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Leveraging Blockchain Technology for Food Supply Chain to Avoid the Intermediaries in Bangladesh

Farhan Labib, Samia Janan, Omar Faruk Nabil, Mohammad Shamsu Uddin*

Department of Business and Technology Management, Islamic University of Technology, Gazipur 1704, Bangladesh

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*Corresponding Author E-Mail:
msuddin16@yahoo.com

ABSTRACT

The blockchain-based structure can be one of the best ways to improve transparency and efficiency in the food supply chain. In the current supply chain of Bangladesh, lack of transparency, manipulation of intermediaries regarding price, and struggle faced by farmers are prevalent. The proposed structure utilizes blockchain technology and smart contracts to connect farmers and consumers directly, thereby eliminating intermediaries. This elimination will ensure fair prices for the farmers and increase consumers' purchasing power. Additionally, smart contracts automatically execute agreements related to pricing, delivery terms, and product information. Furthermore, consumers will have access to a transparent record of the food journey from land to consumers' homes, which will increase trust and confidence in food quality. These contributions can have a significant impact on society by supporting SDG 1 (No Poverty), SDG 2 (Zero Hunger), and SDG 12 (Responsible Consumption).

1-INTRODUCTION

Bangladesh is mainly an agricultural country with industrious farmers; however, the food supply chain has presented many serious challenges. The continuing practice of price manipulation by the intermediaries between farmers and consumers has brought about unfair practices of low income for farmers and inflated consumers' costs. This circumstance worsens farmers' poverty and declines consumers' purchasing power, making quality food inaccessible.

While other initiatives have been taken to boost the agricultural sector in Bangladesh, but the most persistent issue of middlemen is still largely unaddressed. So, intermediaries hinder the sector's growth and create transparency problems. Due to a lack of transparency in the growth and development of agricultural goods, customers have been traumatized by taking food. In addition, the existing supply chain system also fails to supply adequate storage and transportation facilities, leading to significant food wastage (Hasan & Habib, 2022).

To avoid these problems, a sturdy, transparent system is needed to connect consumers with farmers, bypassing the shady middlemen. The blockchain seems able to serve this requirement. It is recommended that, blockchain technology can radically reduce transaction costs by removing the need for middlemen, which traditionally facilitate transactions between parties (Hasan & Habib, 2022). This is relatable in those industries where transaction costs are high due to the involvement of multiple intermediaries (Torres De Oliveira, 2017). In financial markets, blockchain can streamline processes by reducing the need for financial middlemen, thereby decreasing costs and increasing efficiency (Desai, 2023).

Accordingly, this research integrated blockchain-based model with smart contracts and a public-private partnership for cold storage facilities to addresses the lack of transparency in Bangladesh's food supply chain, primarily caused by the overreliance on middlemen. The implementation of blockchain and smart contract technology in a public-private partnership offers a promising solution to these challenges (Apostolidis et al., 2022). It is assumed that this secure, transparent, and tamper-proof platform will completely change how we track and record where food comes from, its quality, and where it goes. Under this proposed model, farmers can also register on a secure platform and create smart contracts with consumers, ensuring fair prices and eliminating the need for exploitative middlemen. This blockchain model will enhance Bangladesh's food supply chain by reducing middlemen and increasing transparency, supporting SDG1(No Poverty), SDG2(Zero Hunger), and SDG12(Responsible Consumption). It proposes to increase farmers' income and reduce food wastage, despite challenges like lower adoption rates and high costs.

Our model consists of three major parts. Firstly, farmers use a platform to display products along with their prices via smart contracts. Next, a delivery system confirms real-time food tracking and then the consumers have access to trace the food from farm to table. Our model will reduce food wastage by leveraging blockchain in the traditional food supply chain. This proposed solution also eliminates price exploitation that farmers are often subjected to through intermediaries, ensuring fair prices for the produce. We thus end this unfair practice of allowing farmers by providing a safe website registration and constructing smart contracts with customers.

Our model provides three practical implications. First, intermediaries will be reduced in this process. Then Blockchain technology enhances trust and confidence in food quality, while improved storage facilities reduce food wastage, stabilize prices, and ensure a steady food supply. Next, this suggested approach is not only improving the agricultural sector of Bangladesh but also developing the economy as a whole; it is increasing farmers' living standards and consumer purchasing power. This discovery is important because it offers a scalable solution to a pressing problem that impacts millions of Bangladeshi farmers and consumers. After that, the approach helps achieve the more general objectives of sustainable development, including the reduction of poverty and hunger.

The paper is structured as follows: a detailed overview of the current situation highlighting the challenges farmers and consumers face. Then, the proposed blockchain-based model is introduced, and the methodology is discussed. Subsequent sections show the findings and analyze the proposed model's impact on the agricultural sector. Finally, it ends with the

significance of the research and future recommendations.

2-LITERATURE REVIEW

2.1 BLOCKCHAIN AND SMART CONTRACT

Blockchain is a decentralized ledger that ensures that data cannot be altered or manipulated after being recorded (Engelmann et al., 2023). All transactions on a blockchain are visible and transparent, increasing trust and reducing the risk of fraud (Flores, 2023). It is a chain of records consisting of relevant info and a hashing algorithm. Hash is like a unique fingerprint for a specific block. The block which does not have a previous hash is called the genesis block.

Using the hashing algorithm, we can track the history of blockchain. Blockchain is nothing but a digital ledger that is conducted automatically through smart contracts. Smart contracts, a self-executing script, automatically create the terms of agreement and reduce the need for intermediaries (Izzul et al., 2023; Ma, n.d.). In many jurisdictions, smart contracts have a similar legal force as traditional contracts (Ma, n.d.; Szabo et al., n.d.). They play a vital role in the system by offering security and automation in implementing agreements without any middlemen. (Engelmann et al., 2023; Varbanova, 2023). According to (Ibrahim et al., 2023) being a tamper-proof and distributed ledger blockchain is crucial for tracking the origin and journey of food products. Every transaction and movement of food products is recorded by blockchain, by which the origin and journey of food items can be traced easily from farm to table. It enhances food safety and consumer trust. There is a consensus rule in blockchain, meaning that implementing any change in blockchain requires a majority win. If any hacker changes data, the hash will be changed for the specific block, which will simultaneously affect the other blocks because of the previous hashing system, and there will be invalid data. Since there is a copy of the blockchain, everyone in the network will notice the change and be alarmed. So, the hacker will fail to generate his plan. So, blockchain helps to build trust and cooperation among people who work together without a central authority to ensure transparency. That's why one research has demonstrated how the integration of blockchain with IoT devices, real-time data acquisition, and monitoring can be achieved (Addou et al., 2023) .Well, that will be an opening of a modernized food supply chain system.

According to research papers, initially conceptualized as the foundation for cryptocurrencies like bitcoin, blockchain technology has evolved into a versatile tool with applications across numerous sectors. Blockchain is a decentralized, append-only ledger system that ensures data immutability and transparency by maintaining a cryptographic audit trail across multiple nodes. Another source showed that in the financial sector, blockchain is a disruptive technology with the potential to streamline processes by eliminating the need for many intermediaries. It offers a secure framework for tracking assets and agreements, thereby reducing the complexity and cost associated with typical verification processes (Gasser & Hubaux, 2023; Gupta & Sadoghi, 2021; Jepkemei & Kipkebut, 2019; Varma, 2019; Wang, n.d.). Despite having many potentials for blockchain adoption in the food supply chain, it faces many significant challenges regarding technological investment and complexity. To prevent these challenges everyone must start with pilot projects to acquire scalability and feasibility (Zhang, 2024).

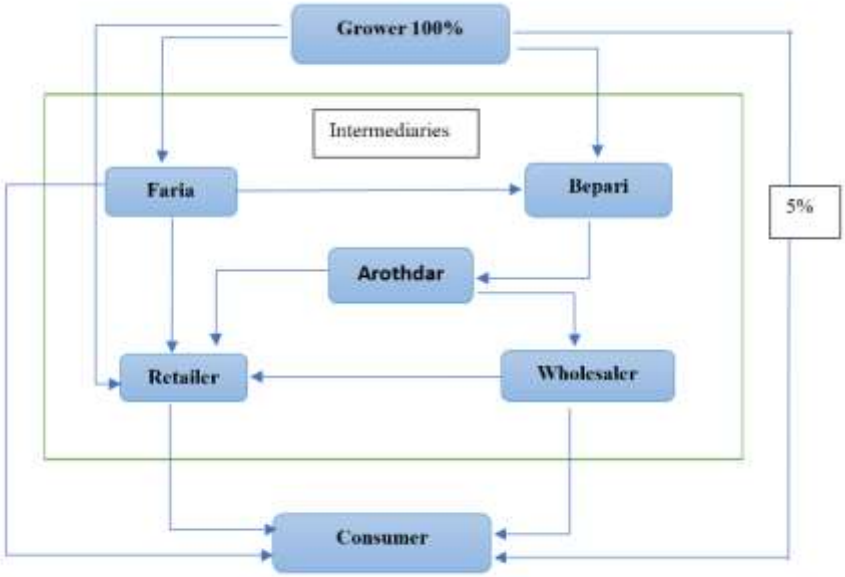
FOOD SUPPLY CHAIN

Food supply chain management monitors the movement of goods from their origin to their consumption. The food supply chain in Bangladesh is a multi-stage complex system. It includes marketing, distribution, post-harvest, and production. Farmers and consumers face numerous challenges since many middlemen are in the traditional food supply chain. Those challenges are related to post-harvest difficulties, price instability, inequity, sustainability issues, and quality concerns. (Jin et al., 2024) has demonstrated that incidents related to food safety affect consumer trust and the development of the food industry. Lack of transparency and traceability in the traditional food supply chain leads to data tampering and loss. To serve these issues blockchain importance is noteworthy (Subramanian et al., n.d.; Tang, 2023) . To enhance livelihoods, we need to guarantee food security and develop a resilient food system in Bangladesh. We, therefore, embrace technology like blockchain to implement sustainable practices and

empower farmers to keep up with modern facilities.

EXISTING FOOD SUPPLY CHAIN IN BANGLADESH

According to (Das & Hanaoka, n.d.) only 5% of the total growth comes directly to the customers from the growers, and the remaining 95% of the total growth comes from 5 intermediaries shown in figure 1. This eventually leads to inefficiency and high costs, lack of market transparency, quality issues, limited access for consumers, lack of value addition (Dr Nazneen Ahmed, 2016).



Source: Rubel& Shinva (1990) Perishable food supply chain constraints in Bangladesh

Figure 1: Existing Food Supply Chain in Bangladesh

We can see in Figure 1 that the most alarming point is the syndicate. The intermediaries' stock the food to create an artificial gap in the market, and the price becomes so high. On the other hand, a significant portion of food wastage is due to proper preservation. That is why, from another perspective, the country needs to import that food from foreign countries. According to another study, the food supply chain in Bangladesh is known to be a complex network of middlemen, and the market dynamics notably impact producers and consumers. Bangladesh's agriculture supply chain (ASC) is usually linear, involving multiple middlemen such as farias, beparies, and aratdars, who facilitate the movement of goods from farmers to consumers. This practice results in a significant part of consumer prices being absorbed by those middlemen rather than profiting the farmers directly. Besides, smallholder farmers face numerous challenges, such as limited resources, sustainable farming techniques that hinder their integration into global value chains, and adopting sustainable practices (Hasan & Habib, 2022, 2023). Similarly, the vegetable supply chain in Bangladesh can be defined by inefficiencies and a lack of control by producers over distribution and pricing. Market syndicates and intermediaries dominate the supply chain, paying consumers more than the producers' margins (Abu & Gazi, 2020; Karim & Biswas, 2016). Then, during the COVID-19 pandemic, the onion supply chain was particularly affected due to high transportation costs, inadequate storage facilities, and limited government intervention, exacerbating the challenges faced by producers (Mila et al., 2022).

EXISTING GLOBAL APPLICATIONS

Several companies use blockchain technology to create healthy relationships with customers built with trust and transparency. We will discuss a few of those companies.

Walmart Global Tech

Walmart and IBM have created a food traceability system using Hyperledger Fabric. This allowed companies to act faster and protect farmers' livelihoods. Now, it takes 2.2 seconds to trace the origin of mangoes. To do this, Walmart worked with GSI (a global organization that sets standards for supply chain management, including barcodes and RFID tags for product tracking) to define the data attributes that need to be sent to the blockchain. Standardizing these data attributes helps to keep it concise and consistent across different systems and organizations in the supply chain. Then IBM developed smart contracts to ensure efficient and accurate transactions. Finally, suppliers had to use new labels that meet the standards created with GSI and share their data through a web-based interface.

Walmart's use of blockchain technology has brought about transparency, speed, and safety. With blockchain, Walmart can track food products from farm to shelf. That is days down to seconds so that they can respond faster to contamination issues and food safety. The immutability of blockchain records has also reduced fraud and errors so that consumers can trust the quality and authenticity of products. The visibility of the supply chain has also led to better inventory management and less waste, making it more sustainable. Blockchain has enabled Walmart to deliver better products that are more reliable and efficient for themselves and their customers (Daley, 2023).

TagOne

Building a more responsible and connected global food supply chain—TagOne deploys blockchain, AI, and cloud computing. Here, supply in the chain focuses on FSMA compliance through capture, storage, and information sharing at predefined events called Critical Tracking Events, along with data elements known as Key Data Elements. Harvesting, Processing, Packaging, and Shipping are CTEs. From here, capturing KDEs in every CTE will ensure greater traceability of food products. This enhances the facility for fast identification and fast measures to address potential food safety issues.

TagOne, aided by blockchain technology, has made several changes in the supply chain system, which have had several positive impacts. Technology increased transparency and traceability throughout the supply chain since it traces products from their origin to the consumer in real-time. This has gained more trust from the stakeholders in that data cannot be altered or manipulated due to its immutable nature associated with blockchain, thus reducing the chance of fraud. Moreover, smart contracts make operations easier by reducing paperwork and administrative expenses, besides ensuring that all compliance norms are correctly followed by automating key processes. The most crucial attribute of blockchain's decentralized nature is to improve principal data security and reduce the risks of breaches and unauthorized access. From the point of view of the research outcomes on blockchain technology currently applied at TagOne, an increasingly efficient, secure, and reliable supply chain system is being birthed, leading to increased stakeholder confidence and operational excellence (Daley, 2023)

Tyson Foods

Tyson Foods, the parent company of Hillshire Farm and Jimmy Dean, has utilized the unique features of the blockchain platform Connect from FoodLogiQ for supplier management since 2018. This platform consolidates all supplier documentation, facilitates product evaluations, and automates food recall actions. It also fosters direct communication with suppliers to enhance product quality and drive informed decisions around food quality, supplier performance, and document expiration. The ultimate goal is to ensure that all supplier-related documents meet corporate quality standards and are readily available for any new product evaluation.

Since the rooting of blockchain technology in the supply chain system at Tyson Foods, several positive impacts have been felt. First, blockchain's enhanced ability of traceability and transparency has improved food safety. At present, utilizing blockchain's tracing ability in real-time, products can be traced from farm to table; as a result, contaminations are easier and faster to identify and solve, hence decreasing the risks of massive outbreaks in foodborne illness events. Moreover, blockchain has made it easy for Tyson to administer supply chain operations that reduce inefficiencies and guarantee correct data sharing among players.

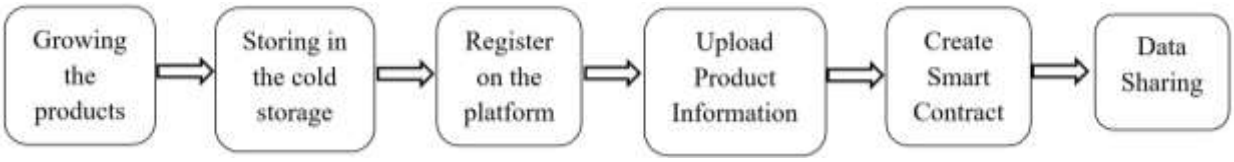
As a result of such efficiency, Tyson Foods was able to save money and further enhance trust and collaboration with suppliers and customers. Integrating blockchain technology into business buttresses quality and safety aspects related to Tyson Foods, rebuilding consumer confidence in the products offered (Daley, 2023).

METHODOLOGY

Our methodology section introduces a blockchain-based model that enhances transparency with its decentralized behavior to eliminate intermediaries and illegal practices in the food supply chain. This approach establishes a fair, efficient system that will improve farmer income and consumer affordability while decreasing food wastage.

MODEL DESIGN

Farmer's side:



Delivery system

Consumer's side

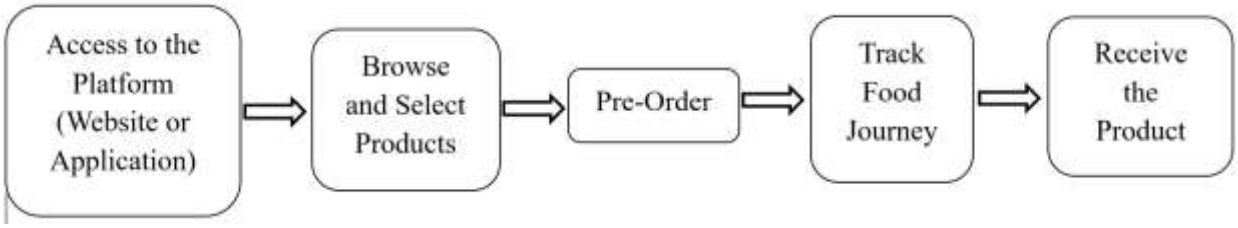


Figure 2: Proposed model for new food supply chain

STRUCTURE OF THE MODEL

The proposed model is designed based on three major components. Those are the farmer's side, the delivery system, and the consumer's side displayed in figure 2. Everything starts from the farm, followed by storage in cold facilities on the farmer's side. This information encapsulates all crop data, harvest dates, and strong conditions. On the other hand, smart contracts could also be created by farmers, who specify the prices and conditions of delivery, hence making the process open and trustworthy. In the case of delivery, a farmer gets confirmation from the delivery system immediately after placing an order. Here, goods are moved around district-wide to local hubs, ensuring efficient and orderly delivery. Dedicated couriers and community-based delivery networks allowing real-time delivery will enable this.

Goods tracking is important to customers because it enables them to monitor the progress of their ordered products, allowing them to trust and feel reliable in the supply chain.

The proposed system encompasses websites and applications which will provide very user-friendly platforms. Accessing these platforms is relatively easy for users, who can view various products and choose which ones they intend to buy. This smooth product selection process enhances the user's experience and makes the system more customer oriented.

As such, consumers can pre-order even before harvesting to ensure the production of the freshest produce. Through delivery, consumers can trace food journeys from the farm to the table, improving their knowledge and assurance of the safety and quality of products purchased. This model tries to integrate the supply chain, eliminate redundancies, and enhance transparency and trust in the entire food supply system (Ehsan et al., 2022; Hameed et al., 2022).

IMPLEMENTATION OF BLOCKCHAIN AND SMART CONTRACT DESIGN

To increase the scalability of the system, we can use two methods: one is storing the non-critical and large data off chain, and the other method is the channel mechanism, which is specially used in the Hyperledger Fabric. In the first method, we store the large data, such as photos of the product, a full copy of the certificate and sensor data, etc. in the off off-chain, which means out of the blockchain in a secure cloud storage. In this case, we reduce the pressure on the blockchain main ledger by saving only the important transaction hash and references in the blockchain. It makes the blockchain lightweight, makes the process faster and converts the overall system more scalable. Another process is the channel mechanism, which is mainly used in the Hyperledger Fabric. Here, the stakeholders, such as farmers or a group of buyers, create a private channel for themselves, and the transaction data of this channel won't replicate in others' blockchain nodes as a result, the person who doesn't need the data won't get the data. This method increases scalability and data privacy at the same time.

To ensure data privacy in our system, we use Permissioned Blockchain, which means that only the verified and authorised people will get access to the system. Here, the authorised people will be permitted to watch and use the part of the system. Again, sensitive information like the farmer's name, the customer's address, etc., will remain encrypted. There will be a data access control policy so that the stakeholders can see only the data that is necessary for them to use. If we use some techniques, then the security system will be much more advanced. These techniques are the Zero Knowledge Proof Technique and the Private Data Collection Technique. In the Zero Knowledge Proof technique, we tell the user to prove something without revealing the actual data, such as asking the buyer to prove that he is a valid buyer without revealing his/ her name and address. Another method is the Private Data Collection method, which is similar to the channel mechanism, where the data of the transaction is kept between a particular group only. By using the techniques, we can keep data confidential, causing no harm to trust and transparency.

If we want to run a blockchain system, then we need lots of energy and electricity, especially if we use Proof- of – Work method. Proof – of – Work method is used in the public blockchain. In this method, the computer solves thousands of math puzzles, and through this, the transaction is approved. But here in our model, we won't use the traditional Proof–of–Work model; instead, we will use PBFT (Practical Byzantine Fault Tolerance) or Raft consensus algorithm, which requires less computational power and energy usage and gives us faster and more efficient service. This algorithm is used in permissioned blockchain platforms like Hyperledger Fabric. The PBFT method avoids redundant computation and thus saves a lot of energy.

Here we proposed a smart contract, an automated digital agreement, which will work among farmers, consumers and delivery partners without the involvement of any middleman.

Table 1: Workflow and triggered conditions

Step	Actor	Trigger	Smart contract action
i	Farmer	List the product and tell the terms, and the price of the product	The contract is ready on the blockchain.
ii	Consumer	Order the product and send the payment through the required method	The condition "Payment Received" gets triggered.
iii	Delivery partner	Deliver the product, and real-time tracking is used	If the product is delivered that the contract checks the "Delivery confirmed" status.
iv	Consumer	Through the app, give feedback such as "Product received and quality matched"	The money is released and transferred to the account of the farmer and the delivery partner.

v	System	If there are any complaints regarding the product or process, such as a delay in delivery or a quality mismatch	The penalty logic will run, causing a reduction in payment or a refund, etc.

Example smart code:
Here is a simplified logic code
IF (Payment Received) AND (Goods Delivered and Confirmed) THEN
Release Payment to Farmer and Delivery Partner
ELSE IF (Delay OR Product Mismatch) THEN
Apply Penalty (e.g., 10% deduction)
Refund the Consumer if necessary
ENDIF
Here, the code says that if the payment is received and the product is delivered, then the payment will be received, but if there is any problem related to the delivery of the product or the quality of the product, then penalties will be applied.

DIRECT FARMER CONSUMER CONNECTION

Blockchain can directly connect farmers to consumers, but the process is surrounded by several challenges, like logistics, infrastructure, and digital literacy. These challenges occur because of the interference of the middlemen, which often causes inflated prices for consumers and lower profits for farmers. A multifaceted approach is required to address these issues that will improve the conditions of farmers and consumers. The current condition of Bangladesh's agricultural supply chain is plagued by inefficiencies, with middlemen playing a vital role in price manipulation (*DHRUSTI : Uplifting Farmer Through A Connected Ecosystem – IJSREM*, n.d.) (Shivale et al., 2024)

Losses up to 40% in value for perishable goods have been reported due to inadequate post-harvest facilities (LODI et al., 2023). Then, the lack of efficient transportation and distribution networks because of the shortage of routes, damaged roads, and weak distribution channels further complicates the direct relationship between farmer and consumer as farmers fail to transport their goods directly to the consumer effectively(LODI et al., 2023). Due to this transport infrastructure deficiency, efficient and timely delivery of goods becomes impossible. Moreover, decentralized delivery of perishable goods needs well-coordinated systems, but these systems are currently underdeveloped. Then, many farmers in Bangladesh have limited knowledge and skills in digital tools and techniques, which act as an obstacle for farmers to engage in e-commerce easily. Unclear thoughts about blockchain and smart contracts in Bangladesh limit legal support and slow adoption. Lack of proper public policy backing decreases initial pilot efforts.

To get rid of these challenges, platforms should be developed with user-friendly interfaces that cater to non-tech-savvy users, providing features such as crop recommendations and market price forecasting, like India's Dhrusti and Krishoker-Hut (*DHRUSTI : Uplifting Farmer Through A Connected Ecosystem – IJSREM*, n.d.)(Noor et al., n.d.). Then, local couriers and decentralized hubs must be leveraged to improve last-mile delivery. Training, programs, and initiatives to improve digital literacy among farmers must be created(Chakraborty et al., 2022). The integration of secure electronic payment methods ensures transactions' transparency, fostering confidence among farmers and consumers (Chakraborty et al., 2022). Lastly, Government support, subsidies, and incentives can help fund technology deployment and farmer training.

Blockchain technology allows real-time data access, which helps stakeholders track the journey of food from source to consumption(Rakhra et al., 2024). Through role-specific web and mobile applications, participants in the supply chain can interact with blockchain. It results in seamless data entry and retrieval(Vidya Sagar et al., 2024). Using Interplanetary File System (IPFS), farmers can record environmental conditions and crop growth data, which is hashed and stored on the blockchain through a hashing algorithm (Vidya Sagar et al., 2024). Data related to food quality and safety, such as temperature control during transportation and storage conditions, is also recorded (Surya Kumar et al., 2024; Vignesh et al., 2025). Consumers can access detailed information about food products by scanning QR codes on packaging, which links to the blockchain-stored data(Gomes et al., 2024; Kansal et al., 2024).

Smart contracts are used to automate and verify transactions, so that consumers receive accurate information about the products they want to purchase (Vignesh et al., 2025). To promote sustainable consumption practices, the system also educates consumers about the environmental impacts of food choices (Gomes et al., 2024).

The proposed solutions utilize blockchain's decentralized nature to enhance scalability. For example, according to research, the AgriFoodCredChain framework uses Hyperledger Indy and Aries library that assures real-time adoption and scalability by focusing on credential issuance and verification time (Kansal et al., 2024). Engaging various stakeholders, including farmers, distributors, retailers, and consumers, is essential for adoption. Adoption across stakeholders varies farmers are motivated by the prospect of fair pricing, and customers are driven by the authenticity of the food products. Private blockchain like Hyperledger Fabric leads to a more scalable and faster procedure for enterprise use, with access control. It increases confidence among stakeholders, reduces wastage, and recalls management. Despite challenges related to cost and technology, it is adaptable for its promise of a transparent and fair food supply chain.

The Successful implementation of a blockchain-based food supply chain system depends heavily on integrating domain-specific knowledge from three key stakeholder groups. Blockchain technologists have advanced expertise in Encryption algorithms, consensus mechanisms, and smart contract development. These experts are responsible for implementing data privacy techniques like Zero-knowledge Proofs and private channels, which assure secure, transparent transaction verification. For comprehensive traceability of food products, their understanding of decentralized applications and cloud-chain integration helps in integrating blockchain with real-time monitoring systems.

On the other hand, Supply chain management professionals look after logistics operations, inventory optimization, demand forecasting, and risk management with their critical knowledge. They know how to minimize lead time, wastage through the last-mile delivery efficiency and optimized cold storage networks. They ensure that blockchain applications are aligned with the realities of agricultural product flows. They help to reduce the dependency on intermediaries by restructuring value chains. Then, sustainability experts apply their knowledge of ecological impact assessments to ensure circular economy practices and sustainable food systems. They are in charge of developing frameworks for measuring sustainability metrics like social equity, water usage, and carbon footprint, etc. They ensure blockchain is used for enforcing ethical sourcing standards, besides transparency. When these three fields collaborate, the resulting food supply chain is both economically and socially sustainable. This collaboration bridges the gap between innovation and inclusive development. For achieving long-term sustainability and food security, this interdisciplinary synergy is inevitable.

PUBLIC-PRIVATE PARTNERSHIP FOR BUILDING COLD STORAGE

A public-private partnership in cold storage facility creation in Bangladesh would involve various stakeholders to ensure the project is efficient and effective. The Ministry of Agriculture will identify lands belonging to the government for cold storage projects and the places most conducive for growing crops. The local governments will provide infrastructure and facilitate obtaining permissions. The financial institutions may offer their services in the form of loans to kickstart the project. The private sector has experience designing, constructing, and managing cold storage facilities. It will design and construct the place with energy-efficient technologies and renewable energy sources such as solar power. It will also ensure best practices are implemented in logistics, storage management, and temperature control to bring out the best output. Local farmers will be organized into cooperatives to share resources, creating bargaining power with the private operators to reduce bulk storage costs. Teaching farmers appropriate post-harvest handling techniques will reduce pre-storage losses before storage. Moreover, all members can afford to use cold storage facilities. Thus, this collaborative model has the general mission to enhance the food supply chain by reducing post-harvest losses so that farmers' livelihoods can be improved.

IMPACT OF THE MIDDLEMEN ON THE PRICE OF THE PRODUCTS

To showcase the reduction of the impact of the middlemen on Bangladesh's food products, we have chosen two staple products: potato and onion. These two products are in the daily diet of millions of people. Focusing on the supply chain system for these necessary goods, especially by integrating blockchain technology, can have a noteworthy impact. It will eliminate exploitative intermediaries, provide fair pricing, and improve storage and distribution facilities. These factors make potato and onion good enough case studies to highlight the positive sides of blockchain-enriched systems in Bangladesh's agricultural sector.

Impact on onion

According to the Daily Star, an onion farmer in Durgapur village said each maund [37 kilograms] of onion sets is selling for as much as Tk 3,500 while it was Tk 1,500 previously (The Daily Star, 14 November 2023). The onion set price and production cost have doubled (The Daily Star, 14 November 2023).

According to (*New Onions Bring No Smiles to Bangladeshi Farmers - Asia News NetworkAsia News Network,* n.d.) report, the production cost of onion is over 40 taka per kg. Farmer's selling price is not fixed, and it varies depending on different factors. Most of the time, they get lower than the actual production cost. They get an average of 35-45 taka per kg.

From the same journal, we learned that several things affect the high price of the onions. For example, the price of fertilizer increases by tk. 10 per kg, and there is an increase in labor costs of approximately about tk. 100. Due to all these factors, the production price of onions has crossed tk.50,000 per bighas. According to some farmers, the price of the onions is tk.1000 to tk.1200 per maund, which was about tk.600 per maund in the last year (2022) (The Daily Star, 14 November 2023)

A kg of onions was sold for around Tk 240 on 9 December 2023, up from Tk 140 on 8 December 2023 at Kazir Dewri market in Chattogram. (The Daily Star, 10 December 2023). The price of onions increases to Tk. 100 per kg overnight, as India has banned the export of vegetables until March 2024.

In contrast, after a big political change in Bangladesh, the intermediaries are absent as they are connected with the corrupt government. That's why the consumer can purchase onions at 60-70 taka per kg (according to the local market on May 1, 2025). However, the problem is that new people will fill up this vacant space of intermediaries. So, the problem won't be solved at all. On the other hand, farmers do not get the proper price and live miserable lives. Blockchain technology can remove the problem.

Farmers in Bangladesh produced around 34 lakh tons of onion this year, but the country still has to import 6-7 lakh tons to meet the demand (The Daily Star, 10 December 2023)

However, our yearly requirement is 27-28 lakh tons. Due to a lack of storage facilities and onion stocks by the middlemen, we need to import this crop from outside.

Summarizing the data, we find that-

Table 2: Price disparity in the onion market

Production costs	40 taka per kg
Farmer's selling price	35-45 taka per kg
The price customers pay to buy onions	240 taka per Kg
Consumer's purchasing price without intermediaries	60-70 taka per kg

Table 2 highlights a significant disparity in the onion market both in terms of profit margin and price distribution. The syndicate uses India's export prohibition on vegetables, which is in effect until March 2024, to justify the rise in onion prices and further their "supply shortage" narrative (The Daily Star, 13th December 2023).

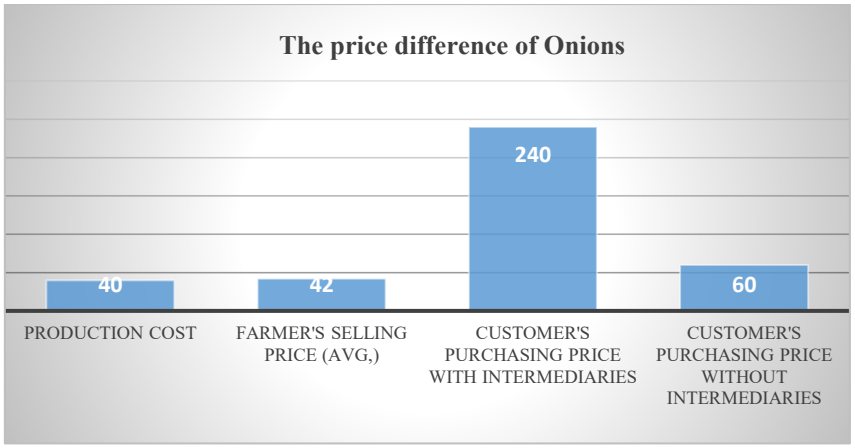


Figure 3: The price difference of onions

From Figure 3, there is a huge difference in the price of the onion because of the intermediaries. As a result, farmers are living below the poverty line, and middle-class and lower-class people are struggling to run their families.

Impact on potatoes

In figure 4, we can see the production cost of potatoes is 16 taka per kg, but the consumers must pay 36-40 taka per kg (150 percent higher than the production cost). So, there is a 20–24-taka gap, but the farmers get only 4 out of 24 taka per kg. The rest of the money goes into the pocket of the middlemen, which is four times higher than the farmer's profit. Among these 24 takas, farmers get 3-6 taka, merchants get 5-7 taka, arothdar gets 1 taka commission, wholesalers get 5 taka, and retailers charge 4-7 taka per kg. The price sometimes rises to 50- 60 taka per kg. Farmers sell 19-22 taka, but consumers must pay more than double the price per kg.

Bangladesh produces an average of 10 million metric tons (10000 million kg). That means almost 240000 million taka goes to the pockets of middlemen every year.

With our proposed model, we can eliminate intermediaries and share the profit with the farmer and consumer by giving more to farmers and lowering consumer purchasing prices (The Business Post, 3 June 2024). Figure 4 shows that the price of potatoes per kg is more than 2 times the production cost.

Table 3: Onion market price breakdown

Production cost	Farmer's selling price	Consumer's buying price
14-16 taka per kg	19-22 taka per kg	36-40 taka per kg

Table 3 underscores the disproportionate profit margin gained by intermediaries, causing a significant financial burden in the supply chain. When blockchain is integrated, the customers can purchase at 34 taka per kg.

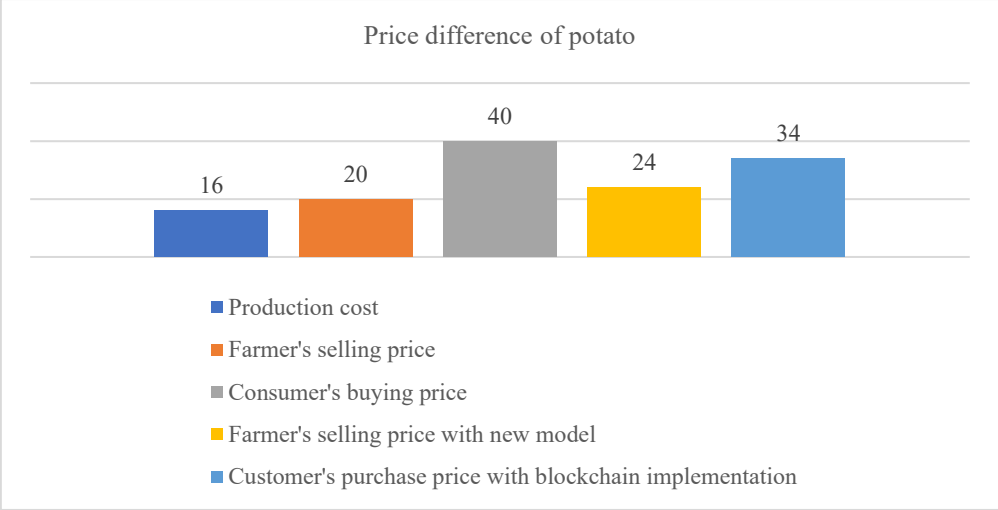


Figure 4: The price difference of potatoes

3.7 ECONOMIC IMPACT ANALYSIS

Eliminating the intermediaries from the traditional model will benefit Bangladesh and its people economically. Using blockchain in the supply chain will be a life-changing solution for the farmers and a breath of relief for Bangladesh's middle and lower-class people.

In the blockchain-based model, farmers can sell a kg of onion at 50 taka with a 10 taka profit from each kg. Farmers will get 4 times the traditional profit margin. On the other hand, customers can purchase onions at 50% less from an average of 120 taka (240 taka in the extreme cases) to 60 taka. The same thing will happen with the potato scenario. The profit of the farmers will be doubled, and customers will get a 15% discount on the previous price. This will increase the purchasing power of the consumers, and they can save a handsome amount from food purchases. As the process will not have any middleman, the price will be set based on production cost. Natural disaster or lower production will not hurt the farmers.

The process will create a ripple effect. Rural income will increase, which will lead to a development stage for the rural people and the country. The market will be stable, and food price inflation will be reduced. The process will reduce food waste, and the country's imports will be lower. For economic sustainability, a country should reduce imports and increase exports. For example, Bangladesh produces 34 lakh tons of onions per year, and the requirement for the people is 27-28 lakh tons. If the total loss is 5% (1.7 lakh tons) of total production, then the remaining product should be 32 lakh tons. That means Bangladesh doesn't need to import onions from India, and they can even export a number of tons. In 2023, Bangladesh imported $334M worth of onions from India ($232M), China ($102M), Pakistan ($656K), Burma ($68.6K), and Egypt ($20.9 K)(*Onions in Bangladesh Trade | The Observatory of Economic Complexity*, n.d.). Bangladesh can save this money and earn money by exporting this product. There will be an efficiency gain of 20-30% as smart contracts and automated logistics systems will reduce transaction costs (e.g., Walmart, TagOne).

As blockchain ensures transparent, traceable transactions, it will reduce tax evasion and corruption. Farmers and consumers will use a digital platform, which will create a formal financial system and increase tax and financial inclusion. Assume 30% of the transactions are digitized and trackable in the next 5 years and which will lead to an approximate 1200-billion-taka food market turnover and a newly trackable share of 360 billion taka. With a 5% VAT, extra revenue will be earned (5%*360) 18 billion taka. The transparent system will attract foreign investors, NGOs, and international agri-tech firms.

Besides, the system will create new jobs in the technology, logistics, and storage sectors. According to (*Bangladesh Unemployment Rate 2024 | Unemployment Rises*, n.d.), the unemployment rate in Bangladesh is 4.49. This new model will impact this rate, and this will have a big economic impact on Bangladesh.

3.8 DEMONSTRATING BLOCKCHAIN'S IMPACT ON REDUCING FOOD WASTAGE AND HUNGER USING PYTHON

To showcase the impact of blockchain adoption on Bangladesh's food supply chain we can utilize scenario analysis using python. We will use secondary data on food wastage and hunger data from 5 countries including Bangladesh, the US, India, Australia, and Last but not least China.

After simulating our approach to see the impact of Blockchain on the food supply chain through Python we get the chart below.

Here are the results:

Table 4: Impact of blockchain adaption on food waste and hunger levels by country

Country	Original Food Waste (Million Tons)	Reduced Food Waste (Million Tons)	Original Hunger (Million People)	New Hunger (Million People)
Bangladesh	14.1	10.58	17.6	11.81
India	50.0	37.50	194.0	173.45
United States	63.0	53.55	34.0	18.47
Australia	7.6	6.46	1.2	0.00
China	35.0	26.25	150.0	135.62

Table 4 illustrates how blockchain adoption decreases food waste and eases hunger, especially in countries with high initial waste and hunger levels. In Bangladesh, food waste will be reduced from 14.1(According to a report by *The Business Standard* (2023)) to 10.58 million tons, lowering hunger from 17.6 to 11.81 million.

To calculate the post-blockchain metrics, we have used these formulas based on logical assumptions –

- New Food Wastage = Food Wastage × (1 - Reduction %).
- Additional Food Available for Hunger = Wastage Reduction × Redistribution Efficiency.
- New Hunger Levels = Hunger - (Additional Food Available / Average Food Needs per Person).

These calculations are shown to give a conceptual understanding of how blockchain could reduce both food waste and hunger by removing unfairness and increasing transparency. However exact results may vary depending on real-world factors like technology implementation effectiveness in each country, infrastructure, and governance.

To conduct our programming, we have defined two critical impact factors which are food waste reduction and redistribution efficiency. Based on the assumption and real data 25% reduction in food wastage was set for Bangladesh as a developing country and 15% for developed countries like the US, and Australia. Then it was assumed that 60% of the food saved from reduced wastage would be distributed efficiently through real-time tacking operations

FINDINGS

FULFILLMENT OF THE SDGS WITH OUR MODEL

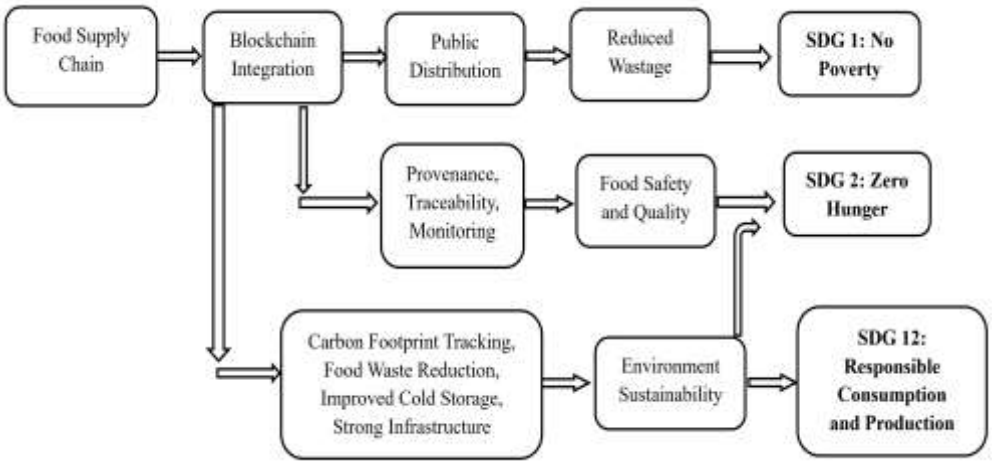
Imagine in Bangladesh; farmers are getting their deserved wages, customers know where exactly food is coming from, and food wastage is shrinking. It is not a dream, but a potential future powered by blockchain technology. We are all aware of the SDG goals. The United Nations adopted 17 worldwide goals called Sustainable Development Goals for the betterment of the world. The aim is to conclude poverty, protect the planet, and ensure all the people live in peace and prosperity by 2030. Blockchain technology is a perfect paradigm for the decentralized system that makes the creation of a distributed ledger of transactions shared and verified by a network of participants possible without requiring any intermediary. In this research work, an effort has been made to enhance the food supply chain in Bangladesh using blockchain. This will help with achieving SDG goals. Problems in the current food supply chain include multiple intermediaries, lack of transparency, price fluctuations, and low farmer income.

The proposed model uses a blockchain platform to connect farmers directly to consumers. It has tried to prevent the current problems and has served 3 SDG goals among 17 goals.

SDG 1: No Poverty: Increasing farmers' income can help alleviate poverty.

SDG 2: Zero Hunger: Improved food security by ensuring efficient production and distribution will lead to a zero-hunger situation in Bangladesh.

SDG 12: Responsible Consumption and Production: Food waste reduction and promoting sustainable practices.



Source: (Chandan et al., 2023)

Figure 5: Comparison of food waste before and after blockchain adoption

Scandals related to food have made people more conscious about food safety. Food safety is optimal for consumer health and connects directly to SDGs like Zero Hunger and good health. To improve food safety, blockchain technology, RFID, and IoT serve as the best boost to consumer trust. Then traceability is must, which means tracking food products from their origin to where they're sold and consumed. Blockchain technology helps consumers to know everything about the food they buy by scanning QR codes. Through smart contracts, feedback analysis, and a credit rating system, Blockchain monitors who is trustworthy in the whole food supply chain. For the assurance of food quality and safety, blockchain fights food fraud by verifying labels and origin. Effective food distribution systems are needed to fight hunger, but in most of developing countries, their systems are corrupt. So blockchain can help here by making the distribution fairer by reducing corruption, and monitoring stocks in real time. Implementing blockchain in the public distribution system empowers consumers with fair pricing information as well.

Making food production more sustainable is critical for the well-being of this planet. Blockchain can trace the carbon footprint of food products throughout the production and transportation phases efficiently and encourages more eco-friendly production. Transporting food creates emissions, but the emissions must be calculated to create a better approach and track them to have a report for future understanding about how to prevent this emission, which approach produce more less emissions. To do this, routes need to be tracked well to reduce environmental impacts. Carbon footprint chain, a blockchain-based system, offers insights into food transportation emissions. Due to poor tracking, packaging, and contamination, a lot of food is wasted. But blockchain can solve this problem by pinpointing problems in early stages, reducing wastage, and managing contaminated batches more effectively. Lack of good cold storage leads to spoiled food. To prevent this, an autonomous storage system integrating ML(Machine Learning) and blockchain technology was suggested to combat food waste effectively. It extends food shelf life.

Blockchain helps small farmers get better prices by reducing intermediaries, making trade fairer. Bypassing exploitative intermediaries ensures equitable profits. Policy development should consider the perspectives and needs of all stakeholders in the food supply chain by integrating blockchain. Because blockchain can do transparent weight recording, fishing management, and overall sustainability (Chandan et al., 2023).

However, blockchain may have some issues, such as high cost and complexity, low adaption, and social and ethical issues.

It may face some issues in blockchain, such as high cost and complexity, low adaption, and social and ethical issues.

We must think of blockchain as something that could complement and enhance the present situation, not replace it. (Anulipt Chandan, 2023).

REDUCTION OF COST FOR THE CONSUMER AND PROFIT FOR THE FARMERS

In our model, we can reduce the intermediaries' costs of both of our selected products.

With our model, the total cost for potatoes (from a field survey) is -

Table 5: Total cost of Potatoes

Parameters	Cost per kg
Production cost	16 TK
Farmer's profit	4 Tk
Bagging cost	1.08 TK (70 Tk per 65 kg or 1 bag)
Labor cost	0.3 Tk (20 Tk per bag)
Local transportation cost	0.5 Tk (35 Tk per bag)
Cold Storage cost	5.92 Tk (385 Tk per bag)
Inter-country transportation cost (Avg)	1.15 Tk (75 Tk per bag)
Total	28.95 Tk

From Table 5, we can see that, from the field to the consumer's house, the cost of the potato per kg is about 29 Tk. If we give the farmer a double profit (8 Tk instead of 4 Tk), the price is still 33 Tk, which is 7 Tk less than the consumers previously purchased. It is a win-win situation for both the farmers and the consumers.

For onion, if we calculate the total cost from the field to the table (50 Tk + 10 Tk ≈ 60 Tk), we can find that consumers need a minimal amount compared to the previous one (240 Tk). Adding 5 Tk profit to the farmers will not harm the consumers, and the farmers will benefit through our blockchain-based model. As, through our model, Bangladesh does not need imported onion from India, and the deduction of the intermediaries, onion will not be Bangladesh's concern in the future.

FINDINGS FROM PYTHON

From the programming outcome, we have seen a 25% reduction that saved 3.525 million tons annually and redistributing 60% of food saved served 5,8 million people, reducing hunger levels to 11.81 million. Our model achieved a 98.8% reduction in hunger based on the real data and logical assumptions we have set.

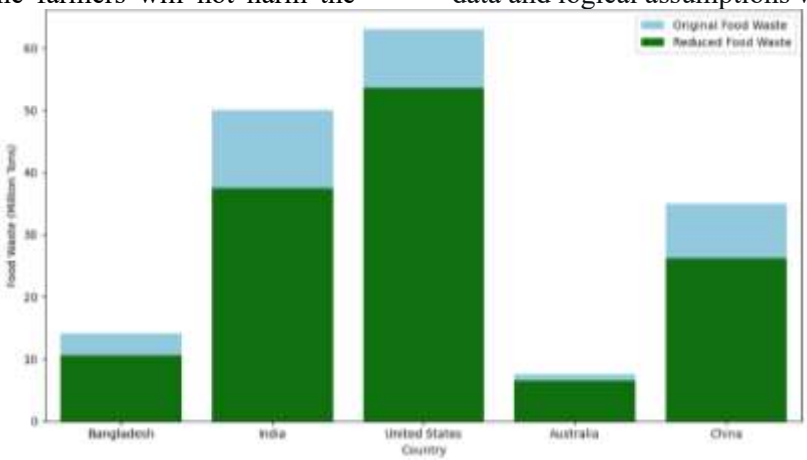


Figure 6: Comparison of food waste before and after blockchain adoption

Figure 5 shows the comparison between food wastage levels before and after adopting blockchain technology across five countries: Bangladesh, India, the US, Australia, and China. It shows a noteworthy reduction in food waste in all countries, with the US having the largest total decrease.

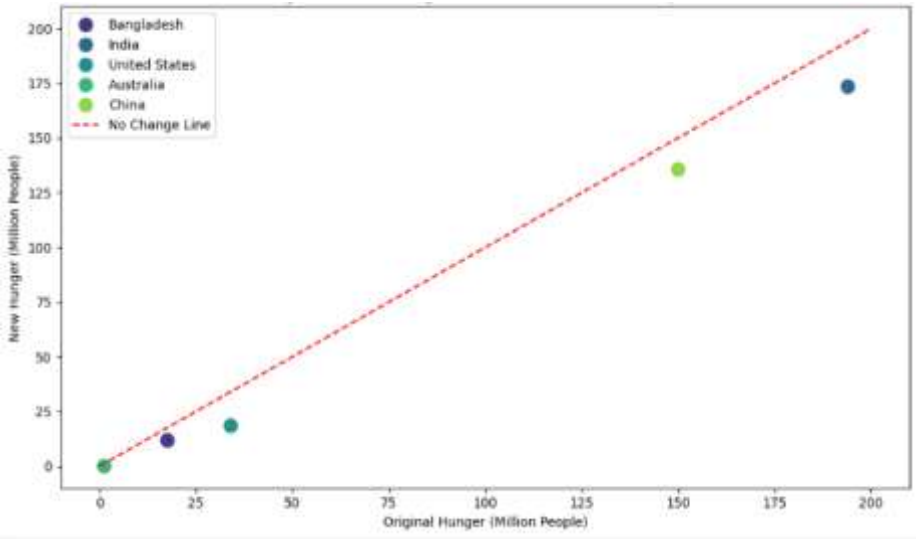


Figure 7: Original vs new hunger levels after blockchain adaptation

Figure 6 demonstrates blockchain's positive impact on decreasing hunger by visualizing food distribution, reducing waste, and enhancing supply chain effectiveness.

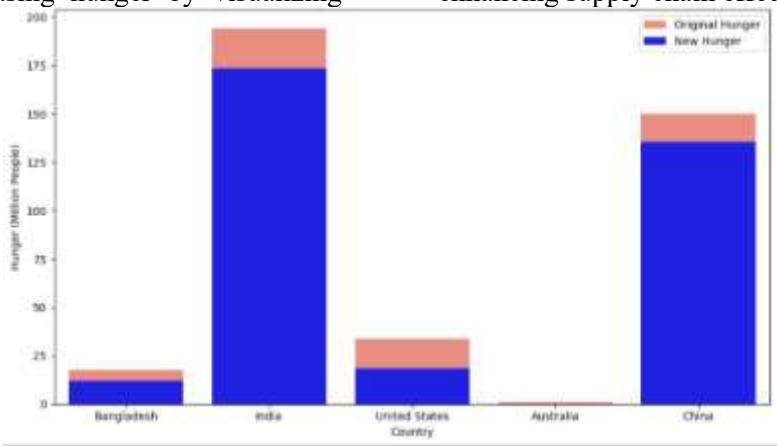


Figure 8: Comparison of hunger levels before and after blockchain adoption

Figure 7 illustrates the hunger levels before and after the adoption of blockchain technology in Bangladesh, India, the US, Australia, and China. The adoption has led to a notable decrease in hunger levels (depicted in blue), with India and China showing the largest reductions.

3-DISCUSSION

Our proposed model is somewhat like the paper (Das & Hanaoka, n.d.). Despite the differences in approach both the paper of (Das & Hanaoka, n.d.) and the proposed blockchain-based food supply chain model share several similarities. For instance, both focus on challenges like economic issues faced by farmers and the importance of stabilizing prices. Both highlight the importance of cold storage to reduce post-harvest losses. However, the approaches are significantly diverged. Das & Hanaoka, (n.d.)identifies systematic constraints, while our model proposes a solution-oriented model leveraging blockchain technology to revolutionize Bangladesh's agricultural sector. This will establish a direct connection between farmers and consumers, eliminating most intermediaries within the system. This would ensure a good price for the commodities for the farmers, raising their incomes and giving them financial security. Incorporation of the public-private partnership model for cold storage facilities reduces post-harvest losses, thereby increasing supply in general and stabilizing prices, which in turn reduces reliance on imports. With improved market efficiency driven by blockchain-induced transparency, accurate and real-time information about supply and demand reduces price volatility and helps in better planning and resource allocation. It means lower food prices to consumers because removing middlemen increases their purchasing power and, more broadly, stimulates general economic growth. With

increased income, better bargaining power through cooperatives, access to better storage and transportation facilities, and exposure to modern farming technologies, farmers are better placed in crop management and yields. Through this, consumers will trust and have confidence in the food they purchase since they can access a transparent record of how the food has traveled from farm to table. Better health outcomes arise from informed choices that reduce health risks. The model also improves food security through stable prices for at least continued food availability, benefiting lower-income groups. Environmentally, it enhances sustainability by reducing food wastage and spoilage, thus helping the United Nations achieve its SDGs. Conversely, the records in blockchain, being immutable, would prevent corruption and fraudulent activities down the supply chain, saving farmers and consumers from agents of exploitation. The model strengthens community empowerment and education through cooperative effort and modern farming techniques, thus leading to a knowledgeable and resilient agricultural sector. This transformative model will bring economic growth, better livelihoods for the farmers, and assured quality food at affordable prices for consumers in Bangladesh.

LIMITATIONS AND FUTURE DIRECTIONS FOR IMPLEMENTING THE BLOCKCHAIN

The setup of blockchain-based technology requires some level of technical expertise and the availability of infrastructure, both of which are absent in most parts of Bangladesh. Therefore, this can be a challenging obstacle in implementing the proposed model in most places. The initial cost of building a blockchain and smart contract system is high. This includes the cost of technology used, training, and maintenance. These costs might be very high and out of reach by a small-scale farmer and business entity. The regulatory environment in Bangladesh may not be fully prepared to accommodate the technology that underlies blockchain. Some legal and bureaucratic hurdles could be addressed to make the implementation smoother. Any success of the proposed model depends on the digital literacy of farmers along with other stakeholders. However, in regions with low digital literacy, it may become cumbersome to ensure that all the participants in the blockchain-based system are not affected by any operational issues. As blockchain requires consistent internet connectivity to work effectively, the model's development would be severely hampered if implemented in rural areas of Bangladesh, where the connection is sporadic and inconsistent. Unreliable internet connection and inefficient energy supply in rural areas of Bangladesh act as an obstacle to accessing digital skills and the internet. While proposed, deploying Hyperledger fabric requires technical expertise and resources, which may be inadequate in Bangladesh. Then Bangladesh may face bureaucratic delays or funding scarcity as PPP for cold storage depends on significant investment and coordination. Then our proposed Python model assumes a 25% reduction in food waste and 60% redistribution efficiency, which may not account for real-world variables. Real-world variables like corruption, logistical infrastructure, cost, or behavioral inertia. Also, projected cost reduction and increased profit assumptions are theoretical and can't account for implementation costs or market fluctuations. Since the model is theoretical, and without any pilot study there is a huge gap or lack in empirical validation. There are legal and regulatory gaps as well. Again, the model doesn't account for potential pushback from middlemen who currently dominate the supply chain and may reject disintermediation. So, traditional systems can exist for a significant number of years, as there can be resistance on the part of multiple stakeholders to implement new technology. This can severely affect the pace of the implementation process.

Such successfully implemented pilot projects will serve as models for wider implementation. Future work should incorporate empirical data and address contextual challenges to visualize the big picture. Training and Education Offer appropriate training and education to farmers and other stakeholders to enhance digital literacy and facilitate the transition. Policy changes and financial incentives by the government can be very proactive in encouraging the adoption of blockchain technology. Additionally, public-private partnerships can play a very important role. Investment in an appropriate, reliable internet connection to other technical tools of physical infrastructure must be made for the proposed model to operate successfully. Local communities can be engaged and brought to trust in transparent communication of how the

blockchain system is working for the realization of benefits relative to the system and their resistance can be overcome. The findings based on repeated reviews of how the blockchain system is performing, with necessary alterations, ensure the effectiveness of the system changes relative to the findings and technological advancement findings in the system again, with relevance guaranteed. Integration of blockchain with other emerging technologies, such as the Internet of Things (IoT) or artificial intelligence (AI), could provide more efficiency and effectiveness in the food supply chain. Since blockchain technology's impact areas are not limited to a food supply chain, it can bring value addition and innovativeness into other sectors in Bangladesh through its application.

4-CONCLUSION

There is a Paradigm Shift in the Food Supply Chain. But our circulating food system in Bangladesh is puzzled by incompetence and hidden processes that lack transparency. Here, farmers face barriers to living an upstanding life and the consumers are unsure where the food comes from. Still, they must pay a heavy price (Hasan & Habib, 2022).

A groundbreaking revolution can be brought by blockchain technology, by creating an unchangeable record of a food item's journey from farm to table with transparency and trust. This transformation is on the way if we keep trying with blockchain, not considering it as a replacement but as a tool for enhancing the outline and bettering the food supply chain. While challenges remain, the blockchain-based model for the food supply chain can be a game-changing solution to bring transparency, effectiveness, and fairness for all. It can bring huge opportunities for farmers, consumers, and the broader economy of Bangladesh toward a more sustainable and fair food supply chain. However, further work is required for implementation and refinement. In this regard, these efforts will be crucial to fully realizing its potential and achieving long-term positive impacts on the agricultural sector of Bangladesh.

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