Framework to Improve the Traceability of the Coffee Production Chain in Perú by Applying a Blockchain Architecture

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Abstract—**The value of coffee is decreasing in the international market caused by the poor traceability that coffee cooperatives offer to the rest of the public in the production chain. There are paper records or storage in centralized databases of the details of the product that is delivered and received at each stage, generating high cost and inefficiency in paper-based processes, fraud, corruption and errors in both processes. Other investigations pose the problem proposing solutions with opportunities to improve. A framework is proposed to improve the traceability of the coffee production chain using blockchain. The proposed framework is composed of 3 phases: (1) Blockchain architecture design, (2) Smart contracts design and (3) Web application design. Blockchain technology is used to guarantee immutable traceability of the production chain. The proposed framework was validated in a coffee cooperative located in Cajamarca (Peru) applying 2 experiments and a survey based on expert opinion. The results show that with the proposed framework, time of process and the number of errors can be reduced in the defined scenarios, where in turn a reduction of 99.87% of the time in the generation of coffee traceability is evidenced. In addition, the results of the survey show that the "performance", "traceability parameters" and "usability" of the system have an average value of 4.6 (Value close to 5).**

I. Introduction

The agricultural production chain is a system made up of many people and activities involved in the generation of agri-food products from the sowing of seeds to their distribution to the final consumer [1]. Its management exposes great challenges due to the level of complexity that it can have [2]. In Peru there are 223,000 coffee-producing families that make up the first stage of the production chain for this grain. 30% of them are grouped in coffee cooperatives producing synergies that allow them access to better economic and technical benefits aimed at improving the quality and yield of their crops. [3].

The value of coffee is decreasing in the international market due to the poor traceability that coffee cooperatives offer to the rest of the actors in the production chain [2]. There are paper records or storage in centralized databases [2], [4] of the detail of the product that is delivered and received at each stage [5], producing a high cost and inefficiency in paper-based processes, fraud, corruption and errors in both processes [6], [7]. Fraud ranges from manipulation of coffee data to smuggling and loss of identity [8]. The digital tracking of the origin and history of coffee is complicated because the data is scattered, forming islands of useless information [8], [9]. The farmer, who is the main actor, remains anonymous and begins to devalue his work in recognition and payment [2]. The identification of the origin of contaminated coffee bags becomes a complicated and very expensive task [4], [5], [7], [10]. Trust is lost between chain actors due to lack of transparency [2], [9], [11]. Final consumers are afraid of getting poisoned or dying from consuming contaminated products [12]. They avoid repeating what happened in Germany in 2013 [9], [13] and Japan in 2014 [12].

Internationally, coffee production has risen since the beginning of the previous decade, going from 113.6 million bags in the 2000/01 campaign to 158.9 million bags during the closing of the 2017/18 campaign. In addition, coffee consumption has increased, estimating 158.5 million bags in consumption at the end of this last campaign [3]. However, Peru has shown a decelerated performance in exporting this grain since the previous decade, from which it has not yet managed to recover [14]. The country's economy seems damaged considering that coffee is the main agricultural export product [3] and provides employment to a third of the population in this sector [15].

To mitigate the problem, different proposals have emerged. Castillo, Caicedo and Sánchez [16], propose a system to manage the traceability of coffee in the initial stage of its production chain (beneficial process) allowing certification of its origin. On the other hand, Salah, Nizamuddin, Jayaraman and Omar [4], propose a system for the traceability of the soybean production chain using smart contracts to manage access and apply business rules that eliminate centralized intermediation. Borrero [6], proposes a pilot system for the traceability of the berry production chain, storing all the data in the blockchain. Patel, Shukla, Tanwar and Singh [10] propose a system for the traceability of the agricultural production chain that allows managing the granting of credits to farmers to buy raw materials and ensure the quality of the product through a qualification mechanism in each stage of the chain. However, Castillo et al. [16] doesn’t consider a decentralized data storage outside of their being manipulated, Salah et al. [4] do not show the execution of a validation process, and Borrero [6] does not only store traceable data in the blockchain, causing its solution to present opportunities for improvement in query and transaction processing times. Likewise, it is considered opportune to apply a product evaluation mechanism in the proposal [10].

For all the above mentioned, a framework is proposed that improves the traceability of the coffee production chain by applying blockchain. This technology will guarantee an immutable, complete and transparent traceability of the production chain, providing the opportunity to know the authentic route followed by the coffee from the farmer to the distributor, make sound decisions in real time and, together, increase the sales opportunities of the coffee. grain nationally and internationally. The framework will be developed in 3 phases: (1) Blockchain architecture design, (2) Smart contracts design and (3) Web application design.

This article is organized into 6 sections. In section 2, the state of the art is presented through a methodology considering literatures on technological solutions for agri-food traceability. In section 3, the framework proposed to guarantee an immutable traceability of the coffee production chain is described. The solution is validated through a case study in section 4. In section 5, the result and discussion are presented. Finally, in section 6 we will find the conclusions and future work.

II. LITERATURE REVIEW

The systematic review of the literature was done based on the work of Wong, Mauricio and Rodríguez [17]. The following phases were proposed: Review planning, Review development, and Review results and analysis.

In the Planning phase of the review, the following research questions were addressed: Q1: What factors are necessary to improve the traceability of the coffee production chain? Q2: What technologies can be applied to improve the traceability of the agricultural production chain?, Q3: To what types of products have blockchain solutions been applied to improve the traceability of its agricultural production chain?, Q4: What types of validation are applied in technological solutions to improve the traceability of the agricultural production chain? coffee or some similar product?

The following keywords were determined to search for the articles: "agricultural", "agriculture", "supply chain", "agri-food", "coffee", "traceability", "technology" and "blockchain". The keywords were applied to the title, abstract and keywords of the articles. Searches were performed in the Scopus and Web of Science databases.

The following inclusion criteria were established: year of publication between 2019 and 2021 and type of Journal source. The exclusion criteria established were the following: language other than Spanish, English and Chinese and quartile Q4.

In the Development phase of the review, the articles were searched in the selected databases using the keywords and defined inclusion and exclusion criteria. The abstract, introduction and conclusion of the articles found were reviewed. Finally, the primary articles resulting from the proposed systematic review process of the literature were selected.

In the Results and Analysis phase of the review, the 20 selected articles were displayed and analyzed. The analysis was carried out using a taxonomy made up of 4 classifications: Factors (Q1), Technologies (Q2), Products (Q3) and Types of validation (Q4). Each of them was related to one of the research questions proposed above. TABLE I presents the number of articles selected by classification.

TABLE I. DISTRIBUTION OF ARTICLES BY CLASSIFICATION

Category	Papers
Factors	[4], [12], [16], [18]–[21]
Tecnologies	[4]–[11], [12], [18]–[26]
Products	[4]–[9], [24]
Types de validation	[5]–[11], [16], [18]-[20], [22], [24]-[27]

In the first classification, "Factors", as a result of the review, the essential factors to improve the traceability of the coffee production chain were: communication [4], information management [4], [16] and technological integration [19]. Information management consisted of product labeling [16] and data capture [4], [16]. In this classification, the study by Castillo et al. [16] presenting a case study of Latin America with realities like that of Peru.

In the second classification, "Technologies", as a result of the review, the applicable technologies to improve the traceability of the agricultural production chain were grouped into 5 segments: blockchain, consensus algorithms, data storage, cloud computing and data network. The blockchains used were: Ethereum [4], [8], [10]–[12], [20]–[23], [26] and Hyperledger Fabric [5], [6], [9], [24]. The consensus algorithms applied were: Mixed Byzantine Fault Tolerance (MBFT) [8], Practical Byzantine Fault Tolerance (PBFT) [8] and Byzantine Fault Tolerance (CSBFT) [8]. The data storages used were: Inter Planetary File System (IPFS) [4], [5], [10], [11], [20], BigchainDB [18], MongoDB [21], Cou-chDB [9], SQL Server [18] and MySQL [9]. The Cloud Computing platforms used were Azure [18] and Google Cloud Platform [7]. The data networks used were: 4G LTE [6] and 5G [10]. In this classification, the study by Shahid, Almogren, Javaid, Al-Zahrani, Zuair and Alam [11] stands out for the variety of technologies applied in their proposal: Ethereum Blockchain to store block chain hashes, IPFS to store secondary information and, Solidity and Remix IDE to create smart contracts that define and execute your business rules.

In the third classification, "Products", as a result of the review, the types of products where blockchain solutions have been applied to improve the traceability of their agricultural production chain were: cereals [5], [8], [24], fruits [6], [9] and vegetables [4], [7], [9]. The cereal group was composed of rice [8] and wheat [5]. The fruit group was made up of berries [6]. The vegetable group was made up of pumpkin [7] and soybeans [4]. In this classification, the study by Salah et al. [4] for considering similar stages of the soybean production chain with respect to coffee in their proposal.

Finally, in the fourth classification, "Types of validation", as a result of the review, the types of validation applied in technological solutions to improve the traceability of the production chain of coffee or similar products were: functional tests [5], [6], [11], [12], [21], [25], [26], performance tests [7]–[10], [18]–[20], [22]–[24] , [27], safety tests [11], [12], [26] and cost tests [11], [19]. The performance tests were made up of: processing tests [7]–[9], [18]–[20], [22], [23], latency tests [9], [10], [19], [20], [23] and storage tests [10], [24], [27]. In this classification, the study by Shahid et al. (2020) [11] due to the variety of tests applied in their proposal: functional tests, security tests and cost tests.

III. Proposed framework

A framework is proposed to improve the traceability of the coffee production chain by applying blockchain. The proposal is made up of 3 phases: (1) Blockchain architecture design, (2) Smart contracts design and (3) Web application design. In phase 1, the blockchain architecture is designed using the components according to the case study. In phase 2, the business rules in the smart contracts are defined and implemented following the following steps: (a) Definition of attributes, (b) Environment configuration, (c) Smart contract construction and (d) Smart contract deployment. Finally, in phase 3, the architecture of the system that will support the functionalities of the web application is designed (see Fig. 1).

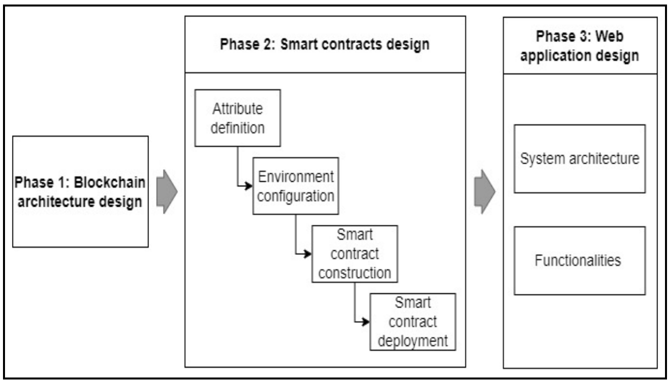

Fig. 1. Proposed framework conceptualization

A. *Phase 1: Blockchain architecture design*

The architecture is made up of Azure and Infura services and the Ethereum blockchain network (see Fig. 2). The Azure services considered are the following: (a) Azure Content Delivery Network (CDN), (b) Azure Active Directory B2C, (c) Blob Storage, (d) API Management, (e) Azure Insights, (f) Azure Key Vault, (g) App Service, (h) Azure Function, (i) Service Bus, and (j) SQL Database.

Next, the role that each service fulfills within the architecture is specified. (a) Azure CDN enables a multi-region connection by generating replications of the web application in different land zones. Latency times are lower. (b) Azure Active Directory B2C allows you to configure and set user and role access policies to the web application. Establishes direct communication with the blob storage. (c) Blob Storage allows unstructured data to be stored and encrypted. (d) API Management allows you to configure and mask IPs; verify API keys, Json Web Tokens and certificates and; enforce speed limits and usage quotas. Responses are cached to improve response latency and minimize the load on backend services. (e) Azure Insights allows analysis and diagnosis of problems through smart alerts, graphs, reports and/or logs. (f) Azure Key Vault, with prior authentication, allows you to securely store passwords, certificates, API keys and/or cryptographic keys. (g) App Service allows hosting web services (RESTful API) without the need for a physical server, automatically scaling the web application or keeping it always available. (h) Azure Function allows you to deploy code without having to worry about having a physical server and scale resources according to the demand of requests, allowing performance to be unaffected. (i) Service Bus allows each request to be queued, kept in order and replicated until it is served. The requests answered are later eliminated. (j) SQL Database allows you to store structured data. The Infura service allows secure communication between the web application and the blockchain network.

The Ethereum blockchain network is made up of (1) nodes (or blocks) and (2) smart contracts. The nodes represent the different actors that interact in the coffee production chain and the smart contracts (SC) represent the business rules to establish consensus given a context. The contexts are of the type "if abc event occurs, then xyz event occurs". The contexts trigger the smart contracts through the API. Smart contracts require Ether gas to be given to miners as payment for establishing consensus, decrypting data by applying algorithms and processing transactions [28], [29]. This mechanism guarantees an immutable, decentralized and authentic record of the data in the Ethereum blockchain network [28].

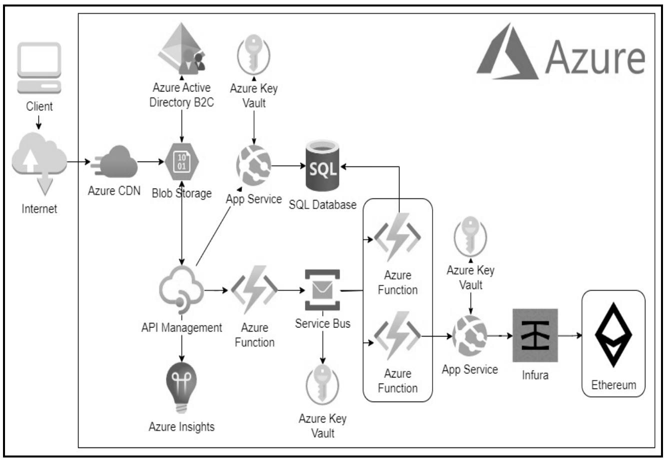

Fig. 2. Blockchain architecture

B. *Phase 2: Smart contracts design*

The proposed framework takes into account the creation of 3 smart contracts: "*UserContract*", "*PurchaseRequest*" and "*PurchaseContract*". The first ensures the authorized permission of the actors to the system. The second and third guarantee the authenticity of the agreements to generate the Application and the Coffee Purchase Agreement, respectively. The third party, independently, endorses the immutable record of grain quality controls.

The following paragraphs present the design and construction of the smart contract “PurchaseContract”. The following steps are followed: (1) Definition of attributes, (2) Environment configuration, (3) Smart contract construction and (4) Smart contract deployment.

1) Attribute definition

The attributes of the entities defined in the system data model are classified as "traceable" and "non-traceable" in order to be stored in the blockchain and in a SQL Server database, respectively. This mechanism provides better response times in the query and transaction processing in the blockchain [5], [11]. TABLE II exposes the data dictionary of the attributes of the smart contract "*PurchaseContract*".

TABLE II. DICTIONARY OF Data OF THE SMART CONTRACT “PURCHASE CONTRACT”

Attribute	Datatype	Classification
HumidityPercentage	String	Traceable
Smells	String	Traceable
Colors	String	Traceable
Responsible	String	Traceable

2) Environment configuration

The smart contract is built using the *Solidity* language and the “Blockchain Development Kit for Ethereum” toolkit from the Visual Studio Code software [30]. The latter is light, simple and has a short learning curve. When a new project is created, a folder structure for the solution components is automatically generated. The “bin” folder contains the smart contract compilation file that is used to communicate the web service with the blockchain network. The “contracts” folder contains the smart contract with the “*.sol*” extension. The “migrations” folder contains the smart contract configuration file on the blockchain network. Finally, the “node_modules” folder contains the packages installed in the entire project (see Fig. 3).

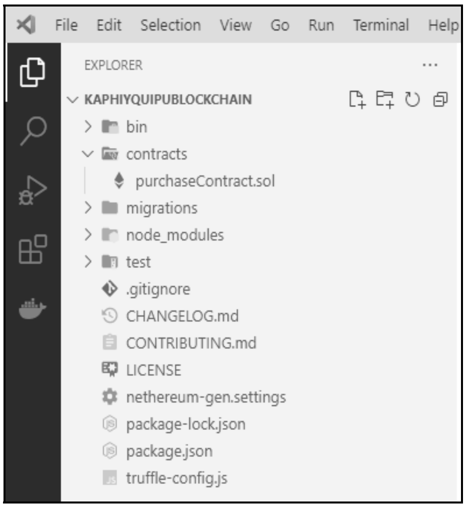

Fig. 3. Project structure with Visual Studio Code

3) Smart contract construction

The creation script of the smart contract "*PuchaseContract*" is presented, elaborated with the Solidity language and supported according to the business process (see TABLE III). Once the smart contract is started in the first lines, the structure is defined. Associations, events, and functions allow you to manage data and communicate with the blockchain network. The important parts of the script are explained in the following paragraphs.

TABLE III. SMART CONTRACT SCRIPT “PURCHASECONTRACT”

```
1:  pragma solidity ^0.5.0;
2:  contract PurchaseContract {
3:    struct QualityControl {string humidityPercentage; string smell;
4:      string color; string observation; string responsible};
5:    mapping (string => Contract) private mappingContract;
6:    mapping (string => Farmer) private mappingFarmer;
7:    mapping (uint256 => QualityControl) private
8:      mappingQualityControl;
9:    mapping (string => PhysicalAnalysisCoffee) private
10:     mappingPhysicalAnalysisCoffee;
11:   mapping (string => EntryNoteStorageWarehouse) private
12:     mappingEntryNoteStorageWarehouse;
13:   event new_contract (string correlative, string distributor,
14:     string product, string byProducto, string typeProduction,
15:     string quality, string degreePreparation,
16:     uint256 requestDate);
17:   event new_farmer (string contract, string documentNumber,
18:     string property, string certification);
19:   event add_quality_control (uint256 contractPartnerPropertyId,
20:     string humidityPercentage, string smell, string color,
21:     string observation, string responsible);
22:   event add_physical_analysis (string guide, uint256 grams_coffee,
23:     string percentage_coffee, uint256 discard_grams,
24:     string percentage_discard, uint256 grams_shell,
25:     string percentage_shell, uint256 total_grams,
26:     string overall_percentage);
27:   event add_entry_note_storage_warehouse (string correlative,
28:     string store, uint256 date);
29:   function addQualityControl (uint256 contractPartnerPropertyId,
30:      string memory humidityPercentage, string memory smell,
31:      string memory color, string memory observation,
32:      string memory responsible) public {
33:      mappingQualityControl [contractPartnerPropertyId] =
34:        QualityControl (humidityPercentage, smell, color,
35:          observation, responsible);
36:      emit add_quality_control (contractPartnerPropertyId,
37:      humidityPercentage, smell, color, observation, responsible);
38:   };
39: };
```

Line 1 of TABLE III indicates the version of the Solidity language that is used to compile the smart contract. Version 0.5.0 is used. The "^" symbol allows superior versions of the language to compile it as well. Next, in line 2, the smart contract “*PurchaseContract*” is defined, using the inherited word “contract” from the language. In line 3, using the inherited word “struct”, the “QualityControl” structure is defined with the attributes: humidityPercentage, smell, color, observation and responsible. The data is stored in this structure.

Using the word “mapping”, from line 5 to line 12, the associations that are used in the smart contract to store the data objects in memory are started. In lines 5, 6, 7, 8, 9, 10 and 11, the structures "Contract", "Farmer", "QualityControl", "PhysicalAnalysisCoffee" and "EntryNoteStorageWarehouse" are associated with the private variables "mappingContract", "mappingFarmer", "mappingQualityControl", "mappingPhysicalAnalysisCoffee" and "mappingEntryNoteStorageWarehouse", respectively.

Using the word "event", from line 13 to line, the events that allow the interaction of the data received from the smart contract parameters with the blockchain are started. In lines 13, 14, 15 and 16, the "new_contract" event starts, which allows registering a green gold coffee purchase contract. In lines 17 and 18, the "new_farmer" event is initialized, which allows a farmer to be registered. Lines 19, 20 and 21 start the event "add_quality_control", which allows registering a quality control applied to the raw material. In lines 22, 23, 24, 25 and 26, the event "add_physical_analysis" is started, which allows registering the analysis applied to the raw material before its entry into storage. Lastly, in lines 27 and 28, the event "add_entry_note_storage_warehouse" is started, which allows registering the data of the entry note for storage.

Using the inherited word "function", functions are created that allow tasks to be encapsulated and reused as many times as required. From line 29 to line 38, the "addQualityControl" function is created with the parameters: contractPartnerPropertyId, humidityPercentage, smell, color, observation and responsible. On line 33, the mapping "mappingQualityControl" is started to store the value of the parameters in memory. Finally, on line 36, the "add_quality_control" event is started, which allows this data to be saved in the blockchain.

4) Smart contract deployment

The smart contract deployment is performed following 2 main tasks: (1) generate smart contract migration file and (2) configure project truffle file.

The first task is done by creating the migration file in the "migrations" folder of the project in Visual Studio Code. The file, with the extension ".js", allows to consider the deployment of the smart contract in each compilation of the project. Line 1 and 2 of TABLE IV, the name of the smart contract and the deployment action are referenced, respectively.

TABLE IV. SMART CONTRACT MIGRATION FILE "PURCHASE CONTRACT"

	4_initial_purchaseContract.js configuration file
1:	const Migrations = artifacts.require("PurchaseContract");
2:	module.exports = function(deployer) {
3:	deployer.deploy(Migrations);};

Additionally, the second task requires installing the "truffle" library to the project and configuring its truffle-config.js file. Lines 9 and 10 of Table V refer to the blockchain network to deploy the smart contract. Finally, after doing all of the above, the deployment runs automatically every time the project is compiled.

TABLE V. TRUFFLE CONFIGURATION FILE FOR DEPLOYMENT

	truffle-config.js configuration file
1:	require("truffle-hdwallet-provider");
2:	const mnemonic = 'purchase armor sponsor secret crawl battle gauge
3:	sorry relief either little slide';
5:	module.exports = {
6:	networks: {
7:	development: {host: "localhost", port: 7545, network_id: "*",
8:	gas: 5000000},
9:	rinkeby: {provider: () => new HDWalletProvider(mnemonic,
10:	/4acb060dfb3x564hj488a63ecf15091f'), network_id: 4}
11:	},
12:	compilers: {solc: {version: "0.5.0"}}
13:	};

C. Phase 3: Web application design

The web application is developed through the Scrum framework. Some concepts of the Extreme Programming (XP) and Kanban methodology are used, such as user stories and the Kanban board, respectively. The front part of the system is built with the Angular language and its backend part with the C# language and the framework NET. Core.

The system architecture is made up of 3 components (see Fig. 4): (1) Presentation layer, (2) Data layer and (3) Blockchain environment. The presentation layer is made up of the Azure App Services service that allows you to host the web application. The data layer is made up of the REST service built with the NET framework. Core under a Domain Driven Design (DDD) architecture at the project level. Non-traceable data is stored in the SQL Server 2019 database. Finally, the blockchain environment is made up of smart contracts that have consensus and context mechanisms to verify and approve transactions and detect malicious events, respectively. Traceable data is stored on the Ethereum blockchain.

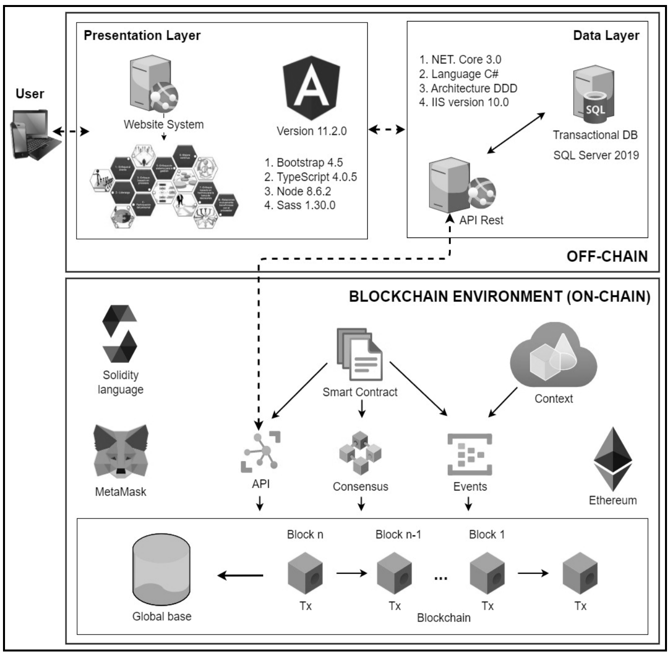

Fig. 4. System architecture

The actors that interact with the proposed framework are farmer, collector, transformer and distributor. The traceable data and complementary traceability data are stored in the Ethereum blockchain network and the SQL Server database, respectively (see Fig. 5).

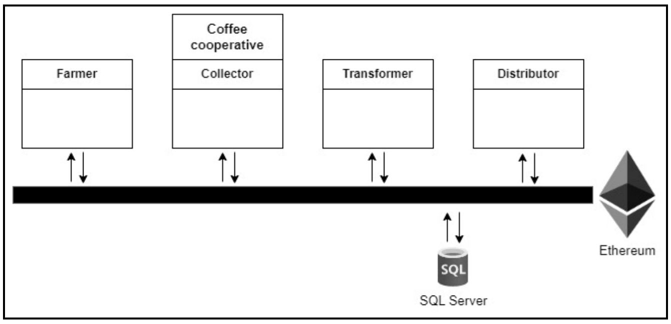

Fig. 5. Interaction of the actors in the proposed framework

The web application provides different functionalities for each of the actors in the coffee production chain according to the business process (see TABLE VI). Which allow to manage the coffee from the harvest to its disposal to the distributor.

TABLE VI. SYSTEM FUNCTIONALITIES

Actor	Functionality
Farmer	- Harvest record - Sale of raw material - Visualization of coffee evaluation
Collector	- Generation of coffee purchase contract. - Purchase of raw materials. - Register of quality controls. - Projection of coffee sales. - Projection of coffee harvests.
Transformer	- Quality control record. - Coffee processing.
Distributor	- Generation of coffee purchase request. - Generation of traceability QR code.

IV. VALIDATION

The proposed framework is validated in a coffee cooperative located in the department of Cajamarca, Peru. The participation of different actors in the production chain is considered: a cooperative that is dedicated to the sale of green gold coffee that includes roles such as: seller, storekeeper, quality controller and collection manager; a distributor; two farmers associated with the cooperative who have raw material and; a processing plant that contemplates roles such as: plant manager, quality controller, warehouseman and transformer. Additionally, a survey is conducted of 4 experts on issues of traceability and quality of coffee.

The validation of the proposed framework is carried out with 2 experiments: (1) Manually and (2) With the proposal. Two scenarios are shown: (1) Generation of traceability flow documents and (2) Generation of traceability. The time of process it takes to generate each element of the scenarios and the number of errors when performing this task are measured.

A. Experiment 1: Manually

The *time of process* and the *number of errors* are measured for the 2 defined scenarios. Scenario 1 includes the preparation of the following documents by the different actors (see Fig. 6): purchase request, purchase contract, reception guide, entry note to the storage warehouse, order of processes and marking of bags, referral guide, plant entry note, plant exit note, plant referral guide, return entry note and return referral guide.

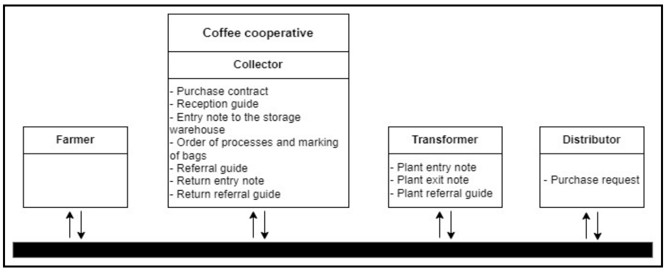

Fig. 6. Generation of documents in Experiment 1

Scenario 2 includes the compilation of several documents and preparation of a technical report on the traceability of the coffee by the collector only to the distributor (see Fig. 7). The documents are purchase request, purchase contract, collection entry note, referral guide, plant entry note, return entry note and collection exit guide.

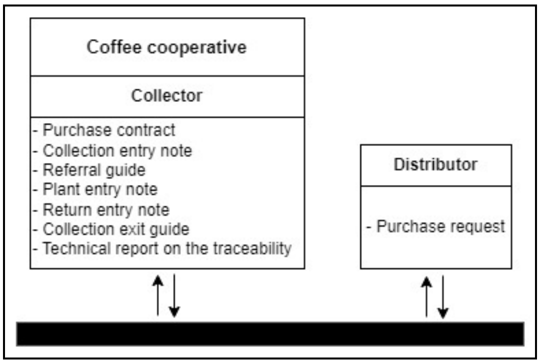

Fig. 7. Compilation of documents and preparation of technical traceability report

B. Experiment 2: With the proposal

The *time of process* and the *number of errors* are calculated by the 2 defined scenarios. Scenario 1 includes the generation of the following documents by the different actors using the proposed framework (see Fig. 8): purchase request, purchase contract, reception guide, entry note to the storage warehouse, order of processes and marking of bags, referral guide, plant entry note, plant exit note, plant referral guide, return entry note and return referral guide.

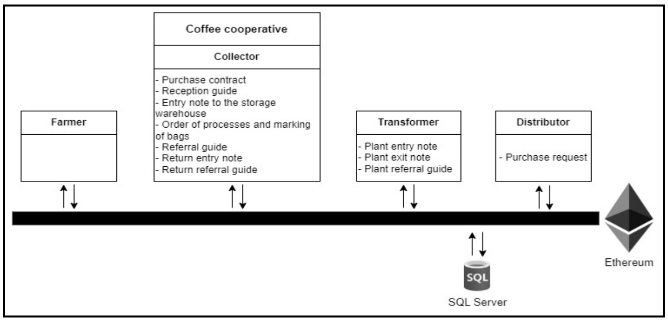

Fig. 8. Generation of documents in Experiment 2

Scenario 2 includes the generation of traceability from the documents stored in the system and its availability to all actors in the production chain through a QR code (see Fig. 9).

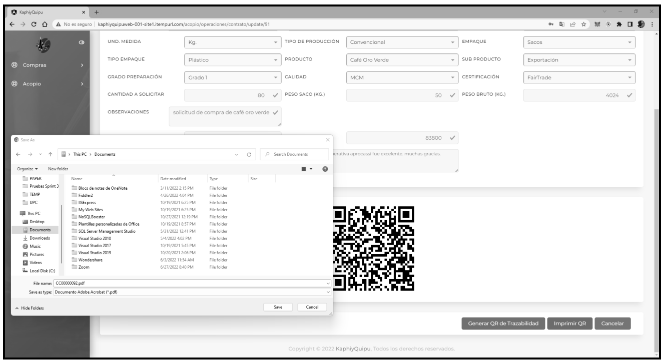

Fig. 9. Generation of traceability with the proposed framework

1) Validation by expert judgment

A validation is done by expert judgment to use the framework and provide their appreciation in this regard. 4 experts in traceability and quality of coffee (environmental and forestry engineers) are contacted.

Validation consists of 3 steps: (1) Explanation of the system, (2) Use of the system by experts, and (3) Survey response by experts [31]. The experiment is executed individually with a duration of approximately 1 hour.

The system is explained using the Zoom tool in a time of 30 minutes. The use of the system is performed following this steps: (a) Login to the system and navigate through all the functionalities and, (b) Generate coffee traceability. Finally, an online survey [31] composed of 7 closed questions and 1 open question is prepared (see TABLE VII). Likert scale is applied for closed questions (1 = totally disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = totally agree) [32]. The open question is formulated with the purpose of looking for opportunities to improve.

TABLE VII. SURVEY QUESTIONS

Category	ID	Question	Type
Traceability parameters	Q1	Is the data collected in the different documents of the system adequate?	Closed
	Q2	Are the registered quality parameters of the coffee adequate?	Closed
Performance	Q3	Is the time to generate coffee traceability short?	Closed
Usability	Q4	Is it practical to navigate through the system?	Closed
	Q5	Is the process to record harvest data simple?	Closed
	Q6	Do the functionalities of the system allow traceability of the coffee?	Closed
	Q7	Is the traceability obtained complete?	Closed
	Q8	What aspects should be restored or included in the system to better fulfill its objective?	Open

V. RESULTS Y DISCUSSION

The results of experiment 1 can be seen in TABLE VIII. The documents are presented which are going to be measured using the indicators of *time of process* and *number of errors* in the 2 defined scenarios (Esc. 1 and Esc. 2). As we can observe, the *time of process* was higher in scenario 1 (305 minutes) compared to scenario 2 (145 minutes) and it is probably because the first included preparation tasks, while the second included data collection and preparation tasks of a technical traceability report. On the other hand, the *number of errors* is higher in scenario 1 because there is a greater number of elaboration tasks here.

TABLE VIII. MEASUREMENT RESULTS OF EXPERIMENT 1

Indicator	Time of process (min.)		Number of errors	
Documentation	**Sce. 1**	**Sce. 2**	**Sce. 1**	**Sce.2**
Purchase request	30	15	3	1
Purchase contract	15	5	1	0
Reception guide	45	N.A.	0	N.A.
Entry note to the storage warehouse	25	10	1	0
Order of processes and marking of bags	35	N.A.	1	N.A.
Referral guide	25	15	0	1
Plant entry note	35	10	2	1
Plant exit note	20	N.A.	1	N.A.
Plant referral guide	20	N.A.	0	N.A.
Return entry note	25	15	0	0
Return referral guide	30	15	0	0
Technical report on the traceability	N.A.	60	N.A.	1
Total	305	145	9	4

Likewise, the results of experiment 2 are shown in TABLE IX. The documents which are going to be measured are presented with the indicators of *time of process* and *number of errors* in the 2 defined scenarios (Esc. 1 and Esc. 2).

TABLE IX. MEASUREMENT RESULTS OF EXPERIMENT 2

Indicator	Time of process (seg.)		Number of errors	
Documentation	**Sce. 1**	**Sce. 2**	**Sce. 1**	**Sce.2**
Purchase request	5	1	1	0
Purchase contract	10	1	0	0
Reception guide	5	1	0	0
Entry note to the storage warehouse	5	1	0	0
Order of processes and marking of bags	5	1	0	0
Referral guide	5	1	0	0
Plant entry note	5	1	0	0
Plant exit note	5	1	0	0
Plant referral guide	5	1	0	0
Return entry note	5	1	0	0
Return referral guide	5	1	0	0
Total	60	11	1	0

In the results we can see that the *time of process* was higher in scenario 1 (60 seconds = 1 minute) compared to scenario 2 (11 seconds = 0.18 minutes) because the first included registration tasks and the second, tasks read only. On the other hand, the *number of errors* is only evident in scenario 1, probably due to the interaction with the person to perform the tasks. The *number of errors* is low for both scenarios because the proposed framework is certified at the quality level.

The results of experiment 1 and 2 are consolidated and shown in TABLE X. It is observed that, in scenario 1, generation of traceability flow documents, a 99.67% reduction in *time of process* is achieved (from 305 minutes to 1 minute) and a decrease in the *number of errors* of 88.88% (from 9 errors to 1 error) in experiment 2 compared to experiment 1.

On the other hand, in scenario 2, generation of traceability, we can observe a reduction in the *time of process* of 99.87% (from 145 minutes to 0.18 minutes) and a decrease in the *number of errors* of 100% (from 4 errors to 0 errors) in experiment 2 compared to experiment 1.

TABLE X. COMPARISON OF RESULTS BETWEEN EXPERIMENTS 1 AND 2

Scenario	Indicator	Experiment 1	Experiment 2
Generation of traceability flow documents	Time of process	305 min.	1 min.
	Number of errors	9	1
Generation of traceability	Time of process	145 min.	0.18 min.
	Number of errors	4	0

Fig. 10 shows the results obtained in the survey (Q1, Q2, Q3, Q4, Q5, Q6 and Q7) performed by 4 experts (E1, E2, E3 and E4). It is shown that, on average, the categories "performance", "traceability parameters" and "usability" had a value of 4.8, 4.6 and 4.4, respectively.

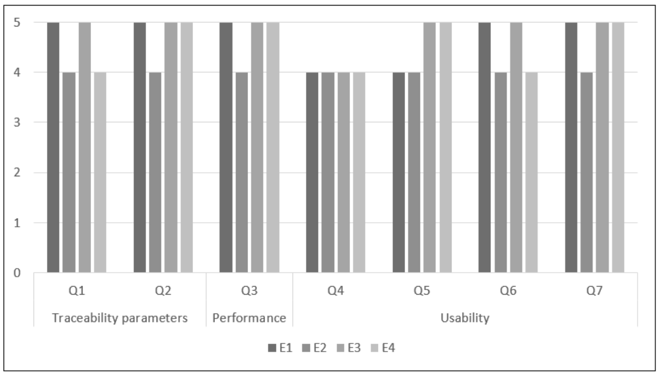

Fig. 10. Summary of questionnaire responses to experts

Regarding the answers to question Q8, an expert suggested to improve the graphical interface of some windows. In addition, two experts suggested specific training per actor. Finally, an expert recommended looking for strategies so that all the actors involved are willing to use the system and see what barriers may arise for its use.

VI. CONCLUSIONS AND FUTURE WORK

In this study, a framework was proposed to improve the traceability of the coffee production chain by applying blockchain. This proposal was developed in 3 stages: (1) Blockchain architecture design, (2) Smart contracts design and (3) Web application design. The framework was validated in a coffee cooperative applying 2 experiments and an expert judgment.

The results showed that in experiment 2 (with the proposal), in both defined scenarios, the *time of process* and the *number of errors* were reduced. In scenario 1, a reduction in *time of process* of 99.67% and a decrease in the *number of errors* of 88.88% were achieved in experiment 2 compared to experiment 1. Likewise, in scenario 2, a reduction in the *time of process* of 99.87% and a decrease in the *number of errors* of 100% were achieved in experiment 2 compared to experiment 1. Finally, the results of the survey showed that, using the proposed framework, the categories "performance", "traceability parameters" and "usability" had an average value of 4.8, 4.6 and 4.4, respectively.

As future work, it is recommended to include the use of IoT (Internet of Things) devices for the automation of harvest data registration in the field and; the use of machine learning to predict the harvest and sale of coffee and the appearance of pests.

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