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ShrimpChain: A blockchain-based transparent and traceable framework to enhance the export potentiality of Bangladeshi shrimp

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ABSTRACT

Despite substantial progress achieved with shrimp production during the last three and a half decades, growth of shrimp export remains minimal in Bangladesh. In the absence of effective traceability and transparency practices, a wide range of malpractice occurs both at the production and post-harvest stages. Traditional paper-based record-keeping methods for the shrimp supply chain are disparate and, therefore, cannot provide efficient traceability capacity and holistic view of the supply chain. These limit the identification of any issues in earlier juncture to proactively ensure food safety, best practice, and good governance. Addressing this multiplexed challenge, we present here *ShrimpChain*, a public-private hybrid blockchain-based conceptual framework. Focusing on the export market and utilizing existing technologies, the conceptual framework addresses the traceability, transparency, and certification challenges associated with shrimp export. In this framework, from the post-larva purchasing to the final packaging stage, relevant data for every stage will be entered by the associated actors via mobile/web app or Internet of Things devices to the blockchain network. Data authentication will be achieved by a novel approach of incorporating community consensus in conjunction with the machine-derived data entry timestamping method. Instead of the traditional central and endpoint certification approach, we propose a distributed and accumulative score-based certification approach that will grade packaged shrimps according to the completeness and accuracy of the authenticated data entered during different stages. Such distributed approach of certification will enhance not only food safety but also the quality and compliance to best practices. Most importantly, engaging shrimp farmers in the safety and quality assurance as well as to the certification process will empower them to have better control over the market and incentive to produce high-quality shrimp for high-value market.

1. Introduction

About 70% of Bangladeshi agricultural export is shrimp, and most (~82%) of the shrimps are exported to the European market [1]. Thanks to the growing interest in shrimp farming, over the last three and a half decades, agricultural sector in Bangladesh witnessed an 11.3% growth in shrimp production [2]. However, during the same time period, the percentage of exports to total production dropped sharply and thereby expanded the gap between production and export (in 1985-1986 it was 3,600MT, while in 2018-2019 it was 224,676MT) [2]. Fig. 1 depicts the shrimp production to export gap during the last three decades. This situation has resulted from many persistent challenges both at the production and post-harvest stages of the shrimp supply chain.

During the production stage, shrimp farmers do not have the adequate scientific technology to test the soil and water quality properly for ensuring sustainable and environmentally-friendly shrimp production. The traceability and transparency of data related to ingredients used and farm locations is also overlooked to ensure the shrimp quality in the international market. Besides, farmers face obstacles in collecting high-quality post-larva (PL) and feeding in the backward linkage of the shrimp supply chain. The majority of PL are transported across long distances from hatcheries in Cox's Bazar to shrimp farms in the Southwestern regions of Bangladesh like Khulna, Bagerhat, and Satkhira districts. Since most farmers lack the capital to acquire PL directly, they rely on intermediaries for the supply of PL. As air travel is expensive, these suppliers frequently use road transportation for logistics. The transportation of PL on the road often results in health and safety hazards, including low water levels, poor water quality, and container damage.

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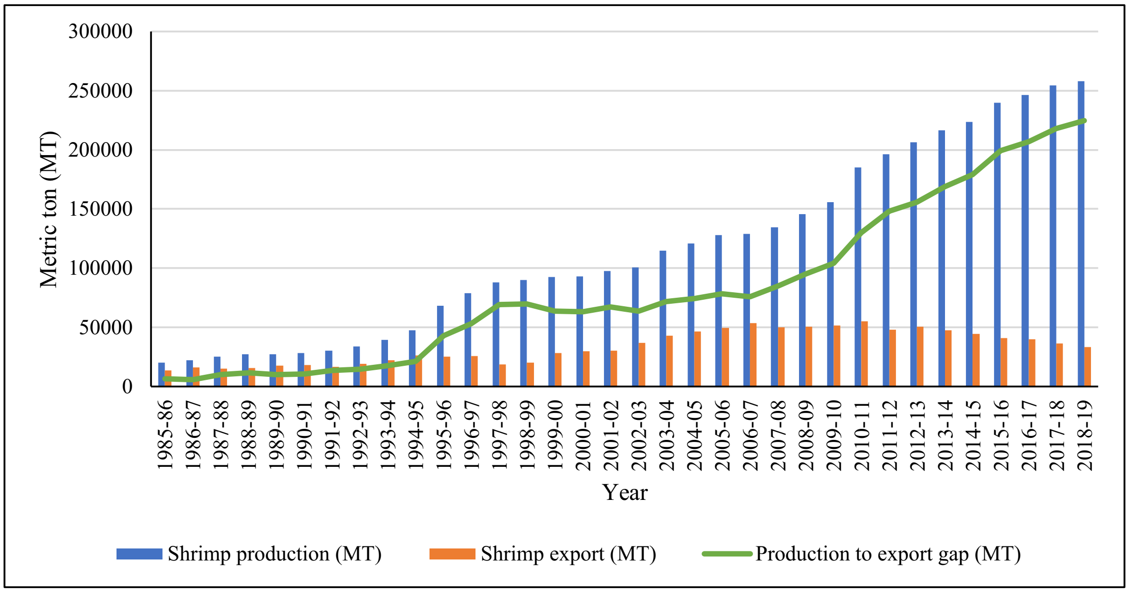

Fig. 1. Shrimp production and export gap: Production to export quantity have increased 62 folds over the last three and a half decades, despite substantial growth in shrimp production in Bangladesh.
Source: Authors' illustration using the data from DoF annual reports [2]

At the post-harvest level of supply chain, Bangladesh lacks an integrated cold chain management system for shrimp export. As a result, during the transport of shrimp for export, notably from farm to processing plant, a variety of freshness and quality issues arise, resulting in the deterioration of the international reputation for Bangladeshi shrimp. Furthermore, the absence of traceability and transparency in Bangladesh's shrimp supply chain is particularly obvious. Due to the use of outdated technology and non-compliance with international standards, the majority of the country's producers and exporters lack internationally recognized accreditation. While not as common as they previously were, there are still a few examples of such misdeeds emerging from the numerous intermediates involved in each stage of Bangladesh's informal shrimp supply chain. The misdeeds have tarnished Bangladesh's shrimp business in the eyes of global consumers, particularly those in Europe and North America, resulting in a drop and cancellation of orders in recent years. More depressingly, Bangladesh has received export bans from different countries and international alliances at various times due to malpractices and unethical trade affairs. For example, in July 1997, European Commission imposed an import ban on Bangladeshi shrimp in relation to food safety that cost a revenue loss of around 14 million US dollars during August – December 1997 [3].

Given the identified socio-technical challenges of shrimp farming and supply chain in Bangladesh Fig. 2), this paper proposes a blockchain and smart contract enabled conceptual framework – *ShrimpChain* that will allow actors at every stage of the production and supply chain to enter their data by using mobile/web app and existing Internet of Things (IoT) devices. The paper also proposes a distributed data authentication and accumulative certification model to replace the existing centralized endpoint certification model.

2. Blockchain technology in brief

Introduced just after the 2008 global financial crisis, distributed ledger technology (DLT), commonly known as blockchain technology, is a shared distributed ledger of records or transactions that is open to inspection by every participant but not subject to any form of central control [4]. The ledger consists of blocks of timestamped data that are cryptographically linked together in such a way that each new block points to the block prior to it, making a chain-like formation, appropriately named the blockchain [5]. This blockchain is distributed between the nodes (computers) participating in the blockchain network so that everyone has the same copy of the ledger, adding to the security and reliability of the network. Whenever a new block of data is created, it is broadcasted to each participant within the network, where each participant then verifies and validates the block and appends it to the existing chain of blocks. At its core, blockchain aims to establish trust in a peer-to-peer fashion without enforcing a master-slave relationship between parties or involving a trusted third party (Chatterjee et al., 2020).

Essentially, anything of value can be transacted on this distributed and decentralized network in a peer-to-peer fashion. For example, it can be cryptocurrencies like Bitcoin, virtual adorable and rare pets like CryptoKitties, purely digital artworks [6], proof of existences, or automated rules to create future value such as decentralized autonomous organisations (DAOs; [7]. Moreover, the distributed nature of blockchains makes them very robust in terms of security and trust.

All blockchains are distributed; however, the level of decentralization can be controlled based on the participation and business use case. The three main categories of blockchains based on access control and centralization are public, private or consortiums and hybrid blockchains [8]. A public-permission less blockchain allows everyone to participate in the network, take part in the consensus process and transact on the blockchain. This public, permissionless and borderless structure enables public blockchains to be highly censorship and alteration resistant while simultaneously permitting decentralized governance. Public blockchains must have an economic incentive for the nodes to support the blockchain network; therefore, users must always pay a transaction fee whenever they use the public blockchain [9]. Bitcoin and Ethereum [7] are typical examples of public blockchains.

Private or consortium blockchains (also broadly known as permissioned blockchains) only allow a selected group to participate in the network and consensus process. Private or consortium blockchains are more suitable for organisations where a certain level of trust already exists among the participants, and they can rely on a trust model based on the authority of the trusted participant. Since organisations have a business incentive to set up a private or consortium blockchain, they do not need to be incentivized in other monetary forms such as transaction fees to support the blockchain network [9].

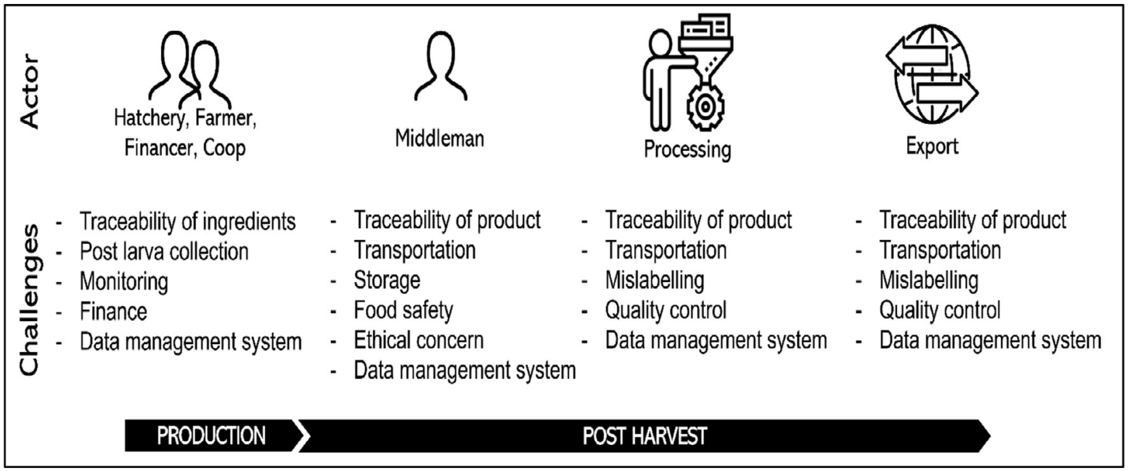

Fig. 2. Challenges of a shrimp supply chain in Bangladesh. Actors within the pre and post-harvest supply chain face a wide range of challenges. Traceability and transparency are pervasive challenges with a substantial negative impact on export.

A hybrid blockchain setup can be achieved by using a combination of public and private blockchains. It allows users to set rules on what interactions or transactions are to be made on the permissionless ledger (public blockchain) and where to apply restrictions and keep information private on a permissioned ledger (private blockchain). For example, a government agency may want to award a contract on a public blockchain for the sake of transparency but would prefer sharing information with law enforcement regarding an investigation on the private distributed ledger. Hybrid blockchain setups can be an attractive choice as they strike an ideal balance between transparency, privacy, and scalability, given the current technological limitations [10].

3. Use of blockchain technology in agri-food supply chain and its prospects in Bangladesh

As researchers and practitioners are increasingly interested in blockchain technology, Tian [11] and Faye [12] investigated the application of blockchain technology in the context of the agri-food value chain from a traceability perspective. The issue highlighted is how to integrate blockchain technology into the current traceability system to improve the agri-food value chain's transparency and security. Currently, most researchers evaluated blockchain technology for agriculture value chain facilitators in the context of traceability to win customer trust and are engaged with the conceptual creation of a blockchain-based traceability system [13]. All actors within the agri-food supply chain can be benefitted from blockchain technology because it allows them to record permanent data that reaches customers and ensure food traceability [14].

Businesses can gain consumer trust by providing information about food's origins, assuring food safety, decreasing food fraud, and thereby improving brand reputation. Several food companies are teaming up with IBM to implement blockchain technology across their supply chain. For instance, blockchain technology has been deployed by 38 pasta, 37 beef, 37 milk, 35 coffee, 35 fish, and 1 beer companies to ensure comprehensive transparency across all supply chain stages [15]. Several researchers chose to integrate traceability in fish value chains using blockchain technology. For example, as Tilapia is one of Ghana's most consumed fish species, blockchain technology was integrated into the Tilapia supply chain in Ghana, from producers to customers, to provide traceability [16]. Zhang *et al.* [17] suggested a traceability platform based on the Hazard Analysis and Critical Control Points (HACCP) regulation, which enabled traceability by utilizing QR codes and the radio-frequency identification (RFID) tag's electronic product code (EPC). The wireless monitoring facilities were combined with quality control modeling to improve fish quality, as well as the safety and transparency of waterless fish transport. Howson (2020) addressed how blockchain may be utilized to increase customer confidence in the fish value chain and set an example of how blockchain technology might aid in the preservation of fish. Cruz [18] proposed a blockchain-based technology that would allow for back-and-forth traceability of fish lots across the whole fisheries value chain. They also created a smart contract to implement the traceability platform on the Ethereum network. Larissa and Parung [19] proposed a blockchain technology framework for the fishing sector in Indonesia, as well as built a new supply chain model based on blockchain technology. They argued that the potential benefits of blockchain technology include traceability and transparency, cost and time savings, and the prevention of illegal or unethical fisheries products entering the supply chain. Some of the ongoing blockchain-based fish supply chain projects across the globe are shown in Table 1.

Bangladesh, in recent months, has started to use blockchain technology for the new and fast-growing carp-producing farm. ByteAlly Software (https://byteally.com/) and Bangladesh Aquaculture Activity (BAA) collaborated on the project, which aims to build a traceable environment by collecting market-relevant data from all aquaculture supply chain participants via mobile and web applications. A total of 50 stakeholders have been successfully onboarded by this project [20]. Also, recently Nagad and Farmer Market Asia's Fund the Farmers (FTF) project have agreed to deploy a blockchain-based eTraceability platform for 2500+ shrimp farmers of Shatkhira that will allow banks and buyers to trace and track each stage of the shrimp value chain.

4. *ShrimpChain*: the proposed hybrid blockchain framework for shrimp production and supply chain

Many farms in Bangladesh have a primitive structure and are small in size; therefore, assuming the risk, they are not ready to utilize fully IoT based blockchain technology on a large scale [21]. Fully IoT based blockchain is a cutting-edge technology that is riddled with technical jargon which even difficult to understand for skilled tech-enthusiasts, and Bangladesh has a dearth of skilled manpower and conducive technical structure to adopt it [21]. Considering these limitations of implementing a fully automated IoT or machine-derived data input system and the prevailing mistrust and malpractice across different actors in Bangladesh shrimp supply chain [22], here we propose a blended input system where users can input data through mobile/web app along with available IoT devices (Fig. 3). These apps and devices will be connected with the hybrid blockchain network that consists of two layers. The private blockchain layer will be cluster-specific and include all shrimp framers from all farms of a given cluster along with other related actors (from hatchery to middleman to processing plants) where business

Table 1
Examples of ongoing blockchain-based fish supply chain projects across the globe.

Project	Distributed Ledger Technology (DLT)	Developers	Current situation (as of [1])	Country	Features
Food trust	HyperLedger	IBM	Active	United States	Walmart, Sustainable Shrimp Partnership (SSP), Nestle, Unilever, and Carrefour are among the brands involved in IBM's Food Trust, which is one of the most high-profile traceability projects. Food Trust fabric is also used in several other seafood provenance projects.
Pacifical-Atato	Ethereum	Gustav Gerig, Pacifical and Atato	Active	Switzerland	The program uses the Ethereum blockchain to enable the traceability of Gustav Gerig's Marine Stewardship Council (MSC) certified canned and pouched Rose tuna range sold under the Raimond Freres brand.
Provenance	Ethereum	Provenance, IPNLF and WWF	Active	Indonesia	Provenance was one of the pioneers of blockchain supply chain solutions used for tracking and recording catch data on a blockchain. The platform collects SMS messages from fishers and employs an RFID and QR tag mechanism.
TraSEAble	Ethereum	TraSEAble, ConsenSys, WWF	Active	Fiji	TraSEAble is a blockchain-ready software-as-a-service (SaaS) platform that allows stakeholders to collaborate and increases transparency by allowing regulators to evaluate and validate end-to-end forward and backward fisheries traceability.
Trium	Ethereum	Consensys	Active	South Pacific countries	Trium is a provenance platform that tracks assets and models supply chains for fishing firms in the South Pacific region.
FishCoin	Stellar	Eachmile	Under development	Indonesia	The Fishcoin-enabled mFish application is a blockchain-based traceability solution designed to encourage data exchange across the fishing supply chain.
Bumble Bee-SAP	SAP Leonardo	Bumble Bee Foods	Active	Indonesia	Bumble Bee has been tracking and collating supply chain data for its Anova yellowfin tuna products using SAP's blockchain platform.
OpenSC	OpenSC	WWF Australia, Boston Consulting and Nestle	Active	Australia	The platform ensures that products are sourced responsibly. Consumers can scan a QR code to find out where fish and other products come from, as well as their journey through the supply chain. Fish are fitted with RFID tags that store data on a blockchain. Additional information, such as storage temperature in transit, is captured at each stage of the supply chain.
Tracey	Streamr	WWF Philippines and UnionBank	Under development	Philippines	The Streamr blockchain will be used to build the Tracey app. The data stream will be linked to the Streamr Marketplace, where third parties will be able to pay for access. This money will subsequently be distributed to fishers. The software will have "Know Your Client (KYC)" functionality, as well as a Peso stable coin and a digital wallet from UnionBank of the Philippines.

Source: Adopted and modified from [23].

relationships already exist. Each actor representing a node, can enter data to the private blockchain network manually via mobile or web app and where appropriate, automatically via IoT devices. Corda, like private blockchain network, will enable smart contract governed *need-to-know* based communication within nodes. For example, if a shrimp farm within the network decides that only certain shrimp farms, intermediaries, and processing plants within the network *need-to-know* about certain parameters of their production data, this can be easily achieved and/or updated as necessary through the smart contract. This *need-to-know* feature will facilitate the real-time transmission of data within the network without divulging the business secret to the competitors within the supply chain. All data (including images or videos) will be kept off the chain on InterPlanetary File System (IPFS), which is a protocol of storing and sharing data on a distributed peer-to-peer file system, and a hash of the data (like a fingerprint of the data itself) will be posted on to the public Ethereum blockchain for immutability and future verification purposes. In parallel to IPFS, data can also be parallelly archived in local databases if deemed necessary.

4.1. Scoring based group certification method

At present, the certification of the shrimp is like pass or fail and is usually done by a third-party inspector at the endpoint (final packaged product) in Bangladesh. Any failure at this stage has a huge financial impact on all actors involved in the supply chain, particularly the farmers. Like energy performance certificate (EPC) for building, here we propose an EPC like score-based certification approach. Instead of the pass or fail, EPC categorizes energy performance of a building by scoring different variables like insulation, heating systems, type of bulbs, etc. For shrimp certification in Bangladesh perspective, some variables (e.g., shrimp size) are not that readily quantifiable like building variables; here, we need to rely on the data entered via the mobile or web app by different actors. However, considering the human and social factors, particularly the prevailing mistrust and malpractice across different actors, we are proposing a community consensus and timestamping based data authentication approach.

At the production level, a consortium within the cluster will verify the data quality for each event or transaction. For example, as part of the best practice, if a farmer needs to give a certain amount and type of feed at a certain time interval, s/he needs to input the data within a specified time window (e.g., +/- 30 min.) around the specified time interval (e.g., every 8 h). Failure to enter data within the specified time window will be penalized by lowering the score for that event by the smart contract. The consortium will ensure data quality through a scoring mechanism (the more members agree or trust the entered data, the more the score is). This combined approach will encourage farmers to enter high-quality data with due diligence as well as deter them from any form of cheating.

At supply chain level for each step, both one step up and down transacting actors need to agree on the shared data, particularly on data entered via mobile or web app (e.g., weight, size, or count of shrimps). If a disagreement arises, the one step-down actor using the IPFS hash can show the authenticated data (including image or video). Like production level, the authentication will again be score-based (full agreement high score and vice versa). One of the pervasive problems that impact the quality of the shrimp is variable transportation time and modality between stakeholders, specifically between farm to a middleman to a processing plant. Each stakeholder will clock out their time of ship-

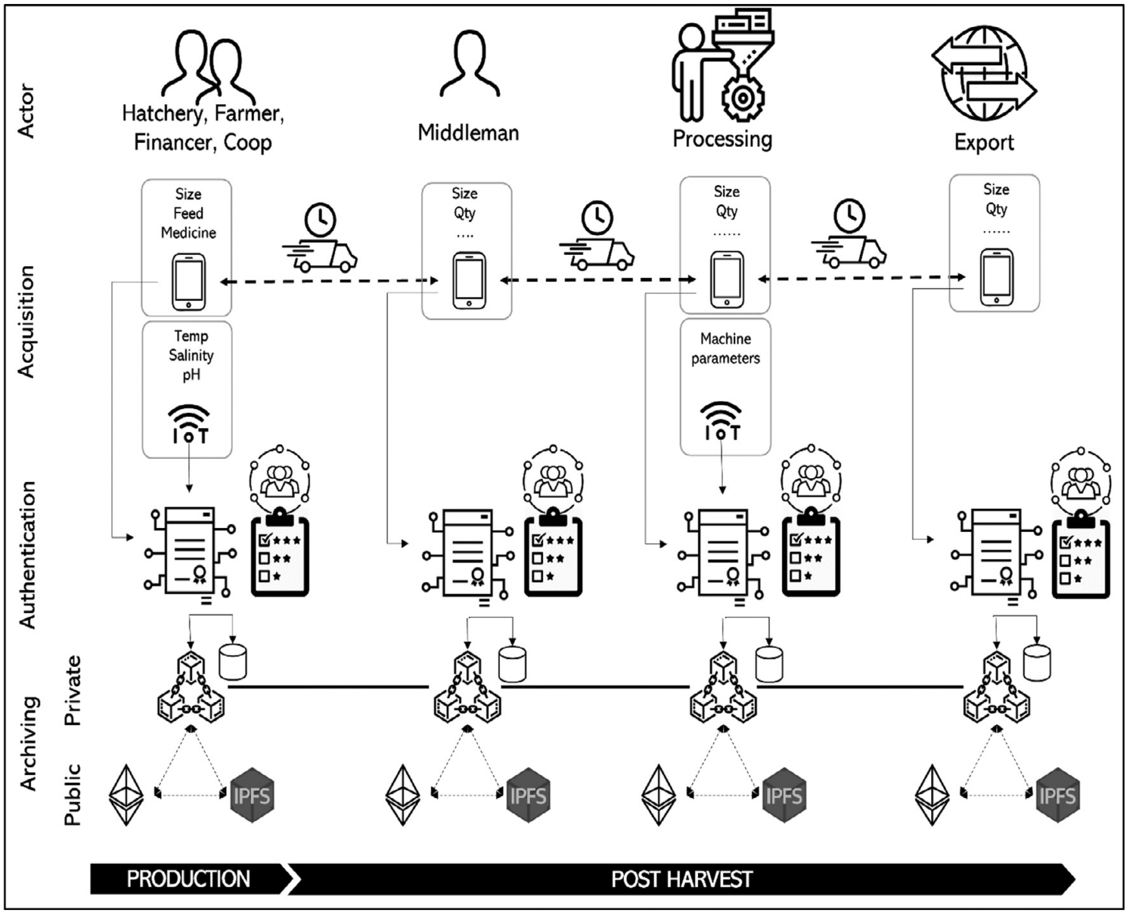

Fig. 3. *ShrimpChain* framework. Actors from different supply chain stages can enter data either via mobile or web app or through IoT devices. Entered data will be authenticated through community consensus and timestamping, which will enable the smart contract to assign a certification score for the data entered. Once authenticated and scored, metadata and data will be archived in the private blockchain network and local database. Data will also be archived in IPFS and hash of the data in the public blockchain network.

ment, and the receiving stakeholder will clock in. Mobile phone internal time will be used for this purpose to attain accuracy and to avoid any malpractice.

Starting from the production level, all human entered data must go through this scoring-based certification process before it is archived in IPFS and blockchain networks. As the product (shrimp) passes through different supply chain stages, it will accumulate score. The final cumulative score will determine the quality of the packaged shrimp. At present, packaged shrimp has only size information, but with the proposed model, packages will also have score-based categories quality information.

Such scoring-based certification approach will benefit producers, exporters, and importers. For the producer, it will create a competitive environment to increase the score; any attempt to increase the score with fabricated data will be identified either by the community or by the one-step up stakeholder. However, diligent and honest data entry will reward the producer with a higher score, making their product valuable. For exporters, they can provide food safety and quality assurance to the importer with a QR code attached to each packet through which the whole backward supply chain and production phases can be easily traced back to the PL level, which again will endow them with better bargaining power. For importers, they can offer their customers different qualities of shrimps with different prices along with the provenance information encapsulated by the QR code. At present, the gradation of shrimp is based on the size and type; therefore, different quality of shrimp will provide another parameter for price-fixing and choice for the customer to make informed purchase decisions. Different markets will have different demands. Importers can feedback that to the backward supply chain actors, including the farmers, to update or include new parameters (like labor payment for fair trade purpose) into the smart contract governed scoring mechanism.

5. Potential benefits of implementing blockchain technology in the shrimp supply chain

Sustainable supply chains have piqued the interest of academics and practitioners in recent years, owing to people's growing awareness of environmental and social issues. As a result, blockchain technology's promising characteristics can be applied to farm productions that reduce environmental consequences, avoid corruption, and advance labor rights [24]. Heinrich *et al.* [25] viewed high-value botanical products as another interesting feature of blockchain technologies. By ensuring high production standards, blockchain technologies protect against contamination threats, allowing all stakeholders in the supply chain to guarantee and certify the information on socio-environmental repercussions consciously. Scholars have conducted significant research during the last two decades on the role of supply chain management in developing sustainable products and information about the quality and origin of food [26]. In this way, blockchain technologies can help make the shrimp supply chain more sustainable by allowing customers to track the origins, environmental effects, and ethical implications.

One of the benefits of integrating blockchain technology in the shrimp supply chain is that it allows for the identification of lower-quality shrimp that have been mislabeled as premium. Temperature and other environmental characteristics can be measured across the shrimp supply chain using blockchain technologies that combine artificial intelligence (AI) with IoT sensors, potentially allowing logistics to be optimized. Using these high volume and quality data, machine learning algorithms will be able to delineate the best practice of shrimp farming which will facilitate the policymakers to formulate effective governance policy, economists to identify critical variables within the value chain that otherwise can't be identified by traditional empirical survey-based methods. Adherence to best practices and an optimized value chain will boost the farm's reputation and profit, which in turn will give access to wider finance options. Financial empowerment will allow a farmer to buy better PL and feed, which in turn will bring more profit. Using near-real time data, machine learning algorithms can also be used as an early warning system which at present is not possible to undertake with paper-based disparate historical data. An early warning system will help farmers to take appropriate precautionary or preventive measures to reduce loss.

The blockchain-based framework will also facilitate to combat contamination-related issues. If contamination or food safety-related issue arises, it will be easy to trace and identify the cause/problem by analyzing the provenance information in detail. This will enable identified stakeholders to take appropriate and effective measures to correct the problem. For example, if a specific pond was identified as contaminated or a transportation step within the supply chain had a major negative impact on the product, that pond can be quarantined, and the transport modality can be changed. At present, in such a scenario, a blanket import ban or cancelation of the whole consignment are usually taken, which negatively impacts all across the board, from producers to consumers. However, with the proposed framework, easy identification and targeted mitigation approach will reduce the uncertainty across the supply chain and thereby will forge an equitable environment for all.

6. Conclusion

The shrimp export business in Bangladesh is at the crossroad. The National Action Plan aims to increase productivity further by implementing extensive farming methods, despite the fact that the gap between production and export is already wider than ever before and there are growing concerns from the buyers with regard to the food safety and quality. The framework proposed here will catapult Bangladesh's shrimp farming approach from the existing informal and inconsistent shrimp supply chain environment to an industry 4.0 compliance environment. The cost associated with the transformation is minimal, since the framework will use the existing data acquisition technologies (e.g., mobile app & IoT devices) along with blockchain technologies, which is open source and incurs minimal fee when transactions occur (e.g., data upload, etc.). However, the benefit of using such a framework outpace the minimal cost involved. The transparency and traceability provided by the blockchain technology and the proposed score-based certification approach will enable Bangladeshi shrimp farmers and exporters to address the importers' food safety and quality-related concerns. At the same time, all actors, especially the farmers, will be empowered by the visibility of the whole supply and value chain, which eventually will enable them to cut the middleman and increase their profit. Wider visibility of the supply chain will also help the government to allocate the right resources (e.g., cold storage) at the right place and visibility of the value chain to earn the right amount of tax and provide appropriate subsidies where necessary. This will eventually help the Bangladesh government to establish a good governance framework capable of adapting to the complexity and agile nature of shrimp farming, meeting international and domestic market demands, and ultimately fostering the export potentiality of shrimp.

Declaration of Competing Interests

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

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