Current Journal of Applied Science and Technology

Volume 42, Issue 47, Page 54-65, 2023; Article no.CJAST.110195
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Revolutionizing Vegetable Value Chains: A Comprehensive Review of Digital Technologies and their Impact on Agricultural Transformation

Sharvari Patil [a++], Nikhil Aklade [a#] and Ashish Ashok Uikey [b†*]

[a] *Department of Agri Business Management, MIMA Institute of Management, Pune, Maharashtra, India.*
[b] *Symbiosis International (Deemed University), Pune, Maharashtra, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2023/v42i474316

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/110195

Review Article

Received: 06/10/2023
Accepted: 11/12/2023
Published: 14/12/2023

ABSTRACT

The agricultural sector, especially in the realm of vegetable supply chains, has undergone a substantial transformation through the integration of digital tools. This review paper investigates the profound impact of cutting-edge technologies on agriculture, focusing on their implementation within the vegetable value chain. It covers in-depth analyses of various technological advancements such as big data analytics, RFID tags, IoT devices, blockchain technology, and artificial intelligence. The

---

[++] *Assistant Professor;*
[#] *PG Student;*
[†] *Research Scholar;*
**Corresponding author: E-mail: ashishashokuikey@gmail.com;*

exploration includes a detailed examination of Ninjacart, a leading agricultural technology platform, as a case study exemplifying the practical application of these technologies. These innovations have revolutionized inventory management, ranging from predictive analytics for crop yield estimation to the utilization of RFID tags for real-time tracking. IoT devices have played a pivotal role in monitoring crop health and optimizing resource allocation, while blockchain technology ensures transparency and reliability in the supply chain. Moreover, AI-powered solutions have efficiently organized transportation routes and addressed complexities within the supply chain, significantly reducing food wastage. This paper provides a comprehensive analysis of how digital technologies have reshaped the vegetable value chain, using the Ninjacart case study to highlight the tangible impact and practical implications of these advancements in real-world scenarios.

Keywords: Vegetable value chain; vegetable supply chain; big data; block chain; IoT; RFID.

1. INTRODUCTION

India's varied climate allows for the abundant availability of a wide range of fresh fruits and vegetables. It holds the global ranking of second in fruit and vegetable production, following China [1]. India harvested an impressive 204.84 million metric tonnes of vegetables from an extensive cultivation area spanning 11.35 million hectares [2]. The growth rate of vegetable market production reached 3.8% CAGR, resulting in an increase to 204.61 million tonnes during this specific period [3]. An approximate estimate from the Food and Agricultural Organization (FAO) suggests that roughly 40% of the food produced in India goes to waste annually, amounting to about one-third of the total food production. This wastage occurs primarily due to a fragmented food supply chain system that proves to be inefficient. Astonishingly, a significant portion of this loss happens before the food even reaches the end consumer. To put it in perspective, India squanders a quantity of fruits and vegetables that surpasses the total consumption of these items in the United Kingdom. Similarly, the wastage of grains in India exceeds the total production of grains in Australia. This issue of food wastage doesn't just represent discarded produce; it also translates to economic losses. The Ministry of Agriculture in India reports that approximately Rs. 50,000 crores worth of food produced is wasted annually. Such enormous food wastage is alarming, especially in a country like India, where around 23 Crore people live below the poverty line. Shockingly, 15% of the population faces hunger daily, and statistics reveal that one in four children suffers from malnutrition. Tragically, about 3,000 deaths occur every day due to illnesses caused by inadequate diets [4]. The primary cause of food wastage often stems from inefficiencies within the supply chain. The vegetable supply chain encounters a multitude of challenges impacting its effectiveness and sustainability. One critical issue revolves around perishability; vegetables are highly vulnerable to temperature fluctuations, desiccation, and rough handling, significantly increasing the risk of spoilage. Seasonal variations, influenced by climate conditions, disrupt production, resulting in unpredictable supply levels. This inconsistency, paired with fluctuating demand, contributes to price volatility. The expenses associated with storage, transportation, and potential damages further strain the economic viability of the supply chain. Moreover, limited access to financial capital, obscured regulatory frameworks, and governance hurdles hinder smooth operations and effective management. Certain fruits and vegetables are susceptible to specific issues like chilling, freezing, and CO_2 injury. The integration of digital technology within agricultural supply chains has become essential for managing the complexities inherent in vegetable production and distribution networks. The adoption of digital solutions has substantially transformed traditional practices, revolutionizing the vegetable supply chain. This review aims to explore and analyze the diverse ways in which digital technology shapes the vegetable supply chain from farm to fork. It delves into various technologies such as big data analysis, which plays a crucial role in predicting crop yields, optimizing transportation routes, and forecasting demand. Real-time data provided by RFID tags on temperature and location streamline inventory tracking and swiftly detect contaminated products. IoT devices monitor and regulate factors like irrigation and transportation, ensuring crop health. Blockchain technology enhances transparency by tracking vegetable origins and authenticating their sources. AI aids in demand prediction, optimizes transportation routes, resolves supply chain bottlenecks, and reduces food spoilage, collectively improving the efficiency of the vegetable supply chain. Leveraging these technologies enables the agriculture and food industry to enhance efficiency, minimize waste, and guarantee the safety and quality of their products.

2. VALUE CHAIN

The value chain represents a systematic method for analyzing and understanding the processes involved in creating value at various stages within the manufacturing and distribution phases. Its primary aim is to identify areas of value addition or expenditure. This analysis aids businesses in enhancing operations, reducing expenses, and bolstering their competitive advantage. The entirety of a product or process lifecycle, encompassing the acquisition of raw materials, production, consumption, and disposal or recycling, constitutes the value chain [5]. An agricultural value chain encompasses the individuals and processes involved in the journey of a primary agricultural commodity, such as maize, vegetables, or cotton, from acquiring inputs and cultivation in the field to its ultimate consumption by the end user. This involves various stages, including processing, packaging, and distribution. The United States Agency for International Development offers a definition, describing a value chain as the complete spectrum of activities necessary to transport a product or service from its inception to its final utilization, encompassing all available market channels accessible to all businesses involved.

Many organizations partake in numerous activities during the conversion of inputs into outputs. Porter [6] categorized these activities into primary and support activities, which are fundamental for all businesses. The primary activities encompass inbound logistics, operations, outbound logistics, marketing and sales, and service. On the other hand, secondary activities comprise procurement, human resource management, technological development, and infrastructure. Inputs such as capital, labor, materials, equipment, buildings, land, administration, and management contribute to the processes of transformation and output. The efficiency of value chain operations significantly influences expenses and ultimately affects earnings.

3. CHALLENGES IN VEGETABLE VALUE CHAIN

3.1 Perishability

Vegetables, being highly perishable, pose a significant challenge throughout the supply chain due to their limited shelf life. Safeguarding their freshness from farm to consumer necessitates efficient storage, transportation, and distribution systems. Maintaining quality demands optimized logistics and well-maintained cold chain infrastructures to prevent spoilage and ensure vegetables reach consumers in optimal condition.

3.2 Seasonality

Seasonal variations greatly impact vegetable availability, leading to supply fluctuations throughout the year. These fluctuations create shortages, particularly during peak harvest times, challenging consistent demand fulfillment. Overcoming this requires improved strategies such as efficient storage, diversified cultivation, and enhanced distribution networks to manage the supply chain and mitigate scarcity during these periods.

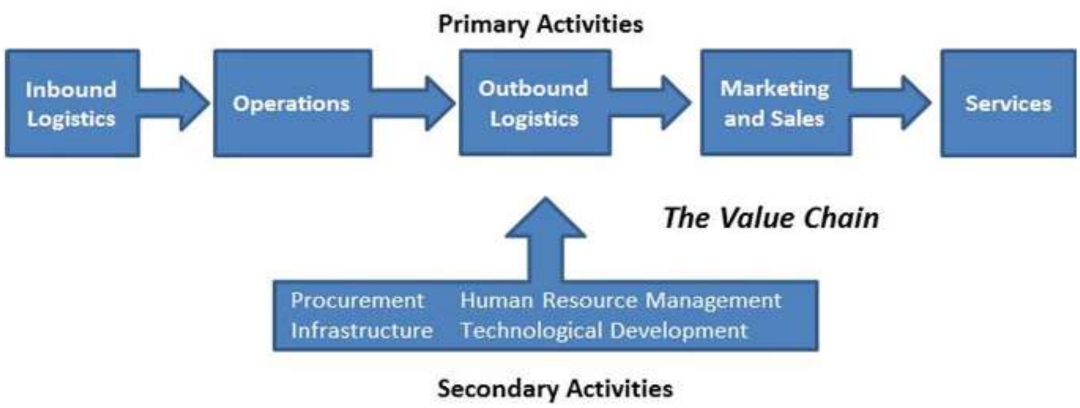

Fig. 1. The Value Chain
Source: Porter [6]

3.3 Transportation

Timely transportation is crucial to preserve vegetable freshness, but inadequate infrastructure, long distances, and improper temperature control can lead to losses and reduced quality. To address these challenges, there is a need for better logistical systems, improved transportation networks, and suitable vehicles with effective refrigeration methods to maintain produce quality during transportation.

3.4 Quality Control

Maintaining consistent vegetable quality is challenging due to varying growing conditions, pests, and diseases. Upholding quality standards from harvesting to transportation is vital to minimize waste and prevent spoilage. Implementing quality control measures throughout the process ensures the freshness and safety of produce for consumers.

3.5 Market Access

Small-scale farmers face hurdles in accessing larger markets due to limited resources, low bargaining power, and information gaps. This limitation impacts their income and restricts access to broader market opportunities and competitive pricing.

3.6 Lack of Information Sharing

Communication gaps within the supply chain inhibit efficient operations. Inadequate sharing of information between farmers, distributors, and retailers delays critical data exchange related to demand, supply, and market conditions. This lack of information affects decision-making and reduces the overall effectiveness of the vegetable supply chain.

3.7 Price Fluctuations

In the vegetable market, these are influenced by factors like weather conditions, market demand, and transportation costs. These fluctuations affect farmers' income stability and consumers' purchasing power, creating uncertainty for both parties.

3.8 Sustainability

It is a significant challenge in the vegetable supply chain. Meeting rising demand while maintaining sustainable agricultural practices requires addressing issues like water scarcity,

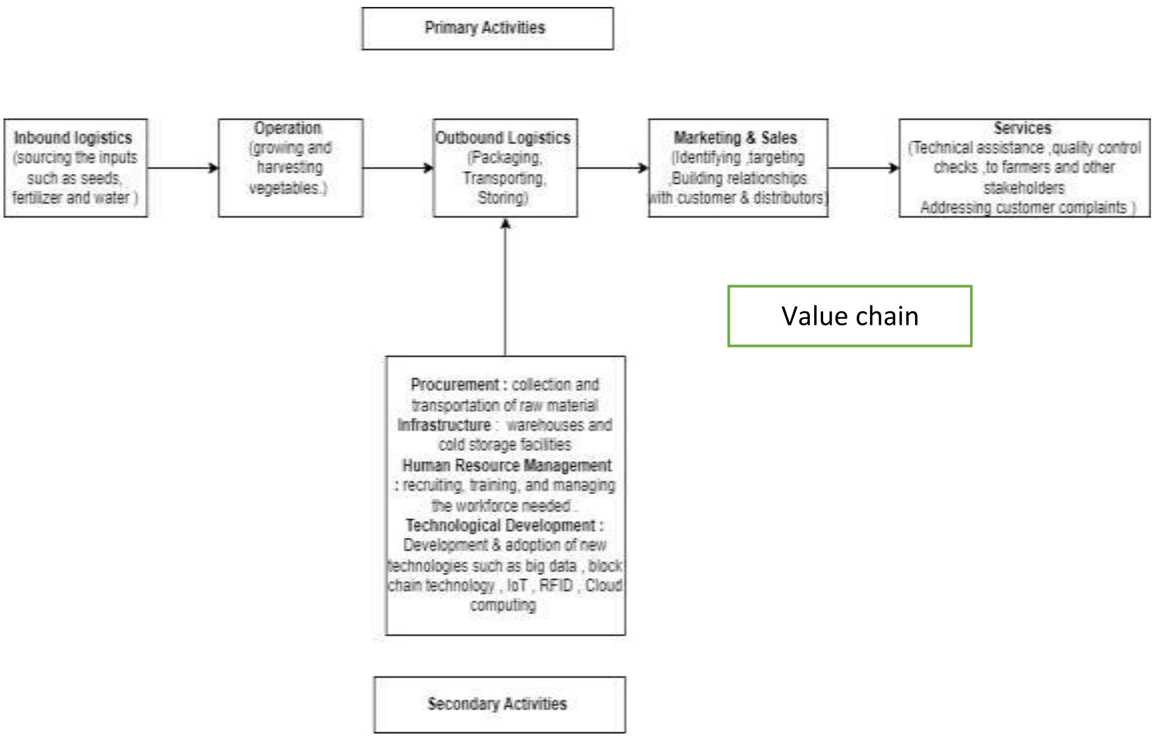

Fig. 2. Improved Vegetable Value Chain
Source: Prepared by authors based on Porter [6]

soil degradation, and responsible chemical use to ensure long-term viability and ecological balance.

3.9 Technology Adoption

It remains a persistent challenge in various segments of the vegetable supply chain. Limited access to modern technologies inhibits process optimization, inventory tracking, and adaptability to market changes, resulting in inefficiencies and reduced competitiveness within the broader supply chain network.

4. DIGITAL TECHNOLOGIES & THEIR ROLE IN VALUE CHAIN EFFECTIVENESS IN VEGETABLES

4.1 Big Data Analytics (BDA)

Big data analytics (BDA) is an emerging discipline focused on deriving value from the substantial volumes of data in the supply chain. It significantly influences the evolution of factories-of-future (FoF), information & communication technologies (ICT), and agricultural methodologies, contributing to the development of robust big data models [7]. BDA holds extensive promise by improving demand forecasts, reducing safety stock requirements, and optimizing supplier performance. Leading software solutions such as IBP, Oracle Fusion Cloud Supply Chain Planning, IBM Planning Analytics, and Streamline are pivotal in providing services linked to Big Data. When integrated with machine learning (ML), BDA equips organizations with the necessary infrastructure, expertise, and mindset to establish data-driven enterprises. It fosters novel decision-making approaches in supply chain management, encompassing operational model selection and performance enhancement. Furthermore, BDA's machine learning and deep learning algorithms proficiently analyze sensor nodes to detect security threats and identify network adversaries [8]. The concept of 'Big Data' stands to revolutionize supply chain management and customer interaction strategies, ushering in an era of personalized sales, services, and logistics centered on the customer while cultivating operational excellence [9]. In agriculture, BDA plays a pivotal role as its capacity to gather and analyze extensive data, including crop yields, inventory levels, and market demand, aids in resource allocation, waste reduction, and maximizing crop productivity, thereby augmenting sales and return on investments. BDA empowers farmers with timely insights by utilizing real-time data streams such as weather updates and farm sensors. For instance, it triggers automated irrigation systems based on weather conditions to ensure optimal resource utilization. Agricultural data spans diverse formats, from structured information like yields and sales to semi-structured data like weather forecasts and unstructured data like satellite imagery and social media posts. BDA harmonizes this diversity to derive actionable insights. Data integrity is critical in agriculture, and BDA plays a pivotal role in ensuring data accuracy, fostering trust in vital decisions related to planting, harvesting, and distribution. Ultimately, the application of BDA yields substantial benefits by enhancing crop yields, reducing operational costs, optimizing resources, and streamlining the entire supply chain, thereby delivering increased value for both farmers and consumers, representing a significant advancement in the agricultural landscape. Focusing on the vegetable supply chain, demand forecasting holds a pivotal role due to the varying daily demand for vegetables. Big data analysis assists in forecasting vegetable demand at the Stock Keeping Unit (SKU) level by considering factors like historical sales data, seasonality, and weather patterns. This aids businesses in maintaining adequate produce in stock to meet customer demand. Additionally, big data analysis assists in setting vegetable prices based on factors such as demand, supply, and market conditions, enabling businesses to maximize profits and ensure competitive pricing [10].

4.2 Internet of Things (IOT)

The Internet of Things (IoT) refers to a network connecting various devices and enabling communication among them and with the cloud. It merges everyday objects with the internet, allowing these smart devices to autonomously exchange data. This concept, comprised of these discrete computing devices and their associated technology, collectively forms the Internet of Things. While the notion of IoT has been around for some time, recent advancements in diverse technologies have made it feasible [11]. An AIoT (Internet of Agricultural things) system, built on Service Oriented Architecture (SOA) principles, acts as a centralized hub for storing and processing data in the agriculture sector. It seamlessly integrates data from the entire fresh vegetable supply chain, providing users, including end customers, with an intuitive overview. Supported by a centralized server, it enhances data reliability, facilitating informed purchasing decisions, it bridges the gap between the physical and digital realms, enabling intelligent identification and management. This system also streamlines remote control of fresh produce cold chain logistics, thereby improving transportation and monitoring efficiency [7]. Utilizing technologies like wireless sensor networks (WSN), RFID, sensors, and GPS is crucial in environmental monitoring, greenhouse management, and cold chain tracking. IoT enables self-adaptive food supply chains, where objects autonomously make decisions and continually learn [7]. It plays a pivotal role in real-time food monitoring, particularly in ensuring safety through Hazard Analysis and Critical Control Points (HACCP). IoT sensors, utilizing spectroscopy and DNA-PCR methods, advance food quality and composition analysis [12]. The collaboration between IoT and blockchain holds significant promise for food tracking systems, promptly addressing food safety concerns through AI-driven big data analysis. Integrating IoT with blockchain, particularly via smart contracts, bolsters network security, ensuring continuous IoT device firmware updates. This fusion enhances traceability, quality control, and safety across the entire food supply chain, providing advantages to both service providers and customers through privacy-preserving smart contracts [12]. IoT tags can be affixed to crates, pallets, and other assets in the vegetable supply chain, enabling companies to monitor their location and movement throughout the supply chain, thereby enhancing efficiency and visibility. IoT sensors can also monitor vegetable temperatures throughout the supply chain, ensuring they remain at optimal temperatures to prevent food safety hazards [10]. Parameters such as temperature, relative humidity (RH), ethylene, O_2, CO_2, and vibration/shock significantly impact the quality and shelf life of fresh fruits and vegetables. Monitoring these parameters using IoT-enabled sensors and communication technology in supply chains can optimize product quality, reducing product rejections and losses [13].

4.3 Blockchain Technology

Blockchain technology is a groundbreaking database system that promotes transparent information sharing among business networks. It operates through block storage, securely linked in a chain, creating an immutable ledger ideal for tracking orders, payments, accounts, and transactions. This system employs robust mechanisms to prevent unauthorized entries, ensuring consistency in shared transaction views [14]. Key features include decentralization, immutability, and consensus, marking a shift from centralized to decentralized distributed ledger networks adopted by various industries. Decentralization transforms how data is stored and shared, while immutability ensures recorded transactions remain unaltered. Consensus, governed by network participants' majority consent, validates new transaction recordings. The blockchain architecture encompasses a distributed ledger as a secure shared database, smart contracts automating agreements, and public key cryptography uniquely identifying network participants [15]. In agriculture, blockchain serves as a versatile tool, tracking plant-related data, enhancing supply chain transparency, and combating unethical operations. It facilitates peer-to-peer transactions, removing intermediaries. Smart contracts aid revenue sharing algorithms, boosting productivity, transparency, and security. This technology simplifies user identity management and supports collaborative logistics projects. For agriculture supply chains, a multi-tiered blockchain architecture enhances security, aiding food provenance tracing and fostering trust. In agricultural insurance, blockchain improves index insurance with timely, automated payouts based on predefined conditions, integrating diverse data sources for efficient risk determination. Decentralized crop insurance providers like Etherisc, WorldCover, and Arbol leverage blockchain for innovative solutions. In managing agricultural data, blockchain tracks farmer, seed, and yield data accurately, employing IPFS and blockchain storage [16]. It monitors crop growth with sensors and creates smart contracts with stored blockchain data hashes. At the processing level, blockchain records batch information on product packages, conducts mandatory inspections ensuring quality, and facilitates storage and sales info for distributors and retailers. Distributors benefit by storing and selling products in batches, maintaining company and product information on blockchain. Retailers leverage blockchain to record purchases from distributors, sales to consumers, and store sales information to ensure data integrity. Consumers can access comprehensive supply chain information by scanning product package barcodes, RFID, or QR codes for detailed product insights [17]. Blockchain technology presents a transformative solution for the agricultural industry, amplifying traceability, transparency, and efficiency within the vegetable supply chain. By integrating blockchain, the traceability of vegetables from farm to fork becomes seamless, enabling swift identification of foodborne illnesses and prevention of counterfeit products. This not only ensures authenticity but also empowers consumers with detailed insights into the journey of vegetables, facilitating informed and ethical decision-making. Additionally, the technology substantially reduces management costs by eliminating intermediaries and automating tracking tasks, thereby fostering seamless collaboration among supply chain stakeholders.

4.4 Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) represents an advanced technology facilitating non-contact, duplex communication via signals like electromagnetic induction, radio waves, and microwaves. Its primary function lies in uniquely identifying objects, animals, or individuals, proving invaluable across various applications [18]. This technology comprises RFID tags affixed to products, housing encoded data, and RFID readers that access this information. Tags typically consist of an integrated circuit, antennae, and protective covering, classified as active, passive, or semi-passive. Active tags possess their power source, while passive tags rely on RFID readers for power. Functioning on automatic identification and data collection (AIDC) principles, RFID necessitates no human intervention, relying on radio waves for communication. Commercial RFID tags and semi-passive tags extend beyond basic identification; they can collect environmental data like temperature, humidity, and light, making them ideal for supply chain management. There's also ongoing exploration into biosensor tags for bacterial contamination detection in food products [19]. RFID technology significantly impacts agriculture by offering a multitude of benefits. It streamlines the tracking of agricultural products from farm to consumer, ensuring transparency and traceability. Enhancements in food safety occur through its integration at every stage of the distribution system, guaranteeing quality and compliance. RFID aids in farm automation and control, facilitating the collection of climate data for improved yields and increased productivity. Moreover, it enables livestock monitoring for health and disease detection, ensuring animal well-being, and keeps consumers informed about the food they consume. Its versatility allows RFID technology to identify various animals and monitor their health, providing farmers with tools to manage operations efficiently, ensure product safety, and deliver fresh produce effectively. Data input and acquisition from RFID tags enhance farm productivity and responsiveness to real-time events. By placing RFID tags on agricultural product packages, farmers can assess product health and provide essential information for processing companies, including processing dates and package details. These tags securely store a wealth of information, proving valuable for crop management. They also find applications in smart greenhouses for equipment management, resource allocation, and data collection. Overall, RFID's extensive utility enhances the entire agricultural supply chain, ensuring transparency, safety, and efficiency [20]. RFID is employed to evaluate the quality of apples by monitoring gases produced by apples like ethylene. Integration of RFID tags with gas sensors (O_2 and CO_2) is used to check the freshness of broccoli. Semi-passive RFID aids in calculating the shelf life of lettuce transported in refrigerated reefers, as well as tracking the quality and shelf life of tomatoes [21]. In the vegetable supply chain, RFID tags offer real-time visibility into product movement and location, ensuring accurate and updated inventory levels, reducing the chances of overstocking or stockouts, and aiding businesses in efficiently meeting customer demand. Manual data entry errors are mitigated through RFID tags' automated data collection, enhancing accuracy in decision-making and reducing costly mistakes in vegetable supply chain management. Moreover, these tags aren't limited to vegetables; they can also track and manage assets like pallets, containers, and equipment, minimizing asset losses and ensuring optimal resource utilization throughout the chain. Equipping RFID tags with security features simplifies theft detection and prevents unauthorized access to valuable items, ensuring product security within the vegetable supply chain [22]. In the vegetable supply chain, maintaining optimal temperature and humidity is crucial to prevent spoilage and preserve freshness. Sensors effectively monitor these conditions, ensuring vegetables remain in the desired environment during transportation and storage. Tracking the precise location of vegetable shipments streamlines logistics, ensuring on-time deliveries and efficient route planning to avoid delays. Given the delicate nature of vegetables, sensors detecting shocks and vibrations help identify potential damage, allowing swift actions to prevent product spoilage. Furthermore, monitoring package handling via sensors is essential; they can detect if a package has been opened or tampered with, ensuring the vegetables remain secure and untouched throughout the supply chain [23].

4.5 Artificial Intelligence (AI)

The realm of Artificial Intelligence (AI) represents a diverse discipline merging computer science with comprehensive datasets to facilitate problem-solving and decision-making. It encompasses subsets like machine learning and deep learning. AI systems generate cognitive models of the world, leveraging past experiences to make informed choices. Despite originating in 1956, AI has undergone significant evolution. Its applications, spanning areas such as image recognition and autonomous vehicles, have revolutionized numerous industries. AI's reach extends across domains like speech recognition, employing natural language processing to convert spoken language into text, thereby enhancing accessibility and enabling voice-based searches. Within customer service, online virtual agents are supplanting human agents, offering tailored assistance and redefining customer interaction. Computer vision, employing convolutional neural networks, extracts valuable insights from digital images and videos, impacting fields like social media, healthcare, and automotive industries. AI-powered recommendation engines analyze user behavior to suggest pertinent products or services, optimizing cross-selling approaches. Moreover, AI has permeated automated stock trading, where high-frequency platforms execute rapid, data-driven trades without human intervention. Rather than supplanting humans, AI serves to empower individuals to unleash their strategic and creative capabilities [24]. AI has spearheaded a transformative phase in the agricultural sector, revolutionizing various facets of farming and supply chains. It encompasses applications like crop monitoring, utilizing AI-powered sensors and satellites for real-time data on crop health, soil quality, and moisture levels, aiding in disease and pest management. Precision farming utilizes AI algorithms to optimize planting, fertilizer usage, and harvesting by analyzing weather patterns, soil conditions, and crop growth data. Livestock farming benefits from AI with sensors monitoring animal behavior, health, and feeding patterns, enabling early disease detection and improved resource management. AI also aids in crop and soil analysis, providing recommendations for nutrient levels and optimizing yield while reducing waste. It plays a role in soil quality analysis, crop forecasting, and weed and pest detection, augmenting overall agricultural productivity. Projections indicate that AI will contribute approximately $15.7 trillion to the global economy by 2030 [25]. AI's pivotal role extends to supply chain management, employing predictive analytics to optimize inventory levels and streamline processes to avert stockouts and overstocking. AI-driven transportation management enhances route planning and delivery efficiency, reducing fuel consumption and enhancing automation and accuracy. In the food supply chain, ensuring traceability and transparency is crucial. Image processing and recognition technologies aid in product safety assessments at various stages, while AI technologies like Bayesian Networks, video surveillance, and crop-monitoring robots ensure food quality and safety. The future prospects of AI in agriculture and supply chain management appear promising, continuing to unlock strategic and creative potentials. With the integration of data-driven agriculture and precise global farm mapping, technology stands to further augment productivity and elevate agricultural product standards. As the sector expands, AI is poised to significantly contribute to the global economy, ushering in an era of enhanced efficiency and sustainability in agriculture and supply chain management. Digital Twin Technology monitors the quality of fresh produce throughout the cold chain, optimizing their storage and transportation to preserve quality. Thermal Imaging aids in detecting damage or defects in fresh produce by measuring temperature variations between healthy and damaged tissues, facilitating quality assessment. Computer Vision Systems (CVS) evaluate the external quality of food products such as fresh fruits and vegetables. Electric noses (Ens) and electric tongues (Ets) are multisensory systems for liquid analysis based on chemical sensor arrays and pattern recognition. By detecting subtle differences in the smells and flavors of various food product batches, companies can adjust production processes to ensure consistent, high-quality products. E-noses can detect and analyze volatile organic compounds (VOCs), while Ets can discern taste characteristics like sweetness, saltiness, sourness, and bitterness, crucial factors in determining overall product quality. ET was utilized to analyze a range of liquid and flesh food samples, including juices, wines, and meat products, classifying different types of liquid and flesh vegetables based on their taste profiles [12].

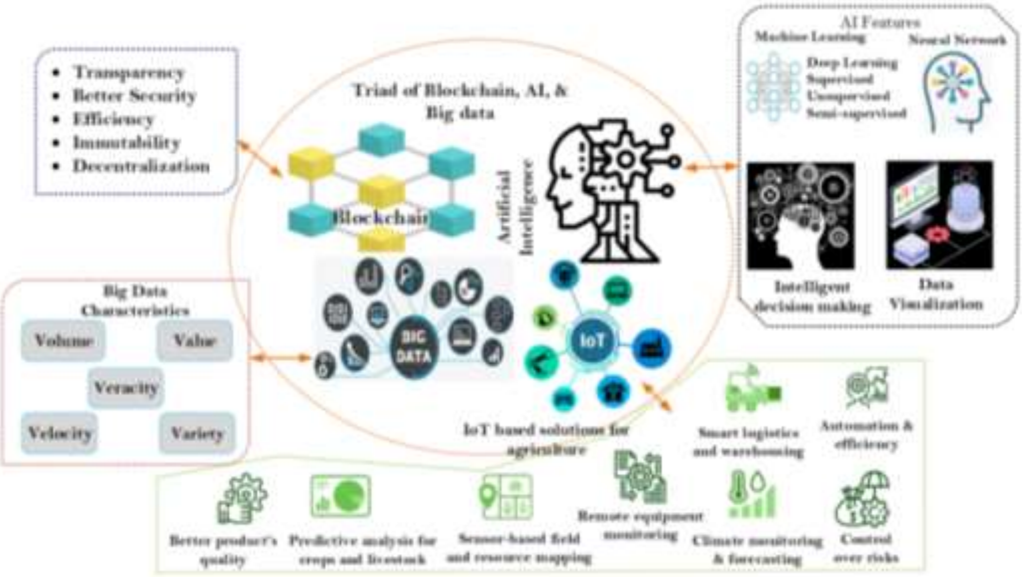

Fig. 3. Characteristics of Blockchain, AI, IoT, and Big Data for Smart Farming

Source: Bhat et al. [8]

5. CHALLENGES OF IMPLEMENTING TECHNOLOGIES IN VEGETABLE VALUE CHAIN

5.1 High Cost

Integration of technological advancements like cold storage, precision agriculture, or blockchain within the vegetable value chain often presents significant financial obstacles. The initial investment and continuous maintenance costs associated with these innovations pose challenges, particularly for smaller businesses and farmers operating within the chain. Limited budgets of small and medium-sized enterprises (SMEs) restrict their capacity to adopt and sustain such technologies, creating disparities in access and impacting the competitiveness and efficiency of these smaller players.

5.2 Fragmentation

The vegetable value chain, involving various stakeholders from farmers to retailers, inherently suffers from fragmentation. The diverse interests, capabilities, and resources of these stakeholders complicate the implementation of new technologies. Coordinating and standardizing technology adoption across this fragmented chain becomes arduous, often leading to resistance and challenges in achieving consensus, thereby hindering seamless integration.

5.3 Lack of Infrastructure and Connectivity

In regions where vegetable production occurs, especially rural or remote areas, inadequate infrastructure becomes a major hurdle. Limited access to electricity, poor internet connectivity, and insufficient transportation networks impede the implementation of advanced technologies like IoT, cold storage, and real-time monitoring. These modern solutions heavily rely on consistent power and internet access, which the absence of such infrastructure inhibits throughout the value chain.

5.4 Lack of Awareness and Skills

Another significant challenge faced by the vegetable value chain pertains to a lack of awareness and expertise among farmers and stakeholders. This issue encompasses insufficient knowledge about the existence and benefits of modern technologies, coupled with a deficit in the required skill sets for effective implementation. Stakeholders might be uninformed about available technologies or lack the expertise needed for efficient utilization.

5.5 Data Privacy and Security Concerns

The increasing dependence on technology in the vegetable value chain raises valid concerns about data privacy and security. The heightened data collection and management pose risks in handling sensitive information. Addressing these concerns demands robust data governance frameworks and protocols to ensure data integrity and privacy while managing the amassed information.

6. CASE STUDY OF THE NINJACART

Ninjacart, founded in 2015 in Bengaluru, India, stands as the largest B2B (Business-to-Business) platform innovating fresh produce supply chains through technology. The company's initiatives optimize the supply chain by eliminating intermediaries, linking farmers directly to retailers. This addresses issues such as information gaps, delayed payments, inefficiencies, substandard produce, price uncertainties, and information disparities. Farmers often contend with challenges like uncertain pricing and insufficient market information, while retailers grapple with increased expenses, subpar produce quality, and market unpredictability. The conventional, inefficient supply chain contributes to disorganized operations, leading to significant food wastage.

Ninjacart has developed an efficient supply chain system for fresh produce, ensuring swift delivery from harvest to store within less than 12 hours and at minimal cost. This achievement is attributed to their adept use of technology and data-driven processes. Utilizing big data, artificial intelligence (AI), and machine learning (ML), Ninjacart forecasts and prices vegetables at a granular level, predicting weekly demand per Stock Keeping Unit (SKU). This approach aids in negotiating better prices with farmers and maintaining adequate stock levels to meet consumer needs. Their predictive models incorporate future expectations and weather forecasts, maintaining a remarkably low error rate of 0.2% - 0.3% over six years. The implementation of RFID tags enables Ninjacart to track vegetable crate locations in the supply chain, updating inventory in real-time and providing customers with instant order status information, enhancing brand credibility and customer trust. This technology also optimizes delivery routes, reducing waiting times and enhancing efficiency by using 'dolleys' instead of conventional loading methods. Ninjacart employs vehicle routing software to plan delivery routes, considering variables like customer locations, delivery types, and traffic conditions. This strategy minimizes fuel costs and optimizes vegetable transportation, facilitating over 1000 daily trips and ensuring produce reaches retailers within 12 hours. Their inventory management system, aided by in-house queuing technology, efficiently processes high volumes with minimal errors, orchestrating supply chain actions seamlessly. IoT sensors monitor humidity and temperature in delivery vehicles and warehouses, preserving the freshness and quality of fruits and vegetables. Drivers are equipped with mobile phones to manage deliveries, facilitating order tracking, payments, and crate collection. This technology has resulted in a 15% increase in farmer incomes, ensuring prompt money transfers within 24 hours. Ninjacart maintains less than 0.5% food wastage and delivers around 500 tonnes of produce to numerous shops across multiple Indian cities daily, boasting a 99.88% delivery accuracy rate. Their system provides retailers with lower vegetable prices compared to market rates, convenient doorstep deliveries, advance notifications of shortages, and high-quality produce. This robust supply chain guarantees timely delivery of quality items at competitive prices, reinforcing customer satisfaction.

Fig. 4. Ninjacart Process
Source: Ninjacart [26]

Ninjacart's initiatives aim to transform the agricultural ecosystem, supporting stakeholders throughout the supply chain by mitigating risks and providing reliable real-time information and sourcing from verified businesses. Their achievements have been recognized through awards such as Startup of the Year 2021 by Agriculture Today magazine and Overall Supply Chain Solution of the Year at the 2020 Agtech Breakthrough Awards [26].

7. CONCLUSION

The integration of digital technologies within the vegetable value chain marks a pivotal shift, holding immense potential in tackling pervasive issues within the agricultural domain. Through the strategic utilization of cutting-edge tools like big data analytics, RFID tags, IoT devices, blockchain, and Artificial Intelligence, the agricultural sector, especially the vegetable supply chain, stands to reap significant rewards. These technological advancements not only confront challenges associated with perishability, price fluctuations, and regulatory constraints but also introduce elevated traceability, refined inventory control, and expedited decision-making processes. Examining the case of Ninjacart illuminates the tangible advantages and effectiveness of these digital interventions. This innovative approach streamlines operations, curtails wastage, and fosters transparency throughout the supply chain. The seamless adoption and amalgamation of these advanced technologies herald a future where the vegetable supply chain exhibits heightened resilience, efficiency, and adaptability to the dynamic needs of both the industry and consumers. Envisioning a scenario where these technologies are fully embraced and integrated promises a paradigm shift. This transformation holds the potential to revolutionize the vegetable supply chain, paving the way for enhanced sustainability, optimized resource utilization, and greater responsiveness to emerging trends and consumer preferences.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. APEDA. Fresh fruits and vegetables. APEDA; 2023a. Available:https://apeda.gov.in/apedawebsite/six_head_product/FFV.htm
2. APEDA. Other fresh vegetable. APEDA; 2023b. Available:https://apeda.gov.in/apedawebsite/SubHead_Products/Other_Fresh_Vegetables.htm
3. IBEF. India's Fruits and Vegetables Industry. India Brand Equity Foundation; 2022. Available:https://www.ibef.org/blogs/india-s-fruits-and-vegetables-industry
4. Times of Agriculture. Food wastage in India: From Farm to Bin Hidden Truth. Times of Agriculture: A Resonance in Agriculture; 2023. Available:https://timesofagriculture.in/food-wastage-in-india-farm-to-bin/?_l=en_US
5. Chai W. value chain. TechTarget; 2021. Available:https://www.techtarget.com/searchcio/definition/value-chain
6. Porter ME. Competitive advantage: Creating and sustaining superior performance. Free Press; 1985.
7. Dadi V, Nikhil SR, Mo RS, Agarwal T, Arora S. Agri-Food 4.0 And innovations: Revamping the supply chain operations. Production Engineering Archives, 2021;27(2):75–89. Available:https://doi.org/10.30657/pea.2021.27.10
8. Bhat SA, Huang N-F, Sofi IB, Sultan M. Agriculture-Food supply chain management based on blockchain and iot: A narrative on enterprise blockchain interoperability. Agriculture. 202112 (1):40. Available:https://doi.org/10.3390/agriculture12010040
9. Chauhan S, Singh R, Gehlot A, Akram SV, Twala B, Priyadarshi N. Digitalization of supply chain management with industry 4.0 Enabling technologies: A sustainable perspective. Processes. 2022; 11(1):96. Available:https://doi.org/10.3390/pr11010096
10. Sarre A. Forests for Food Security and Nutrition. Unasylva. 2013;64(241)2.
11. AMAZON. What is IoT? - Internet of Things Explained - AWS. Amazon Web Services, Inc; 2023b . Available:https://aws.amazon.com/what-is/iot
12. Taneja A, Nair G, Joshi M, Sharma S, Sharma S, Jambrak AR, Roselló-Soto E, Barba FJ, Castagnini JM, Leksawasdi N,

Phimolsiripol Y. Artificial intelligence: Implications for the agri-food sector. Agronomy. 2023;13(5):1397.
Available:https://doi.org/10.3390/agronomy13051397

13. Lamberty A, Kreyenschmidt J. Ambient parameter monitoring in fresh fruit and vegetable supply chains using internet of things-enabled sensor and communication technology. Foods. 2022; 11(12):1777.
Available:https://doi.org/10.3390/foods11121777
14. Xiong H, Dalhaus T, Wang P, Huang J. Blockchain technology for agriculture: Applications and rationale. Frontiers in Blockchain. 2020;3.
Available:https://doi.org/10.3389/fbloc.2020.00007
15. AMAZON. What is Blockchain? - Blockchaining Explained - AWS. Amazon Web Services, Inc; 2023a.
Available:https://aws.amazon.com/what-is/blockchain/?aws-products-all.sort-by=item.additionalFields.productNameLowercase&&aws-products-all.sort-order=asc
16. Jain MK. Blockchain Technology in Agriculture: Application Techniques. Knowledgehut; 2023.
Available:https://www.knowledgehut.com/blog/blockchain/blockchain-technology-in-agriculture
17. El Mane A, Chihab Y, Tatane K, Korchiyne R. Agriculture supply chain management based on blockchain architecture and smart contracts. Applied Computational Intelligence and Soft Computing. 20221–23.
Available:https://doi.org/10.1155/2022/8011525
18. Amsler S, Shea S. RFID (Radio Frequency Identification). TechTarget; 2021.
Available:https://www.techtarget.com/iotagenda/definition/RFID-radio-frequency-identification
19. Kumar V. The role of RFID in Agro-food sector. Agricultural Research & Technology: Open Access Journal. 2018; 14(4).
Available:https://doi.org/10.19080/artoaj.2018.14.555924
20. Sahoo C. Role of RFID in Agriculture. DeHaat; 2022.
Available:https://write.agrevolution.in/role-of-rfid-in-agriculture-b886b5e52495?gi=71405f79448f
21. Calderone L. How RFID Technology Is Used in Agriculture. AgriTechTomorrow; 2019.
Available:https://www.agritechtomorrow.com/article/2019/12/how-rfid-technology-is-used-in-agriculture/11872/
22. Agarwal V, Ankolikar S. Deployment of RFID sensors in supply chain management - a review. Journal of Mechatronics and Artificial Intelligence in Engineering. 2022; 3(2)47–64.
Available:https://doi.org/10.21595/jmai.2022.22565
23. Macharia S. Revolutionizing supply chain management: The role of RFID tags and sensors. LinkedIn; 2023.
Available:https://www.linkedin.com/pulse/revolutionizing-supply-chain-management-role-rfid-samuel-macharia-msc/
24. IBM. Explainers. IBM; 2023.
Available:https://www.ibm.com/topics
25. Jovanovic B. 55 fascinating AI statistics and trends for 2023. Sirisha; 2023.
Available:https://dataprot.net/statistics/ai-statistics/
26. Ninjacart. Ninjacart. Ninjacart; 2023.
Available:http://www.ninjacart.com/

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/110195