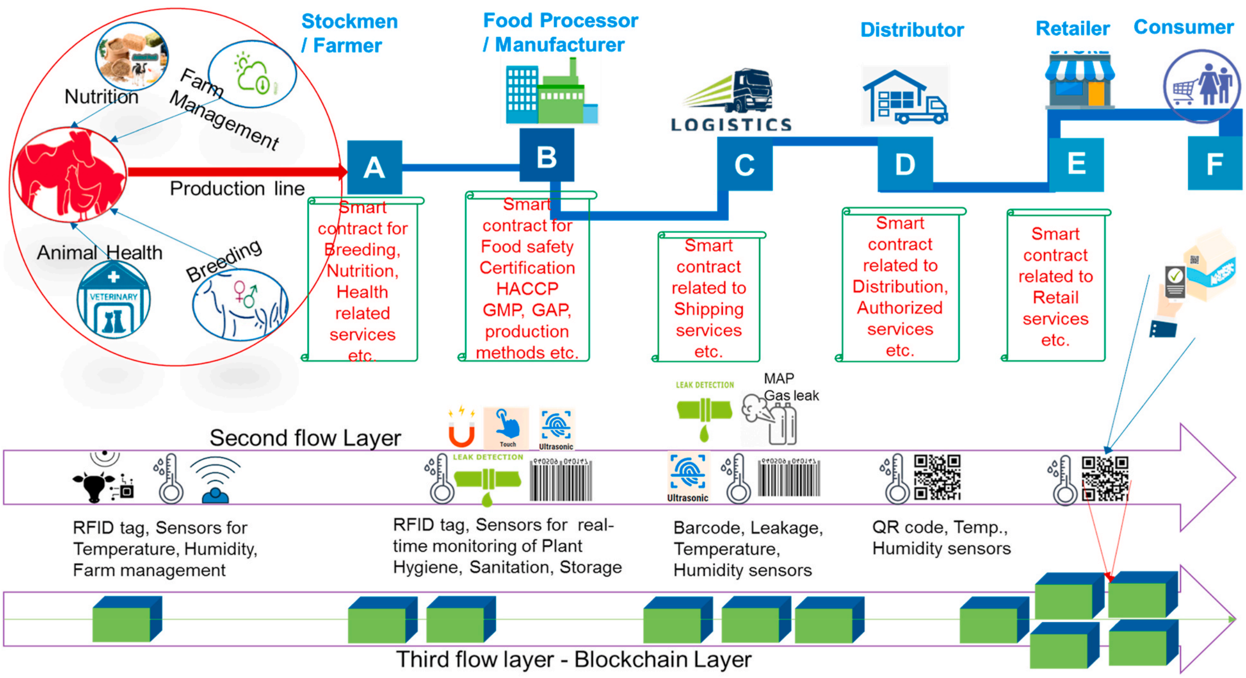

Fig. 2. Blockchain technology driven food traceability.

from farm to fork are necessary to support products safety and quality as well as to improve the management, productivity and profitability which can be possible by application of BCT along with sensors as described earlier [15]. So in the FSC, the stage where standards criteria of process and regulatory and production standards do not match, the parties are informed in a real-time manner to correct the process and further supply chain can be stopped or recall of that particularly affected batch of animal products can be carried out very fast and easily in a time-saving and cost-effective manner that leads to maintaining buyer's faith in safety and quality of product and trust in the company [18,56]. The feed provided to animals, administration of veterinary drugs as well as antibiotics and species, breeds and quantity of animals raised and managed by farmers are also necessary to record on the blockchain. As the data on BCT is verified by a consensus mechanism, if the inconsistent and improper or illegal amount of drugs, hormones and antibiotics used by farmers, the smart contract automatically terminates the transaction and data is not documented in Blockchain [57]. The recording of genomic and proteomic information of farm animals on the blockchain can provide immutable data about whether the animal products produced are from the same animals or different [16] leads to quality assurance and food safety. Food industries can minimize food frauds by real-time detection and relating outbreaks to their definite cause [58]. In this way, the distributed ledger technique like blockchain technology permits more determined and feasible control of food safety and quality.

1.6.2. Blockchain technology-driven food traceability

Locating product-related information starting from animal rearing up to product dispatch in a retail store in FSC is known as food traceability. It includes data for animal breeding, nutrition, health, production and management on farms, processing and preservation related data of product, packaging and logistic information and finally up to the consumer's basket [14]. Now a day, the proof of food integrity and transparency is also inquired about by stakeholders as well as purchasers. The real-time tracking of all data can increase the speed of the supply chain and decrease food fraud in all stages of the product's life cycle. But in current, online and centralized monitoring or offline and paper-based traceability systems, data infringement can be possible by supervisors or intermediators of supply chain management. BCT offers an immutable and consensus mechanism-driven online data recording system in the supply chain at all stages of food production which makes the traceability system concrete, irreversible and unchallengeable by any means [6]. BCT-driven food traceability can be simply illustrated as a three-layer flow (Fig. 2) where the physical flow layer is for the physical food supply chain in which food products go on their way from producer to purchaser. The second flow layer is for a digital record system in which data recording of the physical flow layer is going on simultaneously with the use of various types of sensors, RFID, QR code and other digital technologies as described earlier. The third flow layer is a digital blockchain infrastructure network in which employing a smart contract, the data recorded in the second flow layer is verified by all participant bodies/parties with a consensus algorithm and forms a virtual data block at every stage of the supply chain. This flow layer also follows the physical flow layer and forms a chain of digital data blocks [19]. If any person tries to hack or change information recorded, the hash value of that particular block changes and that does not permit the altered value to enter into that particular blockchain which means it is an immutable record-keeping platform. The food product on its way to the consumer's basket passes through various points of production and at every point some data is recorded to the blockchain as described below.

A. Stockmen: They provide information about the rearing of livestock on a farm, Data in details recorded on blockchain about feeding, breeding, health, production and management practices followed by them and tag number and ownership details of all livestock

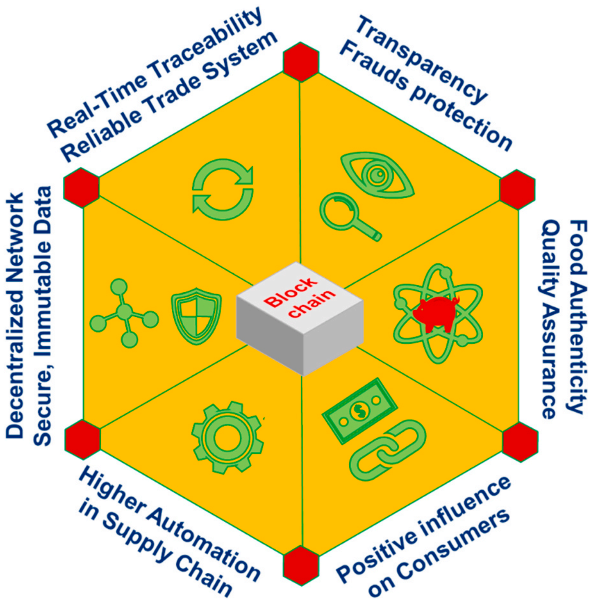

Fig. 3. Benefits of Blockchain technology in food safety and traceability.

whether any animal is directly purchased from the market or not. The hygienic and environmental conditions of farm and animal welfare practices can also be recorded.

B. Manufacturing parties: The information about plant practices, handling of livestock, the hygienic and sanitary condition of a plant, standards and regulations maintained at the plant, equipment availability, utilization and disinfection procedure followed at the plant, data regarding processing methods, use of packaging technologies, labelling details of every batch of product, etc. The data about the financial transaction between manufacturer and stockmen as well as between a manufacturer and logistic supplier is also recorded on a block.
C. Logistic supplier (Distributors): Data regarding transportation method used, shipping details, transit period, and real-time data recorded about temperature, humidity and other product environmental conditions during transportation period. The financial deals between logistic suppliers and authorized dealers should also be recorded.
D. Dealers (Wholesalers): Real-time data about storage condition (i.e. time, temperature and humidity) of product up to its supply to retailers. Transportation details can also be recorded. The monetary transaction between dealers and retailers is also recorded.
E. Retailers: Data about the current stock of each product, storage details, expiry date, and period at the store up to the consumer's purchase is recorded on the Blockchain.
F. Buyer: The buyer scan the QR code labelled on the product to get all the details of the product starting from farm to purchase with the use of an internet connection to have an idea about the quality, safety and reliability of the product purchase.

So, a food traceability system on a Blockchain platform ensures tamperproof data collection and real-time monitoring of livestock products in the supply chain and no need to wait for a company or business partner's authorization to access information of products. The possible advantages of blockchain technology in food safety and traceability are briefly illustrated in Fig. 3.

1.7. Livestock products sector and blockchain projects/initiatives

Soon after the inception and promotion of BCT, it started to be used in supply chain management systems and there are so many shreds of evidence that prove its beneficial application [5,59]. In global supply chain management, this technology is predicted to grow at an annual growth rate of 87% and escalate from $45 million in 2018 to $3314.6 million by 2023 [60].

Globally, a number of large animal products manufacturing food enterprises have already started to incorporate BCT in their food supply chain. First time ever in 2016, the use of BCT in the animal products supply chain was initiated by U.S.-based retailer company Walmart to monitor pork products in China and produce imported to the U.S. via Latin America [61] (Insights, 2017). It has resulted that the tracing of pork products on their route to the U.S. takes a few minutes related to several days taken in past and also provides all the details of pork from farm to Walmart retail store in the U.S. [62]. IBM launched its blockchain technology using a software system namely "IBM Food Trust" and it was started to be applied by many big grocery/food companies like Walmart, Nestle and Unilever [5]. This type of large food sector entities are also involved their suppliers to practice blockchain in their supply of raw materials to the company. The cold-chain monitoring in the supply chain was developed by ZetoChain using the Internet of Things. It was stated that cold-chain problems are identified in real-time and the responsible parties are informed quickly for fast action on the issue. The Zeto tags can be scanned by the purchaser to locate product history [63]. In the pilot project carried out in 2016 by U.K.-based tech start-up "Provenance". The company tested "Tuna" fishing and supply to traders, processors, brands, and supermarkets on a blockchain platform. This digital identity also traces the audit info that verifies that fish were caught legitimately and sustainably [64].

Blockchain-based tracing of turkeys from farms to their shopper's stores was developed by Cargill Inc. [19]. In 2017, the Chinese e-commerce company Jingdong (JD.com) deployed Hyperledger Fabric – an open-source blockchain platform-based supply chain first time in partnership with Kerchin, an Inner Mongolian-based beef manufacturer [65] where the purchaser can find the history like animals used, nutrition info, food safety test reports and slaughtering related information. In 2018, the primary emphasis of the company is to monitor beef supply from Australia and so JD.com declared a plan to adopt BCT for its meat supply chain [5]. Similarly, Alibaba, another China-based e-commerce giant, announced a trial program to track global food consignments sold to China, on its online marketplace T-Mall, which were supplied by Australian healthcare supply firm Blackmores and New Zealand dairy product maker Fonterra [64]. A research project was conducted in Australia to track beef production from origin to consumption with the use of BCT based "BeefLedger" platform [66] which can be useful to reduce the time required to trace infected stock which ultimately improves efficiency and food safety. BCT-based trading of meat subscription boxes was deployed by The Grass Roots Farmers' Cooperative in 2017 to inform consumers in a trustworthy way about the rearing conditions of their animals. In the pilot project performed in San Francisco, where cartoons of chicken distributed were labelled with QR codes that link to the story of the meat they contain [19]. Intel presented the Hyperledger Sawtooth blockchain platform's operating model for seafood supply chain traceability in 2017 [67].

The blockchain-based Pacific Islands' tuna fishing traceability project was announced by World Wildlife Foundation (WWF) in 2018. Through this, fishermen can register their fishing on a network platform by RFID and fish scanning which eliminate illegal activities [68]. The French retailer company, Carrefour announced a plan in 2018 to adopt BCT-directed food traceability for its own branded Filiere Qualite Carrefour (FQC) products like salmon fish, eggs, tomato, chicken, fresh milk, cheese, etc … and planned to expand its application to all FQC products by 2022 as well as indicated that BCT can be a good solution to reduce uncertainty about quality and ingredients by access to detailed information of food product [69]. In a report about Blockchain's use in the Irish beef supply chain, the American company Deloitte said that smart farming technologies like smart feeding equipment and cow collars could share data with Blockchain to shed light on the cows' diet. Through the use of this technology, we will be able to track the whereabouts of all Irish beef that changes hands. In addition to increasing openness, this action reflects Ireland's dedication to beef safety and quality. The use of smart contracts in trade finance has the potential to boost productivity and cut costs for international trade. Using their smartphones, customers can scan a QR code that provides in-depth information on the product's path to the shelf [70]. In 2018, a pilot project was deployed by "Perutnina Ptuj" - the largest poultry producer in South-eastern Europe, to provide trustworthy info to their consumers about the rearing condition of poultry, in partnership with OriginTrail: A BCT provider [71]. In 2019, U.S.-based Bumble Bee foods adopted a seafood traceability system functioning on a blockchain platform in collaboration with German tech company SAP. In this system, a consumer can scan a QR code to access info like products' origins, the size of the catch, the point of capture, shipping history, and trade certification [5]. To build up a shrimp supply chain and fortify customer trust in the product, Walmart Inc. announced a pilot project in 2019 for end-to-end shrimp traceability from the Indian state of Andhra Pradesh to the U.S. [72]. Topco Associates, LLC, a leading U.S. food cooperative, employed Envisible's Wholechain traceability technology in 2019 to help member-owner supermarkets trace and highlight seafood origins [73]. Bumblauskas et al. [74] have described a case study of public blockchain-based egg supply chain traceability used by Bytable Inc. in partnership with "farmers' hen house" in which consumers can get information about a particular farmer from whom the eggs came to their basket like farm photos, management practices and certifications that followed in egg production system by scanning QR code on an egg carton. Ripe Technologies, a software firm that offers B2B solutions to grocery stores in order to boost their store and omni-channel performance, has partnered with Neogen, a food safety company based in the United States, to strengthen the link between animal genomics, feed use, and food safety. Ripe's president and co-founder Phil Harris has said that systems like blockchain can be used to back up claims of value addition and production labels. Production could be streamlined with the use of additional digital tools like sensors, the IoT, machine learning, and artificial intelligence [75]. In keeping with the present push of many sectors towards the Internet of Things era, Leme et al. [76], investigate the usage of a unique infrastructure. They presented a system that is efficient, secure, decentralized, and dispersed, which will modernise the way the cattle sector for beef and milk production operates in predominantly rural areas. They mentioned that while the internet is widely available currently, it is still undeveloped and expensive in rural regions, making widespread deployment unfeasible for most farmers. Surjandari et al. [77], tested a permissioned blockchain-based system for the halal industry utilising Hyperledger Fabric and raft consensus. The Blockchain Network of Halal Meat Ordering Systems solves traceability issues. This case study proved effective for protecting halal transaction data on the blockchain. The "tampered-proof" feature gives end users transparency into the halal supply chain. To boost trust in the international beef supply chain between Australia's cattle farmers, processors, and Chinese customers, Cao et al. [78], prototyped a blockchain-based human-machine reconcile method for beef supply chain traceability. BeefLedger, a commercial developer and provider of a blockchain-enabled beef provenance tool built on the Ethereum platform and the proof-of-authority (POA) protocol, commissioned and co-led the case-based design. This Blockchain-credentialed traceability prototype inspires more faith and confidence in Australian beef products among Chinese customers. As a result of their findings, they have decided to further develop, apply, and test the human-machine reconcile mechanism with a wider range of producers, consumers, and supply chain stakeholders such as customs, agri-departments, quarantine, and regulatory authorities. Through integration with TraceX's blockchain-powered traceability technologies, a dairy foods company based in India, "Milk Mantra", is able to record the digital path of milk in real time, allowing for the creation of reliable consumer brands. Technology makes it possible for all parties in the dairy value chain to share democratic data in a safe and secure way. This addresses consumers' main concern about food safety in the dairy industry [79]. Dey et al. [80], developed a FoodSQRBlock (Food Safety Quick Response Block) based on blockchain technology with Google Cloud Platform to emulate an actual food production scenario with milk as a livestock produce example, which digitalizes the information involved in food production and makes it approachable, transparent, and traceable by consumers and producers via QR codes. Similarly, Khanna et al. [81], proposed a blockchain-based platform with the use of smart contracts, QR technology, and IoT to increase the safety and traceability of the dairy supply chain in India, specifically targeting products like milk, butter, and cheese. Besides the issue of food traceability, this aims to maintain the nutritional quality of dairy products by detecting adulteration and contamination and boosting the efficiency of production. According to them, the framework proved helpful in locating and eliminating adulterated and contaminated food products from a supply chain, which helped build trust between unknown partners and made conflict resolution more manageable. Smart contracts help cut down on the expense of supply chain management by doing away with middlemen. Nonetheless, they emphasised the importance of future research for real-time application, as the interconnection of numerous dairy supply chains operating in different regions may present a complexity for smooth operation. After testing it for more than a year, Dong Nai, Vietnam's largest pork-producing province, put TE-FOOD's traceability system into use all over the country in 2022. The goal of the project is to build a high-tech system for identifying, managing, and tracing animal products and to improve the management and quality control of breeding, slaughtering, transportation, trade, and consumption in the province [82].

Many other experiments and prototypes were proposed to build an IoT and blockchain-based supply chain traceability system for livestock products [83–88]. From these studies, we can deduce that implementing a conceptual framework for animal product supply chain traceability can greatly enhance the efficiency, security, and accountability of supply chain information, boost food quality and safety, and cut down on logistical losses by means of monitoring, tracing, and management. Although the area is still in its infancy and the vast majority of research are still in the design phase, the results of various experiments suggest that a sizeable portion of the effort is already in the implementation or piloting stage. Sendros et al. [89], noted that just 14% of published studies on agricultural blockchain applications address the potential for use in the production and distribution of livestock products. There are several other projects/initiatives that were deployed on a pilot basis or permanent basis in the agricultural food supply chain other than livestock products [19,50,90–95] that show the very good impact of BCT-driven food supply chain traceability and food safety.

1.8. Current challenges

The application of blockchain technology in the food supply chain has shown many benefits, but it is necessary to determine the current challenges faced in the application of this technology in the food supply chain. Development of the Blockchain technology is still in a nascent stage, so the availability of Blockchain specialists is less as compared to other software developers. This leads to an increase in financial load for the deployment of this technology as it was noted that a blockchain specialist charges very high fees as compared to other software technologists [96,97]. So, it's no longer possible for new entrepreneurs or small and medium-sized businesses (SMEs) to use BCT. The skills and awareness regarding BCT are still deficient worldwide [98] and in the livestock food supply chain, the ground-level participants are mainly farmers, who do not have proficiency in advanced technologies, which necessitates the increasing number of training platforms as well as trainers, who can make understanding and operability of this technology easy among the ground-level participants and food entities. In the growing phase of this technology, it is required to demonstrate the scalability, speed, and security to deploy it in the food supply chain [99]. Sometimes, the immutability of data stored on a blockchain can create obstacles to the smooth performance of the food supply chain, as stated by Hald and Kinra [100].

This is the digital ledger technology, which requires a large number of computers and hardware to mine and store data, which leads to an increase in the initial cost of implementation along with the cost of the validation process. However, this challenge can be overcome by using intelligent concepts in a digital framework as described by Cocco et al. [101]. Globally, the public thought of the BCT as a technology used for cryptocurrencies. The high volatility and large daily changes in the value and market share of cryptocurrencies have a negative psychological effect on BCT's reputation [102]. The homogeneity of knowledge and understanding among technical experts and policymakers is still a deficit. The legal conduct of smart contracts in a distributed ledger technology (DLT) framework, particularly in relation to disputes such as enforceability, jurisdiction, the applicability of legal principles of contract law, etc., is still an important and vexed question [103]. The confidentiality of information is still a boundary condition as industries resist sharing their private information with competitors in the market [104]. The lack of common standards may act as a hurdle to the implementation of BCT in the real-life food sector. So, the harmony and regularisation of different blockchain platforms in the food sector are added challenges.

Sustainable, adequate, and safe food supply chain advocacy has also helped bring bioeconomy into the spotlight. The term "bioeconomy" refers to the process by which renewable biological resources are produced and transformed into goods of worth, including waste streams. Livestock production is one of the main production sectors to which bioeconomy would be most closely linked [105]. In order to make the transition to a bioeconomy, it is important to recognize the myriad of interactions that can arise between various governmental objectives and the food industry as well as consumers, which may be solved with blockchain-driven innovations by providing framework for traceable, verifiable, and complete communication of bio-farming practices to consumers who are increasingly wanting to make eco-friendly consumption choices [106]. Blockchain technology within the bioeconomy of the livestock products industry in general does not appear to have attracted the attention of researchers as of yet. More work needs to be done in this area of study, and perhaps in the future an in-depth content analysis of the blockchain-based bioeconomy of livestock output will need to be attempted.

2. Conclusions

In order to improve food safety and traceability in the food supply chain and to increase consumer confidence, distributed decentralized digital ledger technology, like BCT, offers a tamperproof, reliable, fraud-resistant, and trustworthy peer-to-peer network platform. Through the use of Blockchain technology, real-time risk point detection for food safety can reduce food fraud and contamination while also strengthening the mechanism for recalling affected batches of products. In the current food supply chain, the employment of various types of sensors, digital data recorders, and emerging technologies (such as NFC, hyperspectral imaging, RFID, robotics, etc.) paves the way for transparent and secure new edge food traceability and integrity systems in the current food supply chain. The ground-level participants (farmers), the food processing industry, and the supply chain management system can all move to a single track using a blockchain platform. At the moment, the use of blockchain technology in the food supply chain is currently only practical, reasonable, and cost-effective for high-value livestock products and massive market players in the food industry.

Additionally, the technology is still developing and the food supply system requires additional research and practical solutions. Projects, initiatives, or case studies on the use of Blockchain in the livestock products industry are still few in number, in pilot stages, or have just recently been envisioned or addressed in theory. So, more and more research is required to study the potential of blockchain deployment in the food supply chain, as well as the real-life large-scale deployment of this technology for a long time, which is crucial to analysing economic sustainability and scalability in the food supply chain. A number of case studies should be essential to rectify or minimize the barriers and challenges in blockchain integration in the food sector. To make this technology affordable and justifiable for budding enterprises and SMEs, innovations and cutting-edge ideas should be necessary. For the tactical application of this technology, coordination between technical specialists and policymakers is necessary. To keep this technology's legitimacy and make it work better, it is important to understand the legal and regulatory framework for blockchain and smart contracts, as well as other implementation requirements.

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

Data availability statement

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

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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