

Blockchain-Enabled Supply Chain platform for Indian Dairy Industry

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Conventional food supply chains are centralized in nature and possess challenges pertaining to a single point of failure, product irregularities, quality compromises, and loss of data. Numerous cases of food fraud, contamination, and adulteration are daily reported from multiple parts of India, suggesting the absolute need for an upgraded decentralized supply chain model. A country such as India, where its biggest strength is its demographic dividend, cannot afford to malnutrition a large population of its children by allowing them to consume contaminated and adulterated dairy products. In view of the gravity of the situation, a blockchain-enabled supply chain platform for the dairy industry was proposed. With respect to the supply chain platform, the dairy products of choice include milk, cheese, and butter. Blockchain is one of the fastest growing technologies having widespread acceptance across multiple industry verticals.

Keywords: dairy products ; food safety ; traceability ; supply chain management ; blockchain

1. Introduction

Food constitutes one of the most important aspects of human life. Since almost a millennium, humans have been fascinated by the concept of food and from mere mortal pleasure, it has evolved to be a source of goodwill and happiness. Humans consume food on the belief that the products they are consuming are manufactured, processed, stored, and transported in ways that are following the quality standards. However, in the past couple of years, thousands of humans across the world have been infected by consuming contaminated and adulterated food products. One such category of food is dairy products, which have seen significant contamination and adulteration practices in the past. The history of milk adulteration can be traced to 1850 when in New York about 8000 children were killed by the Swill milk scandal ^[1]. Later, it became a serious concern when in China infant milk products were adulterated with melamine ^[2]. The adulteration is made for economic reasons; however, it affects public health ^[3]. Dairy products are one of the largest consumable categories of food products and are seen as a primary source of nutrition across multiple age groups. However, adulteration and contamination affect the nutritional value and host presence of perilous substances making milk inconsumable and harmful. The common milk adulterants are water, starch, urea, glucose, detergents, Vanaspati, and preservatives. Contamination can be biological (microbes), chemical (pesticides, antibiotics, metal etc.), or physical (dust). The contamination in milk initiates in the mammary glands of livestock by excretion of xenobiotic substances such as antibiotics and other veterinary drugs followed by exposure to environmental pollutants, pesticides, pathogens, etc. Fodder is also a significant source of contamination as it may increase the spore load in raw milk. A bad hygiene practice is primarily responsible for microbial contamination in milk, cheese, butter, and other milk products. A knowledge of udder health status, antibiotics administered, and common pathogens in the dairy farm is a must to ensure milk safety and dairy product quality. The other microbial contamination is possible during the long storage period, inefficient cooling storage practices, use of non-sterilized storage tanks, etc. Poor pasteurization paves the path for the survival of microbial pathogens and may cause several food-borne diseases.

Adulteration starts from the mere addition of water into milk. The addition of water decreases the nutritional value of milk and can cause several diseases. The food chain of a dairy product must be transparent to its customers and other participants to maintain the prescribed quality and nutritional values of a product. The lack of transparency, traceability, and provenance in the dairy supply chain has led to large-scale food frauds impacting the lives of millions. The dairy supply chain is one of the most complex food supply chains, as it involves the movement of multiple perishable food products across different stakeholders and complex processing operations. Henceforth, making it a challenging process to ensure food safety for the customer. Thankfully human have blockchain, a new-age technology that enables enterprises to create and manage traceable supply chains ^{[4][5][6][7]}. In its initial years, blockchain was limited in its applicability around the cryptocurrency domain. As time followed, researchers began to identify numerous advantages of integrating blockchain technology across different verticals. One of the recent areas of blockchain research involves its applicability in

the area of supply chain management. Blockchain allows the creation of a decentralised supply chain with immutable transaction records. It helps in tracking the origin of a product and its raw materials from farm to fork ^[8]. The use of a blockchain-enabled dairy supply chain would allow multiple stakeholders such as farmers, consumers, government authorities, and shipping companies to be on one single platform ^{[9][10][11]}. Information regarding products and their movements will be shared with these stakeholders transparently and securely. Apart from providing traceability and transparency to the supply chain, blockchain ensures reduced operational costs and helps in automating the decision-making process. Blockchain technology allows a customer to be aware of the nature and quality of a product and its origin. Blockchain technology coupled with the Internet of Things (IoT) and Cloud has the potential to monitor critical parameters of a dairy product along the entire supply chain. The quality parameters of a dairy product can efficiently be monitored and communicated using a distributed ledger technology such as blockchain. Reduced transportation time, faster payment settlements, and prevention of unnecessary food wastage can be ensured by implementing a blockchain-enabled dairy supply chain. Being an emerging area of research, blockchain-enabled food supply chains have their share of impediments at people and process levels.

2. Overview of the Indian Dairy Industry

India has been one of the largest producers and consumers of dairy products across the world since the late 1990s. The dairy industry is an essential part of the Indian economy and has a significant role in generating rural employment ^{[12][13][14][15]}. As of 2021, the Indian dairy market reached a valuation of INR 13,174 billion with a growth trajectory of reaching INR 30,840 billion by the year 2027. Most of the dairy products in India are consumed domestically, with milk having the largest consumption value. In terms of milk production, India produced more than 198 million tonnes of milk in the year 2019–2020. As per a study conducted by the National Dairy Development Board (NDDB), India will be producing 266.5 million metric tonnes of milk by 2023. States such as Uttar Pradesh, Rajasthan, Madhya Pradesh, Gujarat, and Andhra Pradesh are considered to be the highest producers of milk. In India, the dairy sector holds significant importance as it has huge implications for the socio-economic aspects of its people. Keeping this in mind, the Government of India has launched the National Dairy Programme to boost cattle productivity, enhance milk production, and therefore improve the livelihoods of the farmers. Strategic investments are being made by the governments to improve milk procurement infrastructure in rural parts of India. In recent years, the Indian dairy sector has seen a significant rise in the production and consumption of milk-related value-added products (VAP). Products such as cheese, butter, and yoghurt are witnessing a rise in per-capita consumption. Despite numerous government schemes and the largest bovine population, the milk production per animal in India is less than its contemporaries such as the US and UK. The use of non-scientific methods, inefficient cattle breeding, poor management strategies, and above all the lack of technology intervention are some of the reasons that have led to the diminished growth of the Indian dairy sector. Moreover, a majority of the Indian dairy sector is unorganized in nature and therefore unable to adapt to new technologies and reach competitive markets ^{[16][17][18][19][20]}. With 3/4th of the sector being unorganised, the Indian dairy sector has emerged as a breeding ground for numerous malpractices. The absence of strict audit mechanisms and lack of quality certifications from the governments have led to the surplus use of contaminated and adulterated dairy products. Circulation of adulterated dairy products has become the new normal for the Indian dairy sector causing severe health implications for its people. It is believed that 79% of milk available in the Indian market is adulterated to a report presented by the Consumer Guidance Society of India (CGSI) in the year 2020. The food supply chains in India are significantly unorganised and perform worse when dealing with perishable food items such as dairy products. The Indian dairy supply chain is highly fragmented and even dysfunctional at certain levels. Poor linkages between different stakeholders within the supply chain have led to a shortage of dairy products and even caused price inflation. The Indian dairy supply chain is highly dependent on manual handling thus resulting in hygiene issues and human errors. The supply chains lack the presence of regulatory authorities at small and medium scales thereby allowing the entry of adulterated dairy products into the supply chain. The Indian dairy supply chains are mostly devoid of technologies and therefore are unable to address the changing consumer behaviours and global export initiatives.

A food product must be safe to consume and all the stakeholders (farmers, consumers, cooperatives, processors, and government agencies) share a responsibility to ensure the suitability of a food item. In the dairy industry, regulatory laws are in existence since 1899 for the safety and quality of milk and its products. There have been substantial amendments and increments in the legislation and quality standards of milk and products. The Food Safety and Standards Act received a nod in the year 2006.

In 2008, the Food Safety and Standards Authority of India (FSSAI) was established under the same act. The FSSAI enforced a regulation to control adulteration and contrived milk products known as Food Safety and Standard Regulations 2011. The Milk and Milk Products Order (MMPO) 1992 is regulatory order of the Government of India, under the Essential

Commodities Act 1955, for rheostat of production, supply, and distribution of milk and milk products to uphold or enhance the supply of milk and products from producer to consumer. The MMPO is to rationalize legal registration, define the terms used for milk, e.g., boiled milk, pasteurized milk, etc., and control restrictions on irrational procurement and supply of milk, stringent rates of production, sincere hygiene environment, proper packaging, labelling, penalization, etc. Thus, MMPO warrants the safety and progress of the Indian dairy industry. The Indian dairy supply chain can benefit significantly from the implementation of blockchain technology. Functionalities such as stakeholder management, inventory management, product movements, and returns management can easily be achieved through the use of blockchain technology. Blockchain-enabled dairy supply chains would ensure last-mile product delivery, quality control mechanisms, inventory optimizations, fault analysis, and pricing optimizations ^[21]. Blockchain technology presents itself as a solution to the numerous limitations of the Indian dairy supply chain ^{[22][23][24][25]}.

3. Blockchain Success Factors for Dairy Supply Chain Management

Blockchain has proven itself to be a game-changer technology in the area of supply chain management. The presence of blockchain technology introduces aspects of transparency, trust and decentralization into the supply chains. The following **Table 1** lists some of the prominent success factors leading to the adoption of blockchain technology for dairy supply chain management.

Table 1. Description of Blockchain Success Factors.

Success Factor	Description
Traceability	Blockchain facilitates a stakeholder to track the movement of a particular dairy product across the entire supply chain. The presence of a particular dairy product or a batch or a complete order can be traced by every stakeholder.
Transparency	All stakeholders within the supply chain are aware of any transaction being performed ^[26] . Information regarding a particular dairy product or a complete order is accessible to all stakeholders without any partiality.
Trust	Blockchain enables the establishment of trust between different stakeholders in the supply chain. Most importantly, it prevents the occurrence of a trust deficit between the end consumer and the dairy company.
Knowledge Sharing	Blockchain can assist in sharing valuable insights regarding the distribution and sales of a particular dairy product across different distributors and retailers. The important aspect is the safe and secure mechanism of sharing knowledge.
Smart Contracts	The most essential aspect of any blockchain solution is the use of smart contracts. They enable seamless transactions between stakeholders. Purchasing a product, managing multi-modal shipments, and removing a product are some of the many uses of smart contracts.
Tokens	Financial settlements can be made possible by the use of cryptocurrency tokens. Apart from methods such as cash and credit, tokens are more flexible, secure, and fast when it comes to handling payment settlements.
Immutability	The data stored on the blockchain is immutable in nature, i.e., once created it cannot be edited. A transaction once completed between two stakeholders cannot be revoked.
Auditable	Unlike traditional dairy supply chains, blockchain-enabled supply chains are auditable as every transaction performed within the blockchain network is recorded and stored on individual blocks in a secured manner using cryptographic hash functions.
Quality Assurance	Blockchain enables maintaining the quality of a dairy product throughout the supply chain. The use of blockchain assists in enforcing regulatory standards concerning the production, distribution, and storage of dairy products. Quality parameters of a particular dairy product can be tracked and maintained using blockchain implementation in its supply chain. Quality certificates are also generated using the blockchain network.
Decentralized	Blockchain-enabled supply chains are decentralized in nature thereby preventing any possibility of a single point of failure. Moreover, the decentralized nature prevents chances of data manipulation and spreading misinformation to other stakeholders.
Automation	Blockchain integration supports the highest levels of automation in the functioning of the supply chain. Updation of product information, payment settlements, removing a product, adding a stakeholder, and all functionalities are automated using the blockchain.
Removing Intermediaries	Unlike traditional supply chains, blockchain-enabled supply chains are devoid of intermediaries. Transactions are performed only between legitimate stakeholders ensuring the safety of the dairy products. Unauthorized stakeholders are not permitted to perform transactions or even enter their products into the supply chain.

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