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Blockchain Based DNA Barcoding for Determination of Livestock Based Product Quality

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Abstract: In recent years, DNA sequencing technology has advanced significantly and the genome sequencing cost has decreased, leading to growth in the genome industry. However, managing and analyzing the massive amount of data generated is a challenge, and the security and transmission of this data is a concern. This paper aims to address these issues by proposing the use of a secure storage platform for storing and analyzing DNA data of important livestock products such as meat, honey, and eggs. This would help in validating the quality of food items with real-time monitoring and result delivery. DNA data once barcoded on blockchain can be accessed easily across different geographical location eliminating the need of storing DNA data at every testing center and will also reduce the time taken in determining food quality. Blockchain technology capability of making data completely immutable makes it a suitable technology for storing DNA data.

Keywords: Blockchain, DNA barcoding, Data management, Life-stock products, Sequencing, Genome

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Introduction

DNA research has played a crucial role in the biological sciences as it holds a vast amount of genetic information essential for reproduction, identification and classification of different organisms. The development of sequencing techniques has made the process of reading DNA data more efficient. The amount of information about DNA successions is also growing exponentially (Nguyen *et al.*, 2016). For example, in December 2015, the size of the GenBank, an outstanding collection of DNA successions, surpassed 2 billion base pairs. If such massive amounts of data can be implemented using digital computer, it would make study of DNA much

Table 1: Present day Techniques in Food Traceability

Parameter	RFID	WSN	Cloud Computing	DNA Barcoding	Block chain
Security	X	X	✓	✓	✓
Traceability	✓	✓	✓	✓	✓
Transparency	X	X	✓	X	✓
Information Sharing	✓	✓	✓	✓	✓
Decentralization	X	X	X	X	✓

easier.

Another significant challenge is managing the large amounts of data generated by DNA research, which includes both data storage and transmission. Different modern-day techniques are being implemented for ensuring food traceability as shown in Table 1. One solution to this problem is by using blockchain technology in DNA barcoding. This method uses a short, standardized DNA sequence to identify a species. By storing DNA barcode data on a blockchain, it can be made tamper-proof and easily accessible to authorized parties. This can be useful in fields such as conservation biology, biotechnology, and forensics, for example, for tracking and verifying the authenticity of DNA samples.

DNA data composition:

DNA research plays a crucial role in understanding organisms as it holds the majority of genetic information used for species classification, reproduction and disease identification. (Galimberti *et al*., 2014). This information is stored in form of code composed of different chemical bases namely Adenine (A), Cytosine (C), Guanine (G), and Thymine (T). The bases are known as the DNA sequence, denotes the structure and function of any living being. The DNA sequences are paired such as A with T and C with G. Figure 1 shows all four chemical bases present in DNA by different colors.

There are few types of DNA data file formats, such as "FASTA" and "FASTQ" file designs which are most commonly used. Figure 2 depicts the FASTA file designing, a basic arrangement in plain text format. It is structured in a specific way where the first line starts with a ">" symbol, indicating that it is a header line, which includes information about the DNA sequence such as its name or ID. Following the header, the DNA sequence is written, which can be spread over multiple lines. One important thing to note is that FASTA file format only stores the DNA sequence and does not include any quality scores.

FASTQ (Fig. 3), in contrast to FASTA, is a more advanced file format that includes both the DNA sequence and the quality scores for each base of the sequence. It starts with a header line, similar to FASTA, but in this case, the header also includes information regarding the quality scores. The header is followed by the DNA sequence represented by a string of nucleotides, and the next line contains a "+" sign and the identifier of the sequence. The following lines consist of the quality score of each nucleotide in the sequence, which is scaled using the phred method.

In short, FASTA files include only the DNA sequence, while FASTQ files include both the DNA sequence and quality scores. These quality scores are used to evaluate the accuracy of the read, helping to identify which reads are more likely to be accurate and which may contain errors.

Blockchain Technology:

Blockchain technology allows for the storage and exchange of information between peers (P2P) in a decentralized manner, eliminating the need for any intermediary or third parties. The key advantages of blockchain is its trust-based security, which is achieved through the use of consensus-based algorithms. The infinitely long chained block of blockchain enhances it’s security

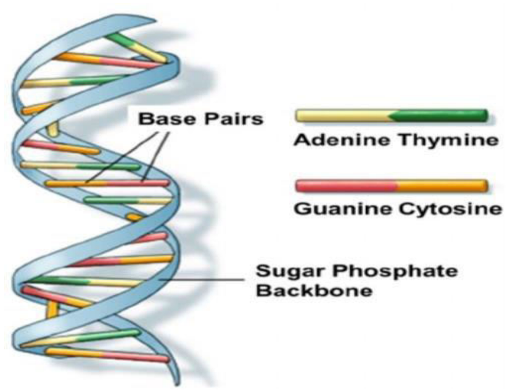

Fig.1: DNA Base Pairs.

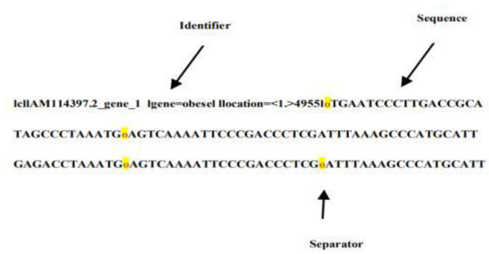

Fig. 2: FAST A.

Fig. 3: FAST Q.

(Khan and Salah, 2018) and difficult for attackers to infiltrate. The blockchain technology has the potential to revolutionize the way we conduct business, transfer value, and govern ourselves by providing a decentralized way of maintaining trust, transparency, and security.

Blockchain is a digital ledger technology that comprises of several integral parts. These components include blocks, which are collections of transactions grouped together and linked by unique identifiers called hashes; nodes, which are computers or devices that contribute in blockchain network and validate transactions and blocks; mining/consensus, which is the process of adding new blocks to the blockchain through validation of transactions by miners or validators; smart contracts, which are self-executing agreements that automatically enforce the terms of the contract when certain conditions are met; cryptography, which uses advanced techniques like public-key encryption, digital signatures, and hashing to ensure the security of data on the network; decentralization, where there is no central authority controlling the system and it is maintained by a network of nodes; and immutability, which ensures that once a block is added to the blockchain, it cannot be altered or deleted, maintaining the integrity and transparency of data.

Blockchain technology is built on a combination of existing technologies that work together to create a secure and decentralized system for storing and verifying transactions. The important elements that make up blockchain include distributed ledgers, cryptography, consensus algorithms, peer-to-peer networks and smart contracts.

Distributed ledgers help in maintaining a digitized copy of ledger by a network of computers, allowing multiple parties to access the same information and increasing transparency and security. Advanced cryptographic methods like public-key encryption, digital signatures and hashing are used to secure data on the blockchain and maintain the integrity and confidentiality of the data stored. Consensus algorithms ensure that all nodes agree on the state of the ledger, which is crucial for maintaining the integrity and security of the blockchain. Peer-to-peer networks enable direct communication between nodes in the network, reducing the need for intermediaries and increasing the efficiency of the system. Smart contracts are self-executing agreements that are programmed to automatically execute the terms of the contract when certain conditions are met.

Features of blockchain includes:

- *Decentralization*: The absence of centralised nodes, allowing data to be recorded, stored, and updated in a distributed manner.
- *Transparency*: The data stored in blockchain is visible to all nodes and can be trusted as transparency allows for greater accountability and trust in the system.
- *Open-source*: Many blockchain systems are open to the public, means that code that powers it is freely available for anyone to inspect, modify, and use. It enables individuals to use blockchain for creating any desired application.
- *Autonomy*: Each node on blockchain can safely transfer or update data, giving autonomy to the entire framework and making it impossible for any one individual or entity to mediate it.
- *Immutability*: The records are saved indefinitely and remain unchanged unless someone gains control of over half of the nodes at the same time.
- *Anonymity*: Blockchain technologies address the issue of trust between nodes, allowing for anonymous record transfer or transactions as long as the individual's blockchain address is known.
- *Decentralized Consensus*: Blockchain allows multiple parties to come to a consensus on the state of the network without the need of a central authority.
- *Interoperability*: The ability of different blockchain network to interact with one another. Blockchain allows different systems to communicate and share data seamlessly and securely, which can lead to increased efficiency and innovation in various industries.

In general, blockchain is being employed to establish trust and increase visibility in situations where trust is lacking or absent. This can be observed in various sectors such as supply chain management, finance, healthcare, and voting systems.

Existing Substitution and Adulteration Issues:

There are a variety of substitution and adulteration issues that can occur with crops and livestock products.There are several issues related to substitutions and adulterations in livestock-based products, such as meat, milk, cheese, honey and eggs. These issues include sellers replacing more expensive meats with cheaper options, diluting milk with water, adding fillers or non-dairy ingredients to cheese, sweeteners to honey, or substituting eggs from industry. Governments have regulations in place to prevent these issues, and consumers can play a role by being aware of the risks, choosing authentic products and validating their authenticity

Other issues like mislabeling of the products, misbranding, and false claims about the origin of the product, nutritional value, and other characteristics of the product can also be a huge problem. Providing other birds for chicken eggs without disclosing this to the consumer. Adulteration in honey with colored sugar syrup base. These practices can lead to consumer confusion and mistrust in the food.

In modern day product substitution and unintentional or intentional adulteration are common due to the global spread of livestock-based products without adequate traceability mechanisms. There are many examples of commercial fraud that have been reported where consumer have been replaced with similar taxa that have higher productivity but deficient in agricultural and nutritional values of the original products (Table 2) (Posadzki *et al*., 2013).

Hence, using DNA barcoding can be used to validate whether the available sample is original or not. It can also validate the nature and identity of replaced sample species. For example, consider the sample of some fish meat-based product. During packaging it can be replaced with inferior quality cheap fish meat. Here, DNA barcoding will minimize the genuine producer loss by revealing the altered quality fish meat added. DNA barcoding will further allow more accurate food fraud detection mechanism and can also protect consumers from frauds.

Research done on blockchain and DNA:

Using blockchain technology store and share DNA sequences for biomedical research is growing at very high pace. Researchers have proposed using blockchain to create a secure and transparent system for sharing genetic data, which would allow for secured and privately data sharing among researchers. Studies have suggested that blockchain has great potential to enhance privacy of DNA data, and improve collaboration and data sharing in biomedical research. However, these are ongoing research and further studies are needed to evaluate the feasibility and scalability of blockchain technology for storing and sharing DNA sequences.

Biomedical researchers often focus on identifying and analyzing DNA sequences to understand genetic diseases. Although, providing efficient security for these DNA sequences is a challenging issue. blockchain technology is one potential solution for storing and sharing data sequences. This method would be secure and tamper-proof, which can help protect the privacy and security of genetic information, while also allowing for efficient collaboration and sharing of data among researchers.

Research has been conducted to find a solution for identifying species using mitochondrial gene COI (Cytochrome c oxidase I) as a unique focal point for a global bio-identification system. This study compares the traditional method of DNA sequence classification using ANN to a modern classification method and highlights the limitations of the traditional method. The modern approach uses the K-means clustering for grouping the dataset and then SVM, a machine learning method, is used for classification. This research was done by (Hebert, 2003; Zhou *et al*., 2011).

Another approach taking different DNA signature entities together for developing an efficient classification algorithm. The developed algorithm was based on DNA sequence and was tested on multiple datasets such as Iris, New-Thyroid and Wine. The results were somehow found to be satisfactory. The algorithm was also tested with different variations of differential evolution (DE) and its performance was observed for further processing. (Pandey and Singh, 2015).

Another study presented a new methodology for classification of DNA sequences by use of Convolution Neural Networks (CNNs). In this approach, DNA sequences are treated as text data, and one-shot vectors are used as input for the model. This allows the model to take into account the fundamental position information of each nucleotide in the sequences. (Nguyen *et al.*, 2016).

A blockchain-based platform namely Shivom was created for connecting users' DNA data with organizations to be used for research purposes. It enables individuals to make secure interaction with healthcare services and companies to enhance medical and pharmaceutical research worldwide while keeping patient privacy protected. In order to achieve this, it provides a library of open data pipelines for researchers to perform analysis on the platform and at the same time ensures that the data owner's identity remains anonymous (Shivom, 2020).

The Zenome project, utilizes Ethereum as their core blockchain for creation of a genomic information storing database. Zenome promoted a reward system for individual by commercializing sale of their stored genome. Moreover, the platform promoted privacy. Zenome also provide an interface for integrating other genetic services easily. The Zenome platform includes four parameters: nodes for providing storage and computing resources, end-users who uploaded their personal genetic attributes, genetics service providers who use the data for business, and analysts who analyze the genetic information for scientific purpose on platform (Kulemin *et al*., 2017).

Another study suggests using a technique called Blockchain Applied FASTQ and FASTA Lossless Compression (BAQALC) for handling large DNA sequence provided by Next Generation Sequencing (NGS) and to address issues related with safety and reliability in large DNA sequence databases. The technique was proven successful in storing DNA data on blockchain upto some extent. The study compares the compression ratio for hereditary biomarkers with that of the World Health Organization's top five infections with the highest death rates (Seo Lee *et al*., 2018).

A paper to improve patient health access by using blockchain technology in healthcare systems and eliminating need for a centralised system was proposed. The paper also highlighted using blockchain technology in healthcare, such as in increased patient record security (Marko Hölbl *et al*., 2018).

A survey paper on implementation of hash function to be used in blockchain was done. The general hashing algorithm is SHA256, also known as the 256 bits Secure Hash Algorithm, which is capable of understanding present day safety issues and also provide solutions to them. The SHAs algorithm are also used in crypto currencies (Wanga *et al*., 2018).

Another study aims to address the problem of unreliable storage and management of patient digitalized records by presenting a Blockchain technology-based Internet of Things model. This model involves collecting ongoing information about a patient's health status using a biological sensor and storing it's data on blockchain, creating immutable data storing mechanism. The medical bill and insurance coverage can also be determined through a smart contract, eliminating the need for third-party providers and creating a transparent system. The study also suggests using the Interplanetary File System for saving discharged patient health records details to reduce load on blockchain. This approach would benefit both patients and doctors by creating a secure and transparent environment with fast response to patient needs (Tushar Dey *et al*., 2017).

Blockchain technology has been gaining attention as a potential solution for improving credibility and transparency of healthcare data. The paper also discussed about the potential use cases and pros of blockchain in healthcare industry such as in Electronic Health Records (EHRs), clinical trials, drug supply chain management and more. This is achieved through a variety of use cases, such as maintaining consent in Electronic Health Record and simplifying claims settling. The author explains the basics of blockchain and highlights current and future applications of this technology in the healthcare industry. (Angraal *et al*., 2017).

Application of Blockchain based DNA barcoding:

Blockchain technology has the ability to create secure and transparent records which can be utilized in the determination of livestock-based product quality by providing a way to trace the origin and authenticity of the products.

DNA data once barcoded on blockchain can be accessed easily across different geographical location eliminating the need of storing DNA data at every testing center and will also reduce the time taken in determining food quality. Blockchain technology capability of making data completely immutable makes it a suitable technology for storing DNA data.

One possible application of blockchain-based DNA barcoding for livestock products is in the traceability of meat products. By using DNA barcoding to identify the specific animal that the meat came from, and then storing that information on a blockchain, it would be possible to trace the meat from the farm to the grocery store or restaurant. This would help ensure that the meat is authentic and that it comes from the source claimed by the seller.

Another application could be in the traceability of leather goods. By using DNA barcoding to identify the specific animal that the leather came from, and then storing that information on a blockchain, it would be possible to trace the leather from the tannery to the manufacturer and retailer, which would help ensure that the leather is authentic and that it comes from the source claimed by the seller.

In both of these examples, the use of blockchain technology would provide a secure and tamper-proof record of the DNA barcode information, which could be used to validate authenticity of the product and its origin.

In feed provider supply chain, the end users can monitor the complete flow of microbial purchasing by tracking it's flow from distributors, wholesalers and retailers. This would moreover increase the potency of the product. The blockchain technology also support the additional features to manufacturer or feed provider features such as temperature monitoring and controlling by integration with IoT devices.

System Architecture:

Based on the outline on issues in livestock authentication as mentioned in Table 2, it can be determined that DNA sequence security is a significant concern in the healthcare field as it holds a large number of genes related information about how different livestock's can be utilized for proper reproduction, enhanced classification and the discovery of illnesses.

However, blockchain technology has gained attention as a platform to enhance the transparency and credibility of healthcare data through a variety of applications. As a result, blockchain can be employed to secure DNA data servers as it makes the data unchangeable and difficult to remove, thus ensuring the precision and security of a patient's healthcare record.

When a node identifies a nucleotide/peptide sequence, the researcher can transmit DNA data through the blockchain module (Fig. 4). The DNA information that is being shared is sent to a server for an open DNA database, which is commonly used around the world. This will trigger a transaction to take place. Another computer on the network (referred to as a miner) will then assess the validity of the transaction.

The researcher serving as a node miner, examines sequence of transactions taking place for verification purposes. This contains processes such as identifying any potential anomalies in the transactions that may have been initiated by specialists with questionable records, short sequences or that are already been tested with reference sequences, chimaera detection, and various other types of errors detection.

The miner examines the transaction sequence for verification and checks for any errors or anomalies. Once transaction is deemed legitimate, the miner broadcasts the updated blockchain to network, which is then synced with biomedical researcher nodes, preventing any false modifications. The DNA data is then stored in the database in a secure blockchain format, making it accessible to other biomedical scientists. However, when DNA information is requested, only a reference to the information on the blockchain is provided, and no actual data is exchanged.

Table 2: Generic benchmark studies on previously developed DNA barcoding on crops and livestock authenticity

DNA barcoding area	Crop/livestock product	Need	References
Minor Crop Traceability	Vegetables	Genuine Capsicum identification	Jarret, 2008
	Aromatic plants	Recognising spices in manufactured or processed goods versus fresh samples	De Mattia *et al.* (2011)
	Herbal product identification	Tea based products supply chain management	Stoeckle *et al.* (2011)
	Medical plant	Tracking of medicinal plants	Zuo *et al.* (2011)
Complex Livestock and plant-based product identification	Honey	Recognition of pollen residuals and authentication	Valentini *et al.* (2010)
	Food supplements	Distinguishing fruit content in commercial products	Madesis *et al.* (2013)
	Beverages	Authentication	(Faria *et al.* (2013)
	Jams, sauces or yogurt	Recognition of real fruit composition in mixture	Arleo *et al.* (2012)
Alteration Detection	Aroma based products	Detection of adulterants	Parvathy *et al.* (2014)
	Vegetal flour	Identifying buckwheat in commercially available foodstuffs	Hirao *et al.* (2005)

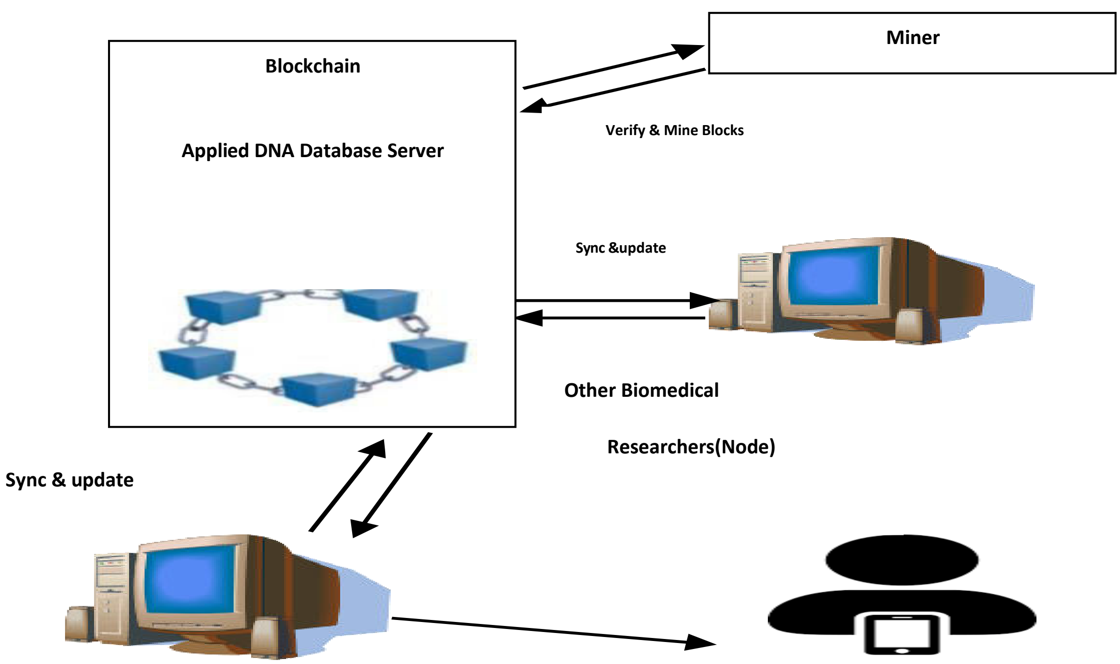

Fig. 4: Generalized Architecture of Blockchain Based DNA Barcoding.

After request acceptance, DNA information can be accessed, and once it reaches the requesting servers at remote location, this can be used by any biomedical specialist, scientist or DNA testing lab. Other biomedical analysts can also upload their own DNA details and may also transmit DNA information, triggering more transactions for verification by miners. Personal DNA data can also be accessed by healthcare users. Customers can request medical researchers for either DNA analysis results from their medical samples. Samples are examined by researchers, and results are communicated to customers. The information is only transmitted when users request DNA data. Medical users can further save their DNA data securely via any electronic devices.

This barcoded data once recorded on blockchain contains data such as age, breed and lineage of livestock. This can further be used for different purposes including tracking the origin of meat products, managing breeding sites and programs, and fraud prevention in livestock industry. The generated barcode can be easily validated by all authorized parties having access to blockchain such as farmers, veterinarians and government agencies. This will in turn provide a more robust, secure and transparent method for managing information of different livestock-based products.

By storing DNA barcoded data on blockchain, the DNA information would be tamper-proof and also be accessible easily to authorized nodes. The decentralized feature would also enhance security, making data manipulation difficult.

Proposed Methodology:

This work employs the blockchain technique to improve data security. In this case, multilevel blockchain improves data accessibility while consecutive blocks improve immunity.

Detailed step by step method for inserting a block of information into a blockchain (Fig. 5) are as follows:

- *Generate Data*: Blockchain technology can be used to store DNA and protein sequences obtained from various sources such as doctors, laboratories, and research institutions. To maintain the accuracy of the data, each dataset is thoroughly vetted to eliminate any duplicates. The sequences are recorded in FASTA format, which uses a series of characters to represent the nucleotide or amino acid sequences, with each nucleotide or amino acid represented by a single letter code (Mathur *et al*., 2020).

ACAACCGTTAAGTACT\CGGAA AGTA is FASTA format DNA sequence example

- *Indexing*: The obtained data is first pre-processed in order to determine the index position for a specific blockchain. Here, hash function-based indexing will be used to obtain blockchain positions in real-time. Hashing is the process of converting large keys into small keys using a hash function. After that, hash values are further implemented on hash table. A key is assigned to each element (converted key) which allows user to access the desired element in O(1) time by using that key. This reduces the time required for blockchain searching and insertion.

As different DNA samples are collected in separate chains, the hash index generates an eccentric key for entered input data for directing the data towards a specific blockchain. As a result, the mined block is inserted into the correct location of dataset.

- *Data Storage*: The blockchain technique is utilized to enhance data security. Here, multilevel blockchain improves accessibility of input data while other blocks enhance immunity. The hash value present in blockchain converts a data with a varying number of characters into data block with a fixed character. Even minor variations in a string result in a completely different hash, and the output cannot be used to deduce or calculate the input.

DNA data once barcoded on blockchain can be accessed easily across different geographical location eliminating the need of storing DNA data at every testing center and will also reduce the time taken in determining food quality. Even a

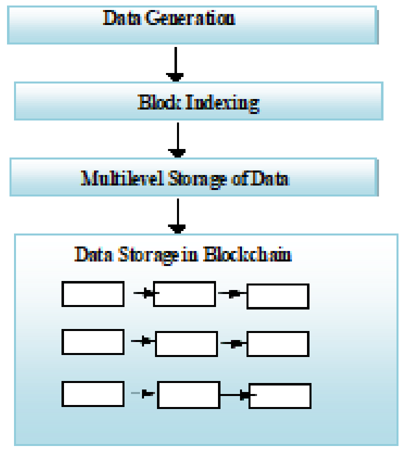

Fig. 5: Proposed Model.

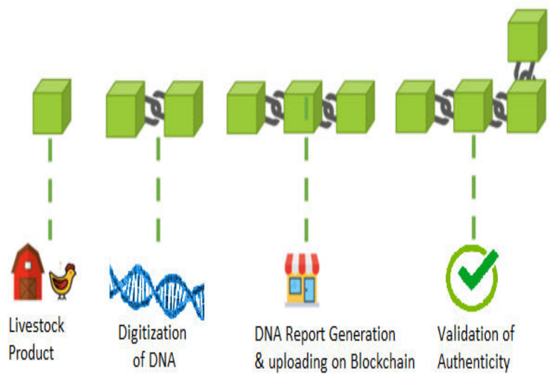

Fig. 6: Generalized flow from real-life livestock product to digitized blockchain.

customer can verify the authenticity of product received by verifying the barcode (Fig. 6). Furthermore, different initiative programs can be promoted so that more DNA data of livestock can be stored in blockchain.

Conclusion

Advances in DNA sequencing technology and decrease in cost of genome sequencing are driving progress in genetic industries. However, the management and handling of large amounts of data generated by DNA sequencing remains a challenge. Additionally, ensuring security and safe transmission of vast amounts of DNA sequence is also a concern. By using DNA barcoding to identify the specific animal that a product came from and storing that information on a blockchain, it would be possible to trace the product from the farm to the grocery store or restaurant, ensuring authenticity and that it comes from the source claimed by the seller. The proposed solution aims to provide a capable and secure transmission and storage capacity database for DNA data. DNA data once encoded on the blockchain can be accessed easily across different geographical locations, eliminating the need of storing DNA data at every testing center and reducing the time duration in determining food quality.

Blockchain technology can be used to establish a secure and unchangeable record of the DNA barcode of a livestock animal. This can be used to monitor the animal throughout its life, including details on its diet, health, and location. By utilizing DNA barcoding in conjunction with blockchain technology, it is possible to create a comprehensive and unalterable record of the animal's life that can be used to assess the quality of its meat, milk, or other products. This can help to ensure that the products are of high quality and free from contaminants, and can also aid in protecting consumers from fraud. Another potential use is the secure storage and sharing of DNA barcode data, which would protect the data from unauthorized access while maintaining the privacy of the individuals or organisms from which the DNA was obtained. Additionally, blockchain technology could be utilized to create decentralized data management systems for DNA barcode data. This would help ensure that data is accessible to scientists and researchers around the world, while also providing a secure and tamper-proof record of the data. Another area of future work is in supply chain management, where blockchain-based DNA barcoding systems may be used in tracking the products movement in supply chain and improving transparency and efficiency. Lastly, blockchain technology could be used to authenticate endangered species and protect them from illegal trade by creating a secure and tamper-proof record of the DNA barcode information.

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