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# Blockchain technology in agriculture: A comprehensive review of applications, supply chain management, food safety, smart contract, benefits, limitation, and prospects

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**Abstract**

Dating back thousands of years, agriculture has been an essential practice in the advancement of human civilization. Over time, humans realized that not everyone in the community needed to be involved in food production, leading to the emergence of specialized labour, tools, and techniques that could generate surplus food for the community. Throughout history, agriculture has continuously evolved and played a crucial role in sustaining humanity.

As the population grew, the evolution of agriculture became driven by the need to feed the expanding population while maintaining food quality and traceability, preventing adulteration of products, and maximizing yield. The recent emergence of blockchain technology has brought about significant advancements that prove beneficial for the agricultural sector. The implementation of blockchain has led to benefits and revolutionary changes in agriculture, facilitating modernization and optimization in various aspects of agriculture.

This research survey also deals on how blockchain technology has positively influenced different market aspects within agriculture. From the production stage to distribution and beyond, blockchain has made its impact felt, enhancing various aspects of the agricultural. Despite its promising benefits, the adoption of blockchain in agriculture is not without challenges. This study also explores these challenges and discusses the potential future developments in the field.

Overall, the survey highlights how blockchain technology has become a driving force in revolutionizing agriculture, offering improved traceability, transparency, and efficiency across the entire agricultural supply chain.

**Research objectives**

1. Blockchain-Based Applications for Addressing Agricultural Challenges: Exploring Potential Solutions
2. Blockchain for Supply Chain Management in Agriculture: A Promising Approach for Ensuring Food Safety and Security
3. Revolutionizing Agricultural Transactions: The Power of Blockchain-Enabled Smart Contracts
4. Enhancing Agriculture with Blockchain in AI, IoT, and Big Data: A Powerful Integration
5. Benefits and Challenges of Blockchain Technology in Agriculture: A Comprehensive Analysis

**Keywords:** Agriculture, blockchain technology, food safety, human civilization

## Introduction

Blockchain is a secure and immutable way of storing and sharing a data across a network of computers without a central authority or intermediary. It is a decentralised, distributed ledger system that can record transactions between two parties efficiently and in a verifiable way. Blockchain is a scalable technology, and it can be used to handle many transactions. Virtually anything of value can be tracked and traded on a blockchain network, reducing risk, and cutting costs for all involved. The blockchain collects transaction information and enters it into a block, like a cell in a spreadsheet containing information. Once it is full, the information is converted into digits, which creates a hexadecimal number called the hash.

## History of Block Chain

### History of block chain technology

The history of block chain technology dates back to the early 1990s, but its most significant development and popularization came with advent of Bitcoin in 2009. Here's a brief overview of the key milestones in the history of blockchain:

**Cryptography Roots (1980s-1990s):** The foundations of blockchain technology can be traced back to research in cryptography and secure communication. In 1982, computer scientists David Chaum and Stefan Brands introduced the concept of digital cash and anonymous cryptographic electronic money systems, which laid the groundwork for future blockchain applications.

**Bitcoin Whitepaper (2008):** In October 2008, an individual or group operating under the pseudonym Satoshi Nakamoto published the Bitcoin whitepaper titled "Bitcoin: A Peer-to-Peer Electronic Cash System." The whitepaper proposed a decentralized digital currency, based on a technology called

the blockchain, which would enable peer-to-peer transactions without the need for intermediaries like banks.

**Genesis Block and Bitcoin Network Launch (2009):** On January 3, 2009, the Bitcoin network came into existence when the first block, known as the "genesis block," was mined by Nakamoto. This marked the beginning of the Bitcoin blockchain, and it also included a message in the coin base parameter, referencing a headline from The Times newspaper that day: "Chancellor on brink of second bailout for banks."

**Growth and Early Adoption (2009-2012):** In the early years, Bitcoin gained traction among cyber punks, cryptography enthusiasts, and individuals interested in the concept of a decentralized digital currency. Miners joined the network, transactions were recorded on the blockchain, and Bitcoin's value began to rise.

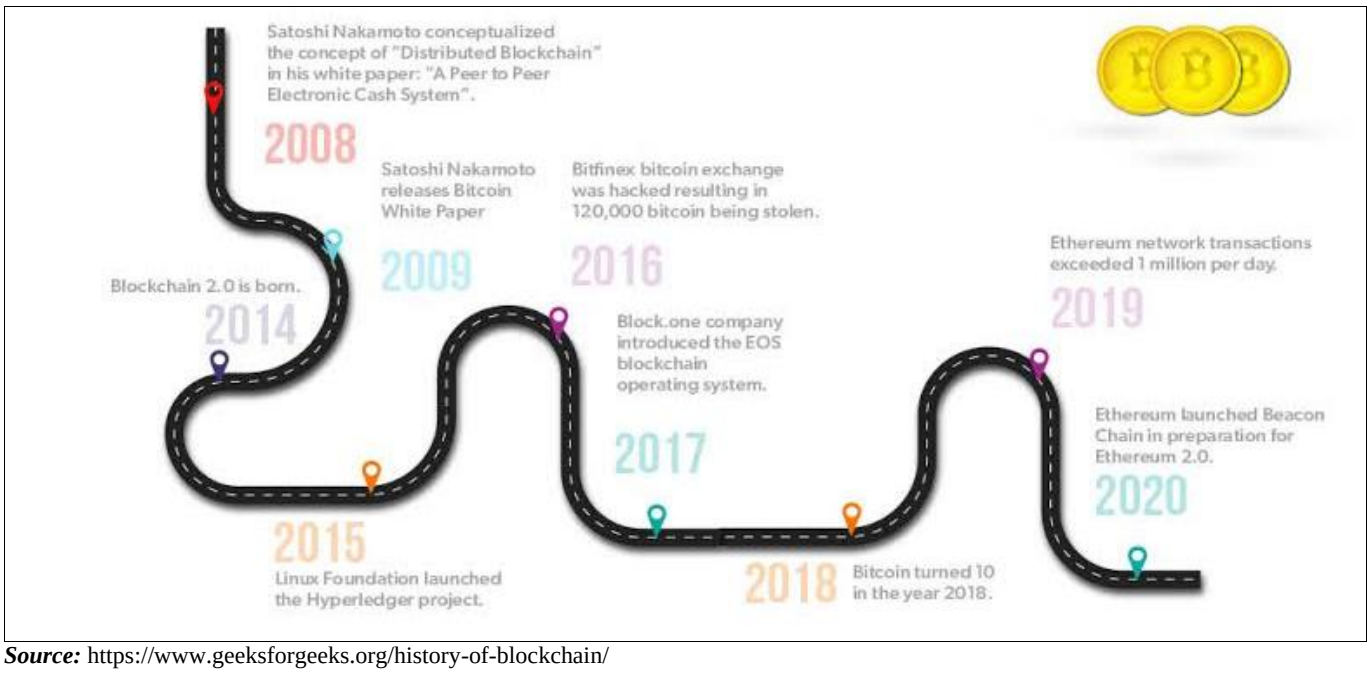
**Introduction of Altcoins (2011-2013):** As the concept of cryptocurrencies gained popularity, alternative cryptocurrencies (altcoins) were introduced. These included Namecoin (2011), Litecoin (2011), and others, each with its unique features and use cases. Litecoin became the first significant altcoin to gain widespread adoption.

**Ethereum and Smart Contracts (2015):** In July 2015, Vitalik Buterin and his team introduced Ethereum, a blockchain platform that enabled the execution of smart contracts. Smart contracts are self-executing agreements with predefined rules, allowing for programmable and decentralized applications (dApps) to be built on the Ethereum blockchain.

**Enterprise Blockchain Adoption (2016-2017):** As the potential of blockchain technology became more widely recognized, major enterprises and industries started exploring its use cases beyond cryptocurrencies. Companies began to experiment with private and permissioned blockchains for supply chain management, finance, healthcare, and more.

**Initial Coin Offerings (ICOs) Boom (2017):** The year 2017 saw a massive surge in ICOs, a fundraising method where new cryptocurrencies were sold to investors. Many of these projects raised substantial amounts of capital but also attracted regulatory scrutiny due to fraud and lack of oversight.

**Cryptocurrency Market Boom and Bust (2017-2018):** In late 2017, the cryptocurrency market experienced an unprecedented boom, with Bitcoin reaching an all-time high price. However, by early 2018, the market entered a significant correction, leading to a prolonged bear market.




***Source:*** https://www.geeksforgeeks.org/history-of-blockchain/

**Fig 1:** History of blockchain technology

**Advancements and Diversification (2018-Present):** Since 2018, blockchain technology has continued to evolve and diversify. Several blockchain platforms have emerged, each with unique features and use cases. Efforts have been made to address scalability, privacy, and interoperability challenges. Moreover, blockchain technology has found applications beyond finance, such as in supply chain management, voting systems, decentralized identity, and more. This brief history provides an overview of how blockchain technology has evolved from its conceptual roots to the diverse ecosystem it is today. As with any rapidly developing technology, new innovations and use cases will likely continue to shape the future of blockchain.

Blockchain technology was originally developed for the cryptocurrency. Since it has been adopted by some industries and supply chain management and railways. It is still rapidly developing technology in many fields and uses to create innovation.

**Block chain componenets**

1. **Distributed Ledger:** The blockchain itself, which is a decentralized and immutable ledger of transactions or data blocks.
2. **Consensus Mechanism:** The algorithm used to validate and agree on the state of the blockchain across multiple nodes, ensuring consensus and preventing fraud.
3. **Nodes:** Individual devices or computers participating in the blockchain network, each maintaining a copy of the ledger.
4. **Cryptographic Hashing:** Algorithms used to create unique and fixed-size digital signatures for blocks, ensuring data integrity and security.
5. **Smart Contracts:** Self-executing contracts with predefined rules and conditions, automatically enforcing and executing actions when certain conditions are met.
6. **Wallets:** Software or hardware tools used to store, manage, and interact with cryptocurrency assets and private keys.
7. **Mining (Proof-of-Work) or Forging (Proof-of-Stake):** The process of adding new blocks to the blockchain by solving complex mathematical puzzles (PoW) or being chosen based on the number of tokens held (PoS).
8. **Public/Private Key Infrastructure:** A cryptographic system used to verify identities, secure transactions, and control access to the blockchain.

**Block chain types**

There are four main types of blockchain networks. Public blockchains, private blockchains, consortium blockchains and hybrid blockchains. Each one of these platforms has its benefits, drawbacks, and ideal uses.

**Public blockchain**

This is the first type of blockchain network where the cryptocurrency like Bitcoin originated and helped to popularize distributed ledger technology (DLT). It removes the problems that come with centralization, including less security and transparency. DLT does not store information in any one place, instead distributing it across a peer-to-peer network. Its decentralized nature requires some method for verifying the authenticity of data. That method is a consensus algorithm whereby participants in the blockchain reach agreement on the current state of the ledger. Proof of work (PoW) and proof of stake (PoS) are two common consensus methods.

Public blockchain is non-restrictive and permissionless, and anyone with internet access can sign on to a blockchain platform to become an authorized node. This user can access current and past records and conduct mining activities. No valid record or transaction can be changed on the network, and anyone can verify the transactions, find bugs, or propose changes because the source code is usually open source.

**Uses**

The most common use case for public blockchains is mining and exchanging cryptocurrencies like Bitcoin. However, it can also be used for creating a fixed record with an auditable chain of custody, such as electronic notarization of affidavits and public records of property ownership. This type of blockchain is ideal for organizations that are built on transparency and trust, such as social support groups or non-governmental organizations. Because of the public nature of the network, private businesses will likely want to steer clear.

**Private blockchain**

A blockchain network that works in a restrictive environment like a closed network, or that is under the control of a single entity, is a private blockchain. While it operates like a public blockchain network in the sense that it uses peer-to-peer connections and decentralization, this type of blockchain is on a much smaller scale. Instead of just anyone being able to join and provide computing power, private blockchains typically are operated on a small network inside a company or organization. They're also known as permissioned blockchains or enterprise blockchains.

**Uses**

The speed of private blockchains makes them ideal for cases where the blockchain needs to be cryptographically secure but the controlling entity doesn't want the information to be accessed by the public.

"For example, companies may choose to take advantage of blockchain technology while not giving up their competitive advantage to third parties. They can use private blockchains for trade secret management, for auditing," Godefroy said.

Other use cases for private blockchain include supply chain management, asset ownership and internal voting.

**Hybrid blockchain**

This is a type of blockchain technology that combines elements of both private and public blockchain. It lets organizations set up a private, permission-based system alongside a public permissionless system, allowing them to control who can access specific data stored in the blockchain, and what data will be opened publicly.

Typically, transactions and records in a hybrid blockchain are not made public but can be verified when needed, such as by allowing access through a smart contract. Confidential information is kept inside the network but is still verifiable. Even though a private entity may own the hybrid blockchain, it cannot alter transactions. When a user joins a hybrid blockchain, they have full access to the network. The user's identity is protected from other users, unless they engage in a transaction.

**Uses**

Hybrid blockchain have several strong uses include real estate also. Many Companies can use a hybrid blockchain to run systems privately but show certain information, such as listings, to the public. Retail can also streamline its processes with hybrid blockchain, and highly regulated markets like see benefits from using it.

Medical records can be stored in a hybrid blockchain, according to Godefroy. The record cannot be viewed by random third parties, but users can access their information through a smart contract. Governments could also use it to store citizen data privately but share the information securely between institutions.

**Consortium blockchain:** This is the fourth type of blockchain, consortium blockchain, also known as a federated blockchain, it is like a hybrid blockchain in that it has private and public blockchain features. But it is different in that multiple organizational members collaborate on a decentralized network. Essentially, a consortium blockchain is a private blockchain with limited access to a particular group, eliminating the risks that come with just one entity controlling the network on a private blockchain.

In a consortium blockchain, the consensus procedures are controlled by preset nodes. It has a validator node that initiates, receives, and validates transactions. Member nodes can receive or initiate transactions.

**Uses**

Banking and payments are two uses for this type of blockchain. Different banks can band together and form a consortium, deciding which nodes will validate the transactions. Research organizations can create a similar model, as can organizations that want to track food. It is ideal for supply chains, particularly food and medicine applications.

Although these are the four main types of blockchain, there are also consensus algorithms to consider. In addition to PoW and PoS, anyone planning to set up a network should consider the other types, available on different ways such as Waves and Burstcoin. For example, leased proof of stake lets users earn money from mining, without the node needing to mine itself. Proof of importance uses both balance and transactions to assign significance to each user.

**Potential application of block chain in agriculture**

Farmers are lagging in adopting newest technology compared to other sectors. For production purposes newer technologies are adopted such as machines but for tracing, storing, and publishing agricultural data still traditional technologies are used. Hence, farmers are not getting the right price and the intermediaries gets more percentage of profit. Block chain can be implemented to solve these issues.

**Agro chain - block chain powered transport marketplace**

Agro chain is a block chain powered transparent agriculture ledger, the main aim of this platform is to bring together farmer and consumer under one umbrella by eliminating third parties agricultural chain aims to implement a zero-debt farming model with appropriate market prediction to meet out supply and demand ratio.

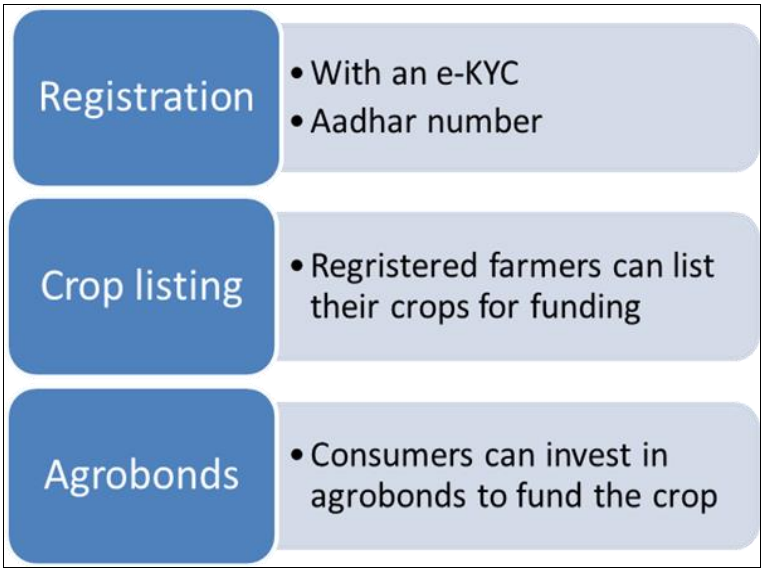



**Fig 2:** Managed logistics marketplace for Agri commodities

**For food safety in agriculture**

In Indonesia it has been successfully implemented in monitoring the animal borne diseases in sea foods as world health organization pointed out many zoonotic diseases is due the presence of livestock which becomes the vector for the infections, another important application is many small groceries have very little amount of profit so that many investors are getting back form it whereas Walmart like company have enough capital to meet out this problems so this technology will make the traceability free to ensure the better profit margin through proper food supply management.

**In agriculture finance**

It is an innovative application on farmers payment side where it has been taken up by the government and NGO for managing the price contracts arising from the brokers this can be solved by enabling real time transactions for farmers through smart contracts that run on block chain. Many companies use block chain for providing crop insurance for the farmers using smart contracts which provides the farmers a trusted weather-based reports microfinancing with sustainable loans to farmers can be provided to the farmers.

- **Access to Finance for Small Farmers:** Blockchain-based platforms can connect small-scale farmers with lenders and investors, facilitating access to credit and investment opportunities. By using blockchain for secure and transparent financial transactions, lenders can reach previously underserved agricultural communities.
- **Cross-Border Payments:** Blockchain technology facilitates cross-border payments without the need for

traditional banking intermediaries. Farmers and exporters can receive payments directly and quickly in cryptocurrencies or stablecoins, reducing delays and transaction costs associated with international money transfers.

- **Identity Verification and Credit History:** Blockchain can be used to establish and verify the identity of farmers, creating a decentralized and tamper-resistant digital identity. This identity can be linked to credit history and reputation, allowing farmers to access financial services more efficiently.
- **Climate and Weather-Linked Finance:** Blockchain can enable the creation of weather-linked financial products that automatically trigger payouts to farmers in case of adverse weather conditions. These products help manage risks associated with climate variability and extreme weather events.
- **Microfinance and Crowdfunding:** Blockchain-based microfinance platforms can offer small loans to farmers, leveraging blockchain's cost-efficiency to serve low-income borrowers. Additionally, crowdfunding platforms can support agricultural projects and initiatives with contributions from a large number of investors.
- **Reduced Transaction Costs:** Blockchain eliminates the need for multiple intermediaries in financial transactions, reducing transaction costs for both farmers and financial institutions. This makes financing more affordable and accessible to agricultural stakeholders.

**In sustainable agriculture**

To negotiate intermediaries and for proper supply chain many foreign countries are developing this technology to make reliably easier for farmers to use in technology in their smart phones roots coup company for monitoring a meat product quality where it has been registered in block chain it can store even down to the DNA level by this production trait mark of cow milk production quality can be assessed proper farm share can be achieved to the farmers.

- **Fair Trade and Ethical Practices:** Blockchain can be used to establish smart contracts that ensure fair and ethical practices in agricultural trade. Farmers can receive fair prices for their products, and the terms of trade can be automatically enforced through blockchain-based agreements.
- **Certification and Labelling:** Blockchain technology can facilitate the validation and verification of certifications such as organic, fair trade, and sustainable sourcing. This ensures that agricultural products meet specific environmental and ethical standards, boosting consumer confidence in sustainable choices.
- **Water Management:** Blockchain based systems can monitor water usage on farms, optimizing irrigation practices and promoting water conservation. This is particularly beneficial in regions facing water scarcity and drought.
- **Crop and Livestock Traceability:** Blockchain enables precise traceability of crops and livestock, helping to identify the origin of contamination or disease outbreaks. This enhances food safety measures and minimizes the spread of diseases in the agriculture sector.

**Intellectual property protection**

Blockchain technology can be used to establish and protect the intellectual property rights of agricultural innovations, such as new seed varieties and farming techniques. Smart contracts can ensure that only authorized parties have access to specific information.

- **Digital Copyright Protection:** Blockchain can be used to timestamp and register creative works such as music, videos, art, and written content. Each registration creates a verifiable and tamper-proof record of the work's creation date and ownership, providing evidence of copyright ownership.
- **Digital Watermarking and Attribution:** Blockchain can embed digital watermarks or fingerprints in creative works to attribute ownership and protect against unauthorized use or plagiarism. This enables easy tracing of copyrighted content and facilitates appropriate attribution of ownership.
- **Smart Contracts for Royalty Distribution:** Smart contracts on the blockchain can automate royalty payments to content creators and rights holders. When their work is used or licensed, the smart contract can automatically execute the agreed-upon payment terms.
- **Patent Tracking and Verification:** Blockchain can record patent information, including application details, claims, and inventors' names. This provides a secure and transparent record of patent ownership and helps prevent fraudulent claims.
- **Trademark Protection:** Blockchain can be used to create a public record of trademarks, ensuring that they are unique and not already in use. This helps in avoiding conflicts and protecting brand identity.

**Decentralized marketplaces**

Blockchain-powered marketplaces can connect buyers and sellers of agricultural products and services without relying on centralized authorities. This can enhance market accessibility for small-scale farmers and promote fair competition.

- **Peer-to-Peer Transactions:** Buyers and sellers can interact directly, enabling faster transactions and reducing costs associated with intermediaries.
- **Trust and Transparency:** Transactions are recorded on the blockchain, providing an immutable and transparent ledger of all activities. This transparency enhances trust among participants and reduces the likelihood of fraud.
- **Smart Contracts:** Decentralized marketplaces often use smart contracts, which are self-executing contracts with predefined conditions. These contracts automate the process of verifying transactions and executing agreements when the specified conditions are met.
- **Cryptocurrency Payments:** Decentralized marketplaces typically use cryptocurrencies as a means of payment. These digital assets facilitate borderless and frictionless transactions, eliminating the need for currency conversions and traditional banking systems.
- **Data Security and Privacy:** Blockchain technology ensures that sensitive data remains secure and private. User identities can be anonymized or pseudonymous, protecting users' personal information.
- **Open and Permissionless:** Most decentralized

marketplaces are open to anyone, allowing anyone to participate without needing approval from a centralized authority. This promotes inclusivity and fosters a global marketplace accessible to all.

**Carbon footprint tracking**

Blockchain can be used to track the carbon footprint of agricultural products, enabling consumers and businesses to make more environmentally conscious choices and rewarding farmers who adopt sustainable practices.

- **Emission Tracking and Verification:** Blockchain can record emissions data from various sources, such as industrial processes, transportation, and energy consumption. This data can be securely stored on the blockchain, creating an immutable and auditable ledger of carbon emissions.
- **Supply Chain Transparency:** Blockchain enables tracing carbon emissions across supply chains. Each participant in the supply chain can record their emissions data on the blockchain, providing transparency and accountability throughout the production and distribution process.
- **Carbon Credits and Offset Mechanisms:** Blockchain can facilitate the creation, trading, and tracking of carbon credits. These credits represent a reduction or removal of greenhouse gas emissions from the atmosphere. Through blockchain, companies and individuals can easily participate in carbon offset projects and verify the legitimacy of these credits.
- **Smart Contracts for Emission Reduction Targets:** Smart contracts on the blockchain can be used to enforce emission reduction targets. Organizations can agree on specific reduction goals and embed them in smart contracts. When the targets are met, the smart contracts can automatically trigger the issuance of carbon credits.
- **Decentralized Carbon Markets:** Blockchain-based carbon marketplaces allow buyers and sellers of carbon credits to interact directly without intermediaries. This streamlined process promotes efficiency and liquidity in the carbon market.
- **Carbon Accounting and Reporting:** Blockchain technology can automate carbon accounting and reporting processes. Companies can integrate data from their operations into the blockchain, facilitating real-time reporting and compliance with environmental regulations.
- **Energy Management and Carbon Footprint Reduction:** Blockchain can support energy management systems that optimize energy usage and reduce carbon emissions. By connecting IoT devices and smart meters to the blockchain, energy consumption data can be recorded and analyzed to identify opportunities for energy efficiency improvements.
- **Green Energy Certificates:** Blockchain can facilitate the issuance and trading of renewable energy certificates, verifying that a certain amount of energy has been produced using renewable sources. These certificates can incentivize the adoption of renewable energy and contribute to the reduction of carbon footprints.

**Land ownership and management**

Blockchain-based land registries can provide secure and tamper-proof records of land ownership, reducing land disputes and ensuring proper land management.

**Data sharing and collaboration**

Blockchain enables secure and decentralized data sharing among stakeholders in the agricultural sector. Researchers, farmers and policymakers can collaborate and access valuable agriculture data while maintaining data ownership and privacy.

**Tokenization of agricultural assets**

The concept of tokenization, where physical assets are represented as digital tokens on a blockchain, is being explored in agriculture. Tokenization allows for fractional ownership and investment in agricultural assets, making it easier for investors to participate in the sector.

**Certification and quality assurance**

Blockchain technology is being utilized for certifying organic and fair-trade products, ensuring that products meet specific quality and ethical standards. This fosters consumer trust and promotes sustainable and responsible agricultural practices.

- **Digital Identity Verification:** Blockchain-based identity systems can securely verify the identity of individuals or entities, preventing identity fraud and ensuring that certifications are issued to the right parties.
- **Certification and Audit Processes:** Blockchain can streamline certification and audit processes by providing a transparent and immutable record of compliance with industry standards and regulations.
- **Timestamping and Data Integrity:** Blockchain can be used for timestamping critical documents and data, ensuring their integrity and preventing tampering or unauthorized alterations.
- **Cross-Industry Standardization:** Blockchain can enable cross-industry standardization of certifications and quality assessments, allowing for seamless verification and recognition of credentials across different sectors.

**Remote monitoring and precision agriculture**

Blockchain's integration with the Internet of Things (IoT) is enabling remote monitoring of agricultural processes. Data collected from IoT sensors on farms can be securely recorded on the blockchain, supporting precision agriculture techniques to optimize resource usage and increase productivity.

**Block chain in agriculture supply chain management**

Block chain is one of the best and reliable method for improving the supply chain thereby we can improve the supply chain management. In blockchain the transparency and the sharing of the transaction details to all the digitalized ledger, it increases the integrity of the actors involved in the supply chain.

**Constraints of implementing block chain in supply chain management:**

The major constraints of implementation of block chain in supply chain management in India is the mindset of the actors involved. Other challenges such as organizational readiness, high cost in adopting the technology, gaining the trust of the actors and the technical knowledge on the BC is lagging, these are the major constraints. However still the BC is worth in tracing the goods within the supply chain.

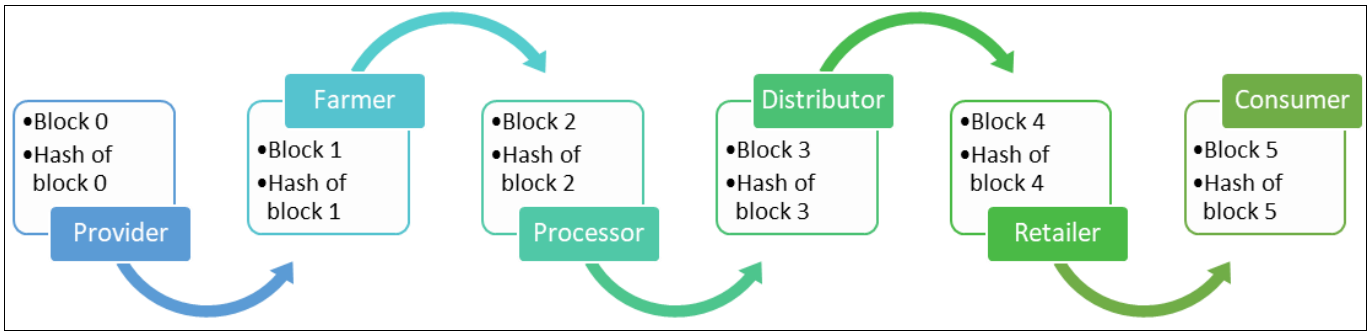



**Fig 3:** Working of the blockchain in a supply chain

**Traceability for blockchain based supply chain management**

Block chain is one of the ways to trace the products in the supply chain industries. There are lot of members involved in the supply chain such as supplier, manufacturer, distributor, retailer, consumer etc.

They are connected into a single block so that they can be traced easily. Since all the transactions in the block chain is visible it is easy for tracing the forward and backward movement of the products within the supply chain.

**Traceability for food supply chains**

The major problem in the food supply chains is the food quality, it is very big problem in the food and beverage industries. This problem can be overcome by the blockchain

**Food traceability using block chain in India**

Sahyadri Farms is one the largest FPO's in the country with a revenue of Rs.4.6billion. It assures its farmers with the 25% share of the final price of goods sold by the firm. The company is using block chain to increase transparency in its business. It uses the block chain to provide details such as harvest details and produce quality. Also, it gives the price the farmer received and the cost for processing, packaging, and transport.

**Blockchain enabled smart contract in agricultural transactions**

**Smart contract**

Smart contract is a self-executing pre-determined set of agreements that automates the workflow, triggering the next action when the conditions of the agreement are met. It is hassle free, trustworthy, intermediate-free, automated, spontaneous, fast, and effective. It is set of programmes set stored on a blockchain that runs when the pre-determined conditions are met.

**Implementing smart contract**

Smart contracts are self-executing contracts by following if/when. Then statements directly written into code in a blockchain.

A network of computers executes these codes after the pre-determined conditions are met and verified. These actions could be transferring fund, releasing goods, issuing credit, or sending notification. The blockchain is then updated when the transaction is completed.

The specific actions and conditions within a smart contract are defined during its development. All parties of the contract must agree upon all the terms and condition of the contract. The parties also must explore all the cases of disputes and define a framework for resolving these issues. Then these conditions are programmed into a blockchain codes by a developer.

One of the key advantages of smart contracts is their immutability. Once a smart contract is executed, it becomes part of a permanent record. This transaction history is stored on the blockchain and cannot be altered. This transparency and immutability provide a high level of trust and accountability in the execution of smart contracts.

Furthermore, smart contracts only grant permission to the parties involved in the contract and can view the results and details of the transaction. This ensures privacy and restricts access to sensitive information to only authorized individuals.


**Fig 4:** Steps of building a smart contract

**Smart contract for the benefit of farmers**

Farmers will obtain a network of contacts, a wealth of resources, and authorities necessary to stay relevant in the agriculture industry. Some new companies have already

launched platforms to increase the profit given to farmers and decrease the waste lost in the agricultural chain by eliminating intermediaries who control communication, marketing, and finance. It connects the farmers and consumers directly without any intermediaries.

Smart contracts can end ownership disputes, track payments on a debt owed until paid off, and organize legal rights to property even in partial majority/minority ownership.

Smart contracts can be utilized for the governmental subsidy money distribution to the farmers providing privacy preserving. These smart contracts can be helpful in eliminating over billing and money mishandling.

**Integration of blockchain with other emerging technologies in agriculture**

**AI and Blockchain in Agriculture**

The integration of AI (Artificial Intelligence) and blockchain in agriculture can bring transformative benefits to the industry, combining the power of data analytics and decentralized, secure data management. Here's how AI and blockchain can work together in agriculture.

- **Data Collection and Analysis:** AI can analyze vast amounts of agricultural data collected from various sources, such as IoT sensors, satellite imagery, weather data, and historical records. It can identify patterns, trends, and anomalies in the data, providing valuable insights into crop health, soil conditions, pest detection, and more. AI-driven analytics can help farmers make data-driven decisions and optimize agricultural practices.
- **Decentralized Data Sharing and Security:** Blockchain's decentralized nature ensures that agricultural data is stored in a tamper-resistant and secure manner. AI-generated insights and data can be stored on the blockchain, enabling secure data sharing among relevant stakeholders while maintaining data integrity and authenticity.
- **Smart Contracts for Agricultural Operations:** AI can help automate the execution of agricultural processes through smart contracts on the blockchain. For example, AI algorithms can analyze weather data and trigger smart contracts to automatically activate irrigation systems or adjust fertilizer application based on real-time weather conditions.
- **Supply Chain Transparency and Traceability:** AI can be used to track the movement of agricultural products throughout the supply chain. When combined with blockchain, this creates an immutable and transparent record of the product's journey, ensuring traceability, authenticity, and compliance with quality and safety standards.
- **Predictive Analytics for Farming:** AI's predictive capabilities can be harnessed to anticipate potential issues in agriculture, such as disease outbreaks, pest infestations, or yield fluctuations. By integrating AI with blockchain, these predictions can be recorded on the blockchain, providing an auditable trail of predictions and outcomes for future analysis and decision-making.
- **Agricultural Robotics and Drones:** AI-powered agricultural robots and drones can be deployed on farms to perform tasks such as planting, harvesting, and monitoring crop health. Data generated by these AI-driven devices can be recorded on the blockchain, ensuring transparency and accountability in farm operations.
- **Crop and Livestock Monitoring:** AI-based image recognition and sensor technologies can monitor crop health and livestock conditions. The data collected can be analysed by AI algorithms to detect early signs of disease or stress. Storing this data on the blockchain provides a tamper-proof record of the health status of crops and animals.
- **AI-Driven Market Insights:** AI can analyse market trends and demand patterns to provide farmers with insights into optimal crop selection and pricing strategies. The use of blockchain ensures that data used for these analyses is accurate and cannot be altered, fostering trust in the information provided.
- **AI-Powered Agricultural Advisory Services:** Blockchain can facilitate the secure exchange of data between farmers and agricultural advisory services that utilize AI. This exchange enables personalized recommendations based on real-time data and historical insights, assisting farmers in making informed decisions.

  While the integration of AI and blockchain in agriculture presents exciting opportunities, it also comes with challenges, such as data privacy, interoperability, and computational power. Addressing these challenges will be crucial in realizing the full potential of these technologies to drive innovation, efficiency, and sustainability in the agricultural sector.

**Bigdata and Blockchain in Agriculture**

The integration of Big Data and blockchain in agriculture can offer a powerful combination that enhances data management, traceability, and decision-making processes in the industry. Here are how the two technologies can work together.

- **Data Collection and Analysis:** Big Data analytics in agriculture involves collecting and analysing vast amounts of data from various sources such as IoT sensors, satellite imagery, weather data, and historical records. This data can provide valuable insights into crop health, soil conditions, weather patterns, and other factors affecting agricultural productivity. By integrating blockchain, the data collected can be securely stored and shared among relevant stakeholders, ensuring data integrity and transparency
- **Decentralized Data Sharing:** Big Data often involves sharing sensitive information among different parties, including farmers, researchers, suppliers, and consumers. Blockchain's decentralized nature allows data to be shared securely without the need for a central authority. This ensures that data is not controlled by any single entity and minimizes the risk of data tampering or unauthorized access.
- **Supply Chain Transparency:** Blockchain can be used to create an immutable and transparent supply chain for agricultural products. By combining Big Data analytics with blockchain, it becomes easier to track the journey of products from farm to consumer. Information such as origin, handling, processing, and transportation can be

recorded on the blockchain, providing consumers with verifiable information about the products they buy.

- **Smart Contracts for Agreements:** Smart contracts can be integrated with Big Data to automate various processes in agriculture. For example, farmers can enter into agreements with suppliers or buyers based on specific conditions such as crop yields, market prices, or weather events. When the predetermined conditions are met, the smart contract automatically executes the terms of the agreement, streamlining transactions and reducing administrative overhead.
- **Crop and Livestock Management:** Big Data analytics can help farmers make data-driven decisions about crop planting, irrigation, fertilization, and pest control. By integrating this data with blockchain, farmers can keep track of their management practices and provide evidence of their compliance with agricultural standards and certifications.
- **Data Security and Privacy:** Big Data often involves sensitive information about agricultural practices and production. Blockchain's cryptographic features ensure that data is secure and tamper-proof, while also allowing farmers to control access to their data through private keys. This empowers farmers to share specific information with trusted parties while maintaining data privacy.
- **Enhanced Research and Development:** Big Data and blockchain integration can accelerate agricultural research and development. Researchers can securely access and share large datasets, leading to the development of innovative solutions for crop improvement, disease prevention, and sustainable farming practices.
- **Farm-to-Table Authentication:** Combining Big Data analytics with blockchain can facilitate farm-to-table authentication. Consumers can scan product QR codes to access information about the product's origin, production processes, and quality, ensuring transparency and building trust between producers and consumers.
- However, there are some challenges to consider when integrating Big Data and blockchain in agriculture, such as data standardization, interoperability, and the computational resources required for processing large datasets. Despite these challenges, the convergence of these technologies has the potential to revolutionize the agricultural sector by enabling data-driven decision-making, supply chain transparency, and sustainable farming practices.

**Internet of things and Blockchain in Agriculture**

The integration of blockchain with the Internet of Things (IoT) in agriculture holds significant potential to revolutionize the industry by enhancing efficiency, transparency, and trust. This combination can address various challenges faced by traditional agricultural systems, such as supply chain management, traceability, data security, and real-time monitoring. Below are some key aspects of how blockchain and IoT can work together in agriculture.

- **Supply Chain Management:** Blockchain can be utilized to create an immutable and transparent supply chain for agricultural products. By integrating IoT sensors and devices at various stages of the supply chain (e.g., farms, warehouses, transportation vehicles), data on product origin, handling, storage conditions, and transportation can be recorded on the blockchain. This ensures that all relevant stakeholders have access to trustworthy information about the product's journey from farm to consumer.
- **Provenance and Traceability:** Blockchain in combination with IoT can enable farmers and consumers to trace the origin of agricultural products easily. IoT devices can collect data about each stage of a product's journey, such as planting, harvesting, processing, and distribution, which can then be recorded on the blockchain. This enables end consumers to verify the authenticity and quality of the products they purchase.
- **Smart Contracts for Agricultural Transactions:** Smart contracts, self-executing code on the blockchain, can automate and secure agricultural transactions. For example, when certain conditions are met (e.g., specific environmental parameters, crop yields), smart contracts can automatically trigger payments to farmers, suppliers, or other parties, eliminating the need for intermediaries and reducing transaction costs.
- **Farm Management and Automation:** IoT sensors deployed on farms can gather data on soil conditions, weather patterns, crop health, and livestock behaviour. This data can be recorded on the blockchain, providing farmers with valuable insights into their operations. Smart devices can also automate tasks such as irrigation, fertilization, and pest control based on pre-defined conditions, improving efficiency, and reducing resource wastage.
- **Data Security and Ownership:** With IoT devices generating vast amounts of data in agriculture, concerns about data security and ownership arise. Blockchain's decentralized and cryptographic nature can provide a secure framework for data storage and sharing. Farmers can control access to their data through private keys, allowing them to share specific information with authorized parties while retaining ownership.
- **Insurance and Risk Management:** IoT sensors can help monitor environmental conditions and predict potential risks to crops, livestock, and infrastructure. When integrated with blockchain, this data can be used to design more accurate and personalized insurance policies for farmers, reducing financial risks associated with agriculture.
- **Tokenization and Crowdfunding:** Blockchain enables tokenization, representing assets or commodities as digital tokens. This concept can be applied to agriculture, allowing farmers to tokenize their crops or farming assets and seek crowdfunding from interested investors. This opens new financing options for small-scale farmers and encourages investment in agriculture.
- **Climate and Sustainability Tracking:** IoT devices and sensors can help track greenhouse gas emissions, water usage, and other environmental factors related to agricultural practices. This data, when combined with blockchain, can aid in monitoring and verifying sustainable agricultural practices, contributing to eco-

friendly certifications and standards.
- In summary, the integration of blockchain and IoT in agriculture has the potential to enhance the efficiency, transparency, and sustainability of the industry. By providing a decentralized, secure, and immutable platform, this combination can facilitate the seamless flow of information, optimize processes, and foster trust among all stakeholders involved in agricultural operations and supply chains. As with any emerging technology, challenges remain, but ongoing developments in blockchain and IoT are continually unlocking new possibilities for the agricultural sector.

**Benefits of farmers by using blockchain**

Farmers can reap numerous benefits by adopting blockchain technology in their agricultural operations. Some of the key advantages include.

- **Transparency and Trust:** Blockchain provides an immutable and transparent ledger, allowing farmers to record all their transactions and data securely. This transparency builds trust among various stakeholders, including buyers, suppliers, and consumers, as they can verify the authenticity and provenance of agricultural products.
- **Improved Traceability:** Blockchain enables farmers to track the entire lifecycle of their products, from seed to harvest and distribution. This traceability helps identify the source of any issues, such as contamination or quality concerns, and facilitates targeted recalls if necessary, minimizing losses and reputational damage.
- **Efficient Supply Chain Management:** By integrating blockchain with the supply chain, farmers can streamline the movement of their products, reducing delays and optimizing logistics. Smart contracts can automate certain aspects of supply chain management, such as payments, reducing administrative burdens and increasing efficiency.
- **Secure Data Management:** Blockchain ensures that sensitive agricultural data, such as crop yields, soil quality, and weather conditions, is securely stored and tamper-proof. This data can be shared with relevant parties while maintaining ownership and control, protecting farmers' valuable information.
- **Access to Finance and Credit:** For small-scale farmers or those in developing regions with limited access to traditional banking services, blockchain-based platforms can enable peer-to-peer lending and microfinancing. Smart contracts can facilitate transparent loan agreements, expanding financial opportunities for farmers.
- **Fair Pricing and Market Access:** Blockchain can help farmers access global markets more easily and directly, removing intermediaries and ensuring fair prices for their products. This democratization of the market can lead to increased profits and more equitable trading conditions.
- **Climate and Sustainability Tracking:** With the rise of consumer demand for sustainable and eco-friendly products, blockchain can enable farmers to provide verifiable proof of their adherence to sustainable practices, leading to eco-label certifications and access to environmentally conscious markets.
- **Automated Payments and Reduced Fraud:** Smart contracts on the blockchain can automate payment processes, ensuring timely and accurate remittances to farmers. This reduces the risk of payment disputes and fraud, as all payment details are recorded transparently on the blockchain.
- **Decentralized Marketplaces:** Blockchain-based marketplaces can connect farmers directly with buyers, eliminating the need for middlemen and associated fees. This creates a more efficient and equitable marketplace, benefiting both farmers and consumers.
- **Incentives for Quality Improvement:** Through blockchain, farmers can receive incentives or premiums for producing high-quality agricultural products. Transparent quality data recorded on the blockchain allows buyers to differentiate and reward superior products.


**Fig 5:** Benefits of Blockchain

In summary, blockchain technology offers farmers numerous advantages, including enhanced transparency, traceability, data security, market access, and streamlined processes. By embracing blockchain, farmers can position themselves at the forefront of the digital transformation in agriculture, gaining a competitive edge in an increasingly global and interconnected marketplace.

**Challenges of using block chain faced by farmers**

While blockchain technology offers several benefits to farmers, it also presents some challenges that may hinder its widespread adoption in the agricultural sector. Some of the key challenges faced by farmers in implementing blockchain are.

- **Cost of Implementation:** Integrating blockchain into existing agricultural systems can involve significant upfront costs, including investment in hardware, software, and skilled personnel. For small-scale farmers or those with limited financial resources, these costs may be prohibitive.
- **Technical Complexity:** Blockchain technology can be complex and challenging to implement and maintain, especially for farmers who may not have a strong technical background. Training and support may be required to ensure farmers can effectively utilize blockchain platforms.
- **Data Connectivity and Infrastructure:** In many rural areas, farmers may have limited access to reliable

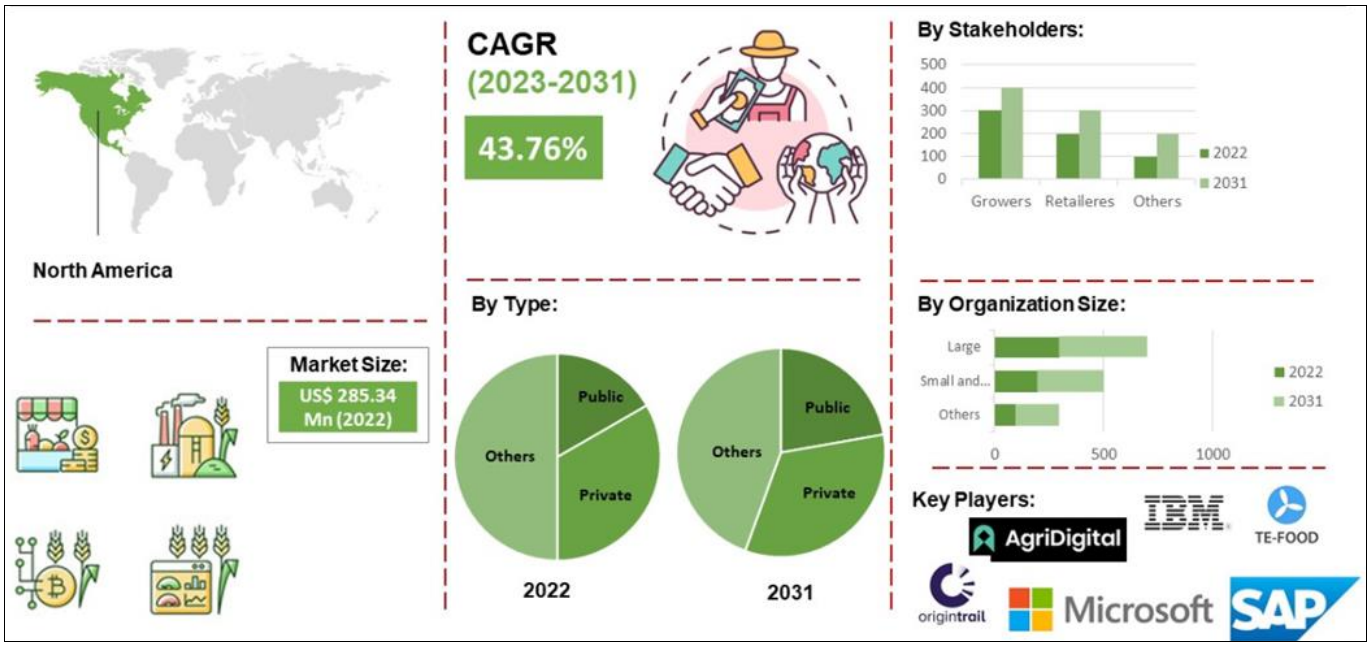
internet connectivity and modern infrastructure. The success of blockchain relies on real-time data sharing, which can be challenging in regions with poor connectivity.

- **Data Privacy and Security Concerns:** While blockchain provides a secure platform for data storage, there may still be concerns about data privacy, especially when sensitive agricultural data is shared on the blockchain. Farmers need to ensure that appropriate measures are in place to protect their data from unauthorized access.
- **Standardization and Interoperability:** The lack of standardized protocols and interoperability between different blockchain platforms can create compatibility issues. Farmers may find it challenging to integrate blockchain solutions with existing systems and collaborate with other stakeholders.
- **Regulatory and Legal Compliance:** As blockchain technology is still relatively new, there may be regulatory uncertainties and legal challenges regarding data ownership, smart contracts, and liability. Farmers need to navigate these complexities to ensure compliance with local laws and regulations.
- **Education and Awareness:** Many farmers may not be familiar with blockchain technology and its potential benefits. Raising awareness and providing education about blockchain's applications and advantages can be essential in encouraging adoption.
- **Scaling and Network Size:** For blockchain to be effective, it requires a significant number of participants in the network. In some regions, the limited number of farmers and stakeholders using blockchain may limit its overall effectiveness and impact.
- **Resistance to Change:** Implementing blockchain may require changes to traditional practices and business models. Some farmers and stakeholders may be hesitant to adopt new technologies, preferring to stick with familiar methods.
- **Energy Consumption:** Some blockchain networks, particularly those using Proof-of-Work (PoW) consensus mechanisms, can be energy-intensive. This may raise concerns about environmental sustainability and may not be feasible in areas with limited access to reliable energy sources.

Despite these challenges, as blockchain technology continues to evolve and become more accessible, solutions to some of these issues are likely to emerge. With proper planning, support, and collaboration, farmers can overcome these challenges and harness the benefits that blockchain offers to enhance their agricultural practices and market opportunities.

**Current trends**

- **IBM:** IBM has been a prominent player in developing blockchain solutions for various industries, including agriculture. They have partnered with companies and organizations to implement blockchain for supply chain transparency, traceability, and food safety in the agricultural sector.
- **Farm AI:** a pioneering technology company, is leading the charge in bringing revolutionary advancements to the smart farming industry through the seamless integration of blockchain and artificial intelligence (AI). With a team boasting extensive expertise in blockchain development, Farm AI is leveraging cutting-edge technologies to transform traditional agriculture and pave the way for a new era of sustainable and efficient farming practices.
- **AgriDigital:** AgriDigital is an Australian-based company that utilizes blockchain technology for supply chain management and commodity trading in the agriculture industry. Their platform enables farmers to directly sell their products to buyers, creating a more efficient and transparent trading ecosystem.
- **Ripe.io:** Ripe.io uses blockchain and IoT technology to provide complete transparency in the food supply chain. Their technology helps capture data about crops at various stages of their lifecycle, which can help farmers make better decisions and consumers understand the origin of their food.
- **Farm2Kitchen:** India-based Farm2Kitchen uses blockchain for farm-to-fork traceability, ensuring food safety, reducing food fraud, and helping farmers receive a fair price for their produce.
- **Arc-net:** Arc-net focuses on using blockchain to tackle food fraud and ensure product authenticity and traceability. They have worked on projects in the agriculture sector to track the journey of agricultural products from farm to consumer.
- **Viant:** Viant is a blockchain-based supply chain platform that has been exploring applications in agriculture. They aim to create a decentralized ecosystem for tracking agricultural products, providing consumers with verified information about the origin and quality of the products they purchase.
- **OriginTrail:** OriginTrail is a blockchain-based protocol that enables supply chain data interoperability and transparency. They have been working on projects related to agricultural supply chain management and traceability.
- **Provenance:** Provenance empowers producers with blockchain-backed 'Proof Points' that give each product a unique digital identity, offering a new level of trust and transparency about a product's origin, journey, and impact.
- **TE-FOOD:** TE-FOOD is a blockchain-based food traceability platform that focuses on the agricultural and food industries. They aim to improve food safety and quality by tracking the journey of food products from farm to fork.
- **Walmart and IBM Food Trust:** Walmart, in collaboration with IBM, launched the Food Trust initiative to improve food traceability and safety. They have been working with various partners in the agriculture sector to track and trace food products using blockchain technology.
- **Bext360:** Bext360 utilizes blockchain and AI to trace the journey of agricultural products, including coffee, cocoa, and seafood. Their platform provides transparency and fair payment to farmers and producers.
- **Skuchain:** Skuchain is a blockchain supply chain platform that has been involved in projects related to agricultural trade finance and logistics management.




***Source:*** https://www.insightaceanalytic.com/report/global-blockchain-in-the-agriculture-and-food-supply-chain-market/1436

**Fig 6:** Blockchain in the Agriculture and Food Supply Chain Market Size, Share & Trends Analysis Report

## Conclusion

Blockchain technology is an emerging technology that can be integrated with the Internet of Things (IoT), Artificial intelligence (AI) and Bigdata in agriculture, enabling real-time monitoring and processing of agricultural processes. The integration of blockchain and IoT, AI and bigdata in agriculture holds significant potential to revolutionize the industry by enhancing efficiency, transparency, spontaneity, and trust. Blockchain offers several advantages to farmers, including enhanced transparency, traceability, data security, market access, and streamlined processes. With proper planning, support, and collaboration, farmers can overcome these challenges and harness the benefits that blockchain offers to enhance their agricultural practices and market opportunities. Many companies have started to implement blockchain in agriculture and its trend in growth is steadily increasing.

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