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Improved services traceability and management of a food value chain using block-chain network: a case of Nigeria

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ABSTRACT

Competitive asset markets and increased globalization have continued to ripple the food value chain with complex dynamics, which has led to a range of challenges such as food safety and quality, traceability, and overall supply chain inefficiency. These have further continued to endanger the general well-being of society. With rice as a staple food in Nigeria, the rice food supply value chain consists of a series of tasks, processes, and activities that are linked together from freshly harvested products to consumer demand and supply. Study advances the SmartRice, a sensor-based block-chain framework that decentralizes as well as provides a decision-support for the food supply value chain process by first ensuring that accurate data of harvested goods are reported, and passed on to a chain. The study advances a decentralized framework to eliminate various forms of fraud rippled across the existing centralized system, minimize corruption through its sensor-based layered model as well as minimize the error in reported data along the value chain.

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1. INTRODUCTION

The food value chain consists of a series of activities that are linked together by raw materials (i.e. freshly harvested agricultural yields, products, and processed foods) and their corresponding flow to or fro a demand-supply chain from the producers to their consumers across organizational boundaries [1]. A typical food supply value chain can consist of farmers or growers, processors, wholesales or distributors, retailers, importers, and exporters-with processes that include handling, packaging, transportation, storage, and trading of these products cum goods for contract services and monies and or financial portfolios. These processes and the much-needed stakeholders involved therein constitute a complex, chaotic and dynamic structure of processes whose behavior impacts the performance therein of the entire system [2], [3].

The asset market has since become the focal epicenter for diversification of financial portfolios and 3-crucial factors that impact human existence include food, clothing, and shelter-mostly with food being a basic need of man-with agriculture playing a dominant role in the front seat of the asset market [3]. With agricultural products traded as assets as well as the inherent challenges therein, optimizing the food value-chain structure becomes imperative and thus, has also become an extensively studies phenomenon. We note

that an effective food value supply chain framework must be able to deliver superior consumer values at a lower cost when compared to the value chain as a whole. It thus should employ the use of contracts and portfolio as policies to drive supply-value chain [2] whilst, satisfying the requirement needs therein of stakeholders [4]. In addition, supply value-chain managers must be able to consider the interactions of known/unknown parameters as well as limitations cum minor shifts from which he/she is expected to create a plan that will render effective and efficient results for the value-chain.

2. LITERATURE REVIEW

2.1. The information-rich supply value chain

A supply value chain thrives on timeliness and transparency of information flow-that ultimately, results in an effective and efficient. Several studies to enhance information-rich supply value chains have led to advances in mathematical modeling, information management, supply chain management strategies, data mining, etc. These were implemented via tech-rich and tech-dependent structures such as virtualization, the internet of things (IoT), radio frequency identifications (RFIDs), and in recent times, the use of blockchain [5], [6]. In Nigeria, agriculture has since become the primary source of livelihood for many of its citizens. It also provides the highest percentage of the total food consumed within her territories. The Nigerian Agri-sector can maintain improved productivity and profitability via a concerted effort to address its many concerns such as: i) disorganized regulatory system, ii) lack of funding and subsidizing of raw materials to producers and farmers, iii) non-provision of modern equipment to farmers, vi) non-existent inventory/traceability systems, v) poorly functional data system, and iv) inefficient food supply value chain [2].

2.2. The rice-value chain: the Nigerian frontier

In Nigeria, rice has since become a staple food; And, the price of both locally-produced and imported rice has continued to skyrocket cum increased (year-on-year) at an approximately 14.6% and decreased month-by-month to a 0.67% ranging from N544.21 per kilogram of rice to N540.58 in April 2021 according to the National Bureau of Statistics Selected Food Price Report [7]. Obsi *et al*. [8] posit that there is a need to employ effective and efficient systems to monitor and control the rice value chain via a series of plan-do-check-and-act events. Figures 1 shows the price of locally-produced-rice as sold in Kebbi State per kilogram as the lowest price sale, and with Lagos witnessing the highest price sold per kilogram measure. Also, Figure 2 shows the price of foreign-produced cum imported rice as sold in Jigawa State per kilogram as the lowest price sale of two hundred and seventy-seven Naira per kilogram, and with Imo State witnessing the highest price sold per kilogram at Seven Hundred Naira per kilogram measure respectively, for the year 2021.

There is thus, an urgent need for the Federal Government to increase its spending in this sector so that small-scale farmer in rural area is been exploited as he tries to get their products to consumers while the urban dwellers are experiencing a shortage in food supplies leading to excessive importation. The solution thus requires the Nigerian government to look inwards and execute investments to revive the agricultural sector once again. There is a great deal of research out on ways to improve the sector including subsidizing production units for farmers, small-scale finance support, embarking on massive industrial projects, mechanized farming, and inherent use of technological innovations like blockchain technology.

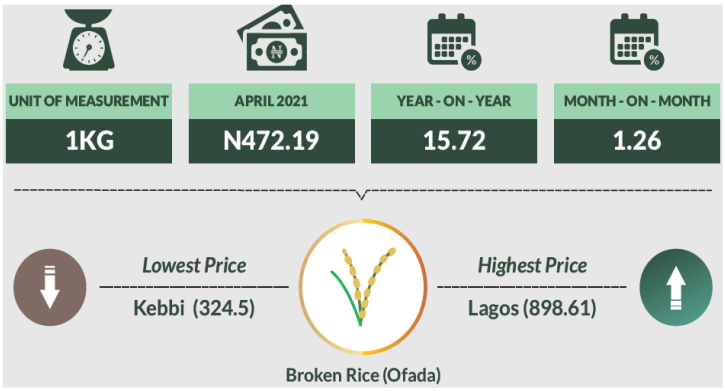

Figure 1. Locally-produced broken rice lowest or highest price ranges

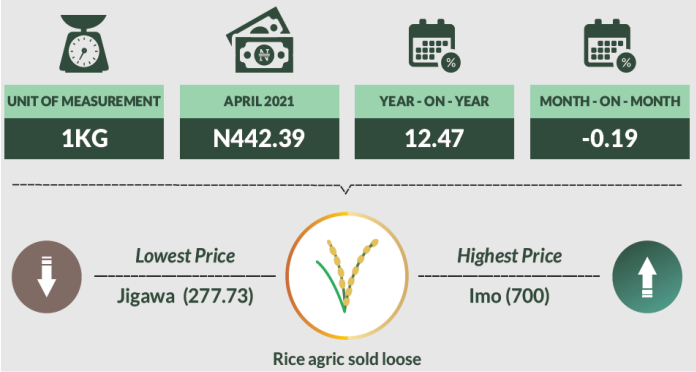

Figure 2. Imported and foreign produced rice lowest or highest price ranges

2.3. The block-chain network and model

The blockchain framework has today, easily become one of the best innovations created. Originally designed for the digital currency called Bitcoin- it is now adapted to smart contracts and used robustly in other sectors including healthcare, voting systems, and supply chain modeling. It is a shared ledger of digital transactions that are executed and distributed amongst shared (block-chain) nodes [9]. Here, a node is referred to as a computing device (physical or virtual) that is part of the blockchain network. Its benefits are poised from the inherent characteristics and feature it possesses such as security, decentralization, smart contracts and portfolios, and auditability [3], [6], [10].

The basic idea and usage cum adoption of the Block-Chain platform for new applications is to help decentralize the storage of information that renders it immutable such that it cannot be owned, edited, controlled, or manipulated by a central authority. The blockchain is a network of nodes (which forms a chain of blocks)-all of which contain information. The data stored in each block depends on the sort of block-chain; but, each block consists of i) data, ii) hash, and iii) hash of the previous block. The blockchain further uses hashing, distributed peer-to-peer networks, and proof of work-as mechanisms to ensure security, non-repudiation, integrity, and immutability of data as contained in the chain [11].

If a new node or data is to be added to the blockchain, the data is first broadcasted onto the blockchain via a peer-to-peer network for verification. Once approved by the majority of the nodes on the network according to the pre-approved rules, such data is then added to the chain as a new block. Next, a record of this transaction is thus, distributed to several nodes for security. A smart contract is an important feat of the blockchain, which helps it to support the performance of credible transactions without a third party. A major distinction of the blockchain from other existing internet designs is that the blockchain was created to protect and transmit valuable, original data [12], [13].

2.4. Related literatures

The application of blockchain technology to the food supply value chain can help ensure food quality and safety. Recent works by Mao *et al*. [14] have studied the traceability of food in the value supply chain-rather than its supervision and management. Tian [15] used RFID and Blockchain on the food supply chain traceability system. It sought to help the Chinese food markets to enhance food safety and quality. The RFID ensured that the Agri-food data is easily tracked and monitored via intelligent devices. It fuses with blockchain tech to activate a system for which Agri-food data cannot be manipulated to assure clients of quality and safety.

Caro *et al*. [16] used AgriBlockIoT, a decentralized supply management and traceability system that sought to address issues of centralized infrastructure. With its support for IoT, AgriBlockIoT creates transparent, robust, fault-tolerant, immutable, and auditable records. Leng *et al*. [17] used a public block-chain agricultural supply chain (using a double chain architecture to provide user and transaction data over a Chinese public service platform). The proposed framework sought to enhance service credibility over the platform with various benefits including the ability to view the resources on the platform without knowing the private data of the organization. Thus, ensuring the privacy of user information.

Behnke and Janssen [18] investigated blockchain boundary conditions-which, according to them, certain conditions exist that need to be met before blockchain can be implemented for traceability in food supply chains. These are conditions related to government regulations and policies, standards, and so on. The findings implied that supply chain systems need to fulfill the boundary conditions. It also explained why many block-chain projects remain at the piloting level.

Bako *et al*. [19] used a similar model for the Nigerian poultry supply chain through a policy framework that sought to understand the food traceability systems. Investigations on the issue of food recall as well as its success rate were studied. They posited a realistic strategy for achieving supply chain visibility while emphasizing the significance of food safety and its recall. In conclusion, they provisioned a clear roadmap for technology to contribute to the Nigerian food industry. This study exposed further works that could be carried out in developing electronic management systems and virtualization of processes to achieve food traceability.

2.5. Motivation or problem of statement

The study posits the following as issues cum motivation therein [2]:

- Unwillingness of stakeholders on food supply chain, to disclose accurate data about their asset or produce, and the corresponding chain processes has led to unavailability of data for extensive study. We thus, signed a non-disclosure agreement with the Rice farmers association to get the requisite information needed for the study. However, to combat this-we propose a hyper-ledger fabric framework.
- Previous studies as well as current mobile applications that implement the existing food supply value-chains employ a centralized model, which does not provide the assured user-trust level, transparency, and transaction security that is required to ensure food quality and safety. This study ensures food safety and quality via its decentralized model that uses RFID, which is fused and layered over the blockchain model.
- The Nigerian agricultural and food industry has no existing supply chain management system. With no control of such asset (food) prices, we have irrational hikes in prices as well as a monopoly of the food networks, which further threatens food availability, quality, security, and safety. e.g., the centralized system as practiced currently in Nigeria, the nation witnessed from October 2020 through April 2021-the ban of beef (cow meat) from the Northern parts of the country to the Southern and or Eastern parts of the country. Such bans are followed by food shortages in various regions and a decrease in revenue generation for small or medium scale farmers or producers, whose livelihoods are continually impacted (by such unregulated policies and decisions). But, such is averted via a decentralized mobile system-with such data, accurately and timely disseminated to users by various stakeholders.

The goal the study is to develop a framework that extends [2] by utilizing an RFID on a blockchain network to optimize the food supply chain in Nigeria by: i) understudying the current food value chain network in Nigeria, ii) model a SmartRice frame that will facilitate from farm-wholesale-retail-consume transaction(s) using the block-chain model, iii) ensure all transactions are authenticated using the smart-contracts approach via hyper ledger fabric, and vi) ensure transactions are validated with data security using cryptographic techniques to eliminate fraud, corruption as well as errors resulting from centralization policies.

3. METHOD

3.1. Proposed framework

We adopt Tian [15] model as in Figure 3, which employs an object-oriented methodology for an n-tier fat client block-chain smart contract application with RFID. The application interface is modeled against the backdrop of smart-mobile phones to ease portability, access, mobility, and speed of user transaction(s) for the various stakeholders. For mobile applications, we employ a functional programming mode in the development of the application program interface (API) to implement the blockchain smart contract on the android platform. Our *n-tier, fat-client* model will help users effectively and efficiently resolve the various data inconsistencies from various stakeholders on the blockchain at various points in the Nigerian rice value-chain problem using the hyper-ledger fabric [20], [21].

With rice being the staple food for most Nigerian families, the rice value chain thus creates an ever-increasing and spiraling (demand-and-supply) need(s) for traceability and management systems that seek to foster growth and expansive development in this sphere. Thus, we seek to design and model a framework SmartRice, that explores the RFID layered over the block-chain model for the Rice production value chain in Nigeria. SmartRice seeks also to advance a pragmatic solution to the deployment of a block-chain model in rice farming, processing, distribution, and consumption [22].

The various components of the SmartRice are as thus [20]–[24]:

- Farm: The system registers all rice crops from planting to harvest season as duration. Farmers record and validate these data at various stages (i.e. seedling purchase, planting, irrigation, fertilization, and harvest). SmartRice collates relevant data on consumption rates across the country-which serves as a layer of validation that pragmatically audits the Farmer (farm process) with smart contracts and

portfolios issued automatically to stakeholder nodes on the chain. This data also acts as an immutable record(s) to help detect anomalies (and record values that lie outside certain thresholds);

- Processing includes all tasks from harvest-to-storage in the processing pool. Comparisons and checks are considered in the smart contract to validate inflow or outflow of a processing pool. Detailed amount of received product from producers, packaged amount, and amount of product lost at processing phase is recorded. Also, the sensors are automated so that such data-entry processes are via connected weight scales with smart contracts automatically generated to create hash records on the nodes that help to track and detect anomalies (if the packaged amount is larger than the received amount).
- Wholesale: Processors transfer ownership of processed product to distributors, directly via the chain. The data is entered via a Distributor's app-via GPS sensors and smart contracts can automatize such process and create records as anomalies are detected during delivery (e.g., sensor values outside certain thresholds).
- Retail stores detail the received amount of product from distributors and at regular intervals, sensors autonomously store status information of the retail environment. Smart contracts can asynchronously fire to create records if anomalies are detected (e.g., sensor values outside certain thresholds).

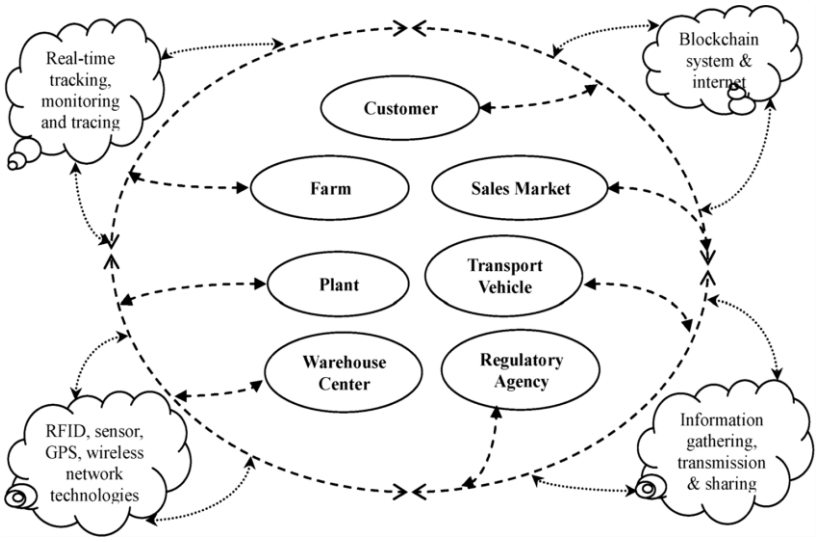

Figure 3. Existing framework by Tian [15] model

- Consuming: retailers store in the blockchain details about the sold products, while consumers can transparently verify the whole history of the price product before buying it. Note: smart tags can be associated with each package so that consumers can easily retrieve a complete history of the asset.

3.2. Procedural workings of experimental framework

We implement the proposed SmartRice food traceability and management system-leveraging both RFID and block-chain model. The SmartRice is established with broad coverage ranging from data gathering, and info management within the chain to enhance monitoring as well as product traceability management. This will help to minimize corruption, fraud of all forms as well as other issues as may arise. Thus, yielding Figure 4 the proposed experimental model that uses RFID sensors on a blockchain using hyper-ledger fabric (a key-value database) as implemented for the Android platform via a user-friendly mobile API [25]. This fusion results in improved features, and in turn, an improved block-chain system.

The framework is thus developed from a business perspective with requirement analysis, processes inquiry, data design, and other major technical activities requisite for smart contract(s). We model the smart contracts as a gateway to the *k-chains* and depending on the business cum transaction rules, this resulting system may vary in complexity, capabilities of both the selected block-chain framework as well as that of the client interfaces for the chain. Smart contracts are defined from farming to consumption of rice and employed as certificates to foster and authenticate the traceability of food along the supply chain.

Thus, the system SmartRice-should be able to provide consumers with a history of the food being purchased, once the said consumer is a registered user within the SmartRice network. With registration, each client/consumer is ceded a public or private key pair to digitally sign each operation on the distributed ledger.

The system makes use of weights all through the value chain. Internally, some validation and checks are carried out. The system detects anomalies and records the same such as the total sum of rice purchased from a farm not exceeding the total weight of rice harvested from a given farm within a given harvest season.

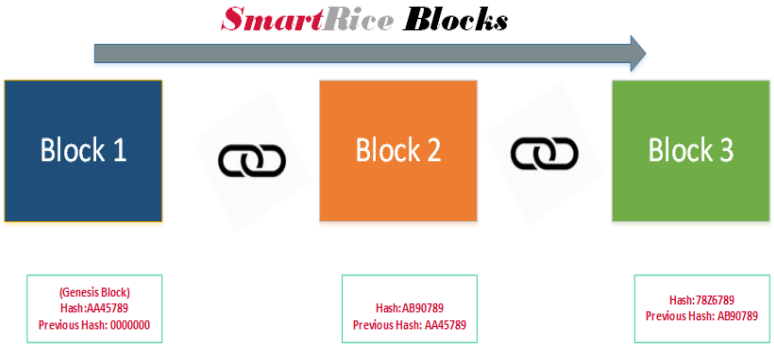

Figure 4. The SmartRice block

4. RESULTS AND DISCUSSION

4.1. The resultant SmartRice network

With the SmartRice implementation, we have the resultant framework [26]–[28] as in Figure 5. The working of its smart-contract processing with the various components, is described as thus: (a) mills contract allows registered farmers and mills to record harvests, track and validate assets; And further transmitted for processing on to the mills. The contracts are immutable recorded transaction to help detect record anomalies, (b) standard organization of nigeria (SON) and other regulatory agencies aims to ensure the safety of assets to be consumed, effective tracking of assets from one data-point to another–so that products are identified as coming from a known source. These records are also used for recall processes.

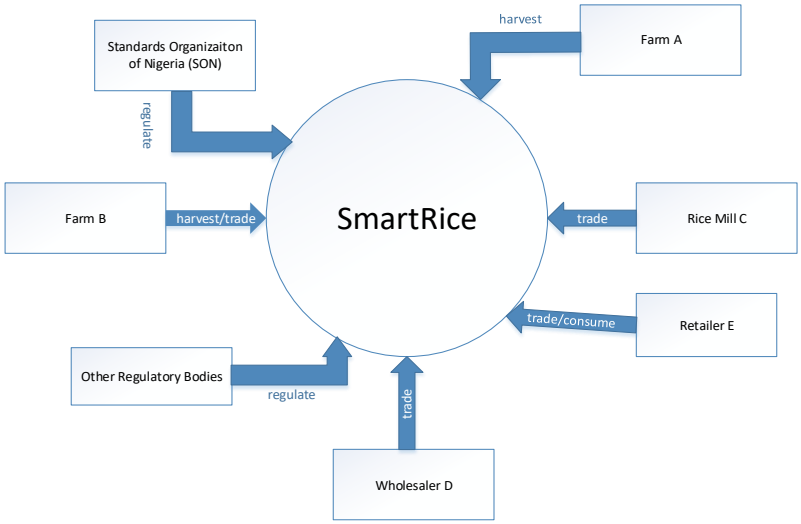

Figure 5. The SmartRice network

Detailed in the states below are its attributes and values as in Listing 1. The first stage of the asset_1234 is ***harvested***. It states the transaction's nature and brings Farm A's first batch into existence. This is in agreement with [29]–[33], respectively. Thus, if a 1kg rice asset_1234 is harvested at Farm A on January 1.

Listing 1: Mill_A_Harvested_Rice

```
Harvester = Farm_A
Rice = 1234
```

```
Owner = Farm_A
Harvest Date = 1st January
Current_State = Harvested
```

Shortly afterward, the rice is bought by Rice_Mill_C. this is seen in Listing 2. We note also how the same 1kg rice asset changes from a ***harvest_state*** to a ***processing_state*** due to the ***buy*** transaction.

Listing 2: Mill_C_Buys_Harvested_Rice_From_Mill_A

```
Harvester = Farm_A
Rice = 1234
Owner = Rice_Mill_C
Harvest Date = 1st January
Value = 2000Naira
Current_State = Processing
```

The owner [Rice_Mill_#] is most significant change and the current_state_value helps in identifying that the rice asset is now being processed or milled. The asset can thus, be safely transported across the value chain through its consequent distribution to wholesalers-retailers-consumers chain-and results in consume_state transaction to end the rice asset lifecycle on the value chain. Mandatorily, records of consumed assets are also kept on the chain, and the current_state of consumed is noted to aid traceability and management purposes. Additionally, the value of the owner_property of a rice asset can be used to carry out access control on the trade/consume transaction by comparing this owner_property alongside or against the identity of each transaction initiator or creator. The hyper-ledger fabric supports this through the chain-code API.

4.2. Discussion of findings

The SmartRice applet allows users to register as either a farmer/farm corporation, processor plant, wholesaler, retailer, or consumer. Depending on the users' role registered, permissions are granted (e.g. only a farmer or farm corporation can add a new rice harvest record to the chain). A processor can only buy harvested rice from the system, process or mill the same rice and consequently, update the status of the same rice, as being ready for consumption. The wholesaler and retailer can also buy processed rice directly from farms or the processing plants from any site [34]–[36].

Thus, farmers-wholesalers-retailers are linked therein the network, and can effectively/efficiently trade their goods. Such links make possible the fact that a small-scale rice farmer in Ejiba (Kogi State) can communicate with a wholesaler in Shoprite Mall in Asaba (Delta State)-and with planned shipment is made for the assets to the buyer. Users can track a particular shipment also via the mobile application to know its history and essentially how it has been handled on the rice production network as seen in the Appendixes. The hyper-ledger fabric employs a peer-to-peer network, to establish a decentralized structure for the app. It runs a 3-tier peer mode (namely orderer, peer-one, and peer-two). If any of the peer-mode crashes, any active peer performs pending tasks. This feat eliminates manipulation of resources, fraud and corruption that otherwise exist when food supply and supervision decisions are controlled from a centralized point [37], [38].

4.3. Study contribution(s)

This study looks at the following parameters:

- SmartRice yields a resultant network of the rice value chain that provides accurate and timely information on rice in the chain as it gathers information from both demand and supply stakeholders on the chain.
- It yields an API that is easily ported, with ease in mobility, ease of access to the Internet, durability, and speed of processing [26], [39], [40] with its seemingly user-satisfaction upload and download times.

4.4. Sample test results

Figure 6 shows the Add_Rice menu window for the application; while, Figure 7 shows the requisite information detailed by the SmartRice framework and details how the Rice assets are traded by stakeholders. The Figure 8 shows the registration of all stakeholders on the block-chain smartrice model.

Sample results shows that the blockchain-based SmartRice aims to effectively tackle a majority of the corrupt practices for the Nigerian food value chain. It uses a hyperledger fabric, a key-value database, and a mobile applet interface-resulting in a user-friendly, and open-source permissioned blockchain framework that is ideal for the privacy and confidentiality of transactions and data related to business transactions. Sample applets, are seen as below, developed and deployed for an optimized rice value chain.

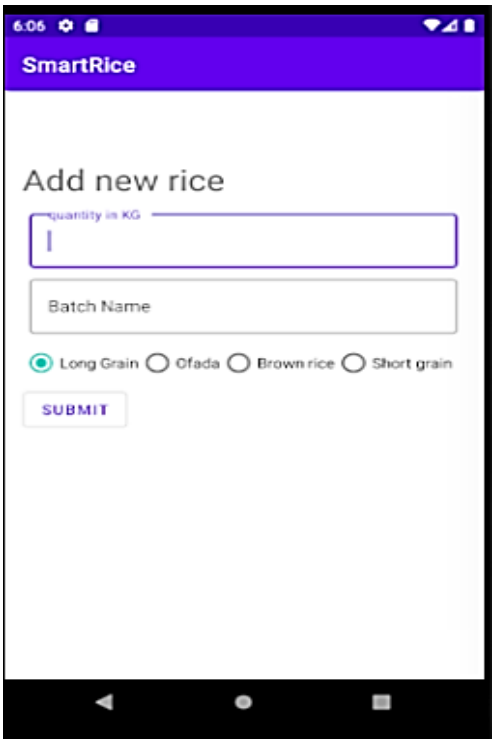

Figure 6. The Add Rice Window Applet

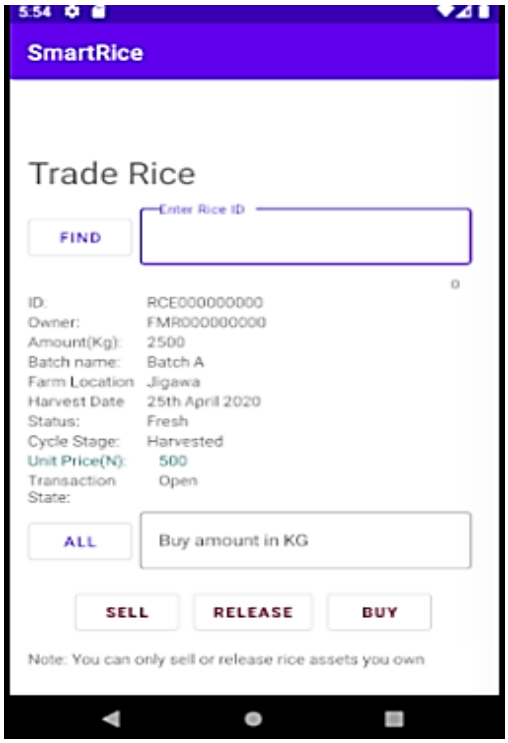

Figure 7. The Trade Rice Window Applet

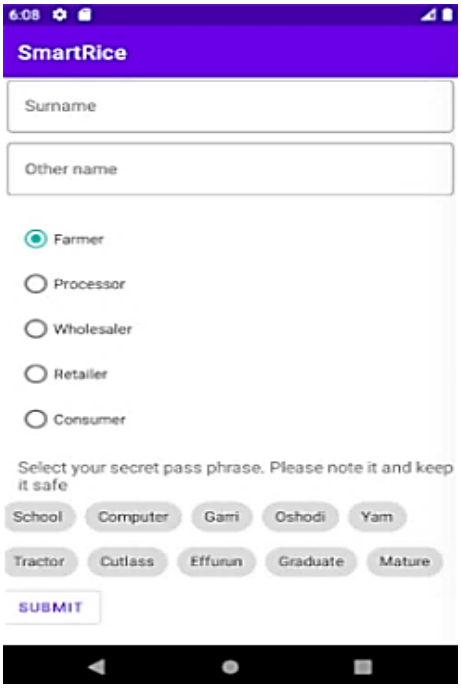

Figure 8. The registration pane on the SmartRice application

5. CONCLUSION

The study implements SmartRice (with RFID hybrid over the blockchain network) as means to manage the rice food chain from production to consumption. The system seeks to effectively tackle inherent challenges of the Nigerian food chain using the hyper-ledger fabric (a key-value database) for Android mobile smartphones; And yields a high-performing, user-friendly, and open-sourced permissioned block-

chain framework that is ideal for the privacy and confidentiality of transactions and data related to business transactions. In conclusion, the SmartRice model and framework are deployed to help effectively and efficiently manage the rice value chain in Nigeria.

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