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Blockchain in Agri-Food Traceability Systems: a Model Proposal for a Typical Italian Food Product

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***Abstract*—Controlling the product quality in food industry throughout its supply chain is today one of the most challenges in the world especially when it comes to typical food products. In recent years, various companies are trying to experiment with joint use of Blockchain and Radio Frequency Identification technologies to solve problems in scenarios where numerous untrusted actors get involved. Blockchain is gaining increasing popularity as a technology to enable product traceability in a certified and immutable way from the farm to the fork of food products and to avoid fraud and counterfeiting by guaranteeing trusted, transparent and shared information in the agri-food supply-chain. By combining smart contracts, Interplanetary File System and Internet of Things technologies, this paper tries to address these issues and presents a proposal of an implementation model for the supply chain management of a typical Italian food product - *Carasau bread*. The main goal of the model proposal is to guarantee and certify a transparent, secure and auditable traceability in such a way each actor of the supply chain can verify the quality of the product.**

I. Introduction

Blockchain technologies have become popular in these last years and several new applications are being explored. Strong expectations exist around their use and different companies are trying to adopt them in various sectors by harnessing in particular its transparency to solve problems in scenarios where numerous untrusted actors get involved. One of these sectors is represented by agri-food. Apaiah et al. [1] assert that the continuous change in the quality from the time the raw materials leave the grower to the time the product reaches the consumer is the main fact that differentiates food supply chains from other chains. Today more than ever, customers are demanding transparency especially with food, they want to feel secure and to know how a product was farmed or manufactured and which ingredients are involved in its production. The demand for transparency and traceability in agri-food supply chain and consequently controlling the product quality is becoming a relevant challenge to face in the world especially when it comes to typical food products. Typicality expresses the differentiation of agri-food products based on an inseparable link between the product and its territory. Nowadays, agri-food supply chain is less digitalized [2], food documentation on provenance and other attributes are typically stored on paper or private databases and can only be inspected by trusted third-party authorities [3]. Blockchain and Radio Frequency Identification (RFID) are technologies which have a great potentiality to solve together some problems such as to provide trusted, transparent and shared information in the supply-chain and improve the product traceability. In particular, blockchain is gaining increasing popularity as a technology to enable traceability in a certified and immutable way from the farm to the fork of food products and to avoid fraud and counterfeiting. It can create a completely different relationship between producers and consumers based on transparent information that allows to better describe the products by offering consumers greater visibility on the origin of raw materials and production processes. Blockchain technologies can communicate a different concept of quality that is not given only by the specifications or certifications. It can provide an added value linked to the identity of the product - an identity that starts from the territory, from the raw material, from how it is produced with methods based on ancient knowledge.

Blockchain technology appeared for the first time in 2008 when, with a pseudonymous, Satoshi Nakamoto published a peer to peer electronic cash system [4] based on a digital currency known as Bitcoin, which does not need any intermediaries like central authority to transfer money from one person to other person.

Blockchains allow for the decentralized aggregation of vast amounts of data generated from IoT devices and ensures that benefits are shared more equitably across supply chain exchange partners. Blockchain is a specific type of distributed database able to store data in secure, immutable and not alterable way and simultaneously to create transparency of the data history. Its key is the technological protocol that enables data to be exchange with third parties within a network without the need for intermediaries since participants interact anonymously with encrypted identities using peer-to-peer communication. Each transaction or event must be validated by a community of users through a consensus process and then recorded in the ledger and added to an immutable transaction chain and distributed to all network nodes.

Several studies and pilot projects about the possibility of applying such technologies in agri-food domain have been conducted (See Sections II and IV-B).

For enabling the traceability of the goods in the agri-food domain and preserving the quality of a typical food along the entire production chain - before, during and after production

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- we propose the application of a blockchain technology in traceability system of the *"Carasau bread"*, that is a traditional flat bread of ancient origin from Sardinia, insular Italy, made from the durum wheat flour, salt, yeast and water.

We chose this domain because it provides an interesting case in terms of analysis of all steps of the supply chain, from raw material production, processing, to consumption. But not only, Carasau bread is classified as PAT that stands for Traditional Agricultural Product and it is an official approval for traditional Italian regional food products similar to the Protected Geographical Status of the European Union. It is an Italian excellence, with a limited production, linked to a territory and its history. The requirement to be recognized as such is to be obtained with processing methods, preservation and seasoning methods consolidated over time, homogeneous for the entire territory concerned, according to traditional rules, for a period of not less than twenty-five years.

In light of these considerations, the following three research questions were formulated:

RQ1: How can Internet of Things be combined with blockchain technologies in order to address the potential issues in the agri-food industry with special reference to typical food product?

RQ2: How can Internet of Things be combined with blockchain technologies in order to implement a new decentralized traceability system in the whole agri-food supply chain?

RQ3: Which approach can be adopted for identifying the requirements able to implement an efficient decentralized system for the agri-food domain?

In this paper we tried to address some key issues and focused on three main research questions in order to improve knowledge on an important topic as traceability systems in the context of agri-food industry, especially bakery industries, in particular with regard to the typical and regional food product: the Carasau bread supply-chain.

We propose an IPFS/RFID/blockchain-based implementation model, that by combining the application of the Internet of Things (IoT) - in particular RFID sensors - and the files storage on the Interplanetary File System (IPFS) with the Blockchain technologies, can guarantee a transparent and auditable traceability of the goods from the farm to fork and provide at the same time data that demonstrate the quality of all intermediate products.

This work aims at further integrating the research on automatic traceability systems in the context of agri-food industry, especially bakery industries, in particular with regard to the typical and regional food product as in the scenario that we present here: the Carasau bread supply-chain. Note that this paper is part of a research industry project, in which the design, functioning and characterization of Wireless Sensor Networks (WSNs) to allow the real-time monitoring of the processing parameters of the Carasau bread manufacturing has been already dealt [5], [6].

The paper is organized as follows.

Section II gives an overview on pilot or proof of concept projects of Blockchain applications in the agri-food sector.

Section III provides the concepts of traceability and quality to which we refer in this paper.

Section IV gives a description about RFID tecnologies and their usage, discusses some key issues to be addressed in order to enable IoT with Blockchain and finally summarizes some recent studies in agri-food domain referring to blockchain systems combined with IoT.

Section V describes an IPFS/RFID/blockchain-based implementation model proposal.

Finally, Section VI concludes the paper.

II. Related works

In this paper we also investigated the potential applications of blockchain technologies in the agri-food sector by some large companies that have declared their intention to develop pilot or proof of concept projects even if they did not report detailed information about the technical implementation of such projects. According to [7] most existing blockchain systems for traceability management have been developed since 2015, but there are still few uses to the state of practice.

Some of the largest software companies offering cloud services, such as IBM, Accenture and Baidu, offer supply chain-oriented versions of blockchain ledger running on their cloud space. These systems are configurable, and the blockchain can be tailored and integrated into existing systems.

IBM Food Trust™ [8], for example, is a blockchain-based suite of three different modules - data entry designed to ensure food safety and regulatory compliance and enhancing brand reputations for safety and quality. For instance, the module called Trace allows users to trace the status of food products along the chain in a secure and transparent way. The solution connects network participants - growers, processors, wholesalers, distributors, manufacturers, retailers, and others - through a trusted, authorized, immutable and shared record of data. It enables to track each step of the food supply chain and to share data on an immutable ledger in order to ensure the quality of the product.

Many companies in the agri-food sector, such as Walmart, Auchan, Carrefour have demonstrated their interest in blockchain technology applications, mainly for tracing the products. In 2016 Parker [9] asserts that retail giant Walmart, IBM and Tsinghua University are collaborating to improve the way food is tracked, transported and sold across China, using blockchain technology. In 2017, the news on Blockchain Food Safety Alliance was released. The project aims to create a new model for food traceability, supply chain transparency and auditability using IBM Blockchain based on the open source Linux Foundation Hyperledger Project fabric.

In 2019, Carrefour [10] gradually integrated the blockchain technology into the following Carrefour Quality Lines: chicken from Auvergne, Cauralina tomato, farm-raised eggs from Loué, rocamadour AOC cheese, Gillot fresh milk, Norwegian salmon and Christmas chicken. By 2022, the objective is to apply this technology to all FQC food products.

Auchan Retail [11], one of the five largest world-scale food retailers with operations in 17 countries, is launching blockchain technology internationally to improve the traceability of the products along its supply chains. After successful tests in Vietnam, with Te-Food, using a public blockchain solution known as FoodChain, the innovative solution is now being used in France on the organic carrots supply chain and in Italy, Spain, Portugal and Senegal for other specific products.

The solution has been declared to have three interfaces: i) an inventory management tool that allows the local competent authorities to check the certificates issues by farms; ii) a Business to Business application through which the various operators in the logistics chain can provide product traceability data; iii) a Business to Consumers application that allows consumers to access information on the product's life cycle up to the point it reaches the store.

In recent years, Italy is playing a very important role in terms of experimentation in the agri-food sector of solutions able to provide a new level of protection and enhancement to Made in Italy companies, as evidenced by numerous pilot projects. Therefore, in addition to the large companies it seems useful to mention, just to name a few, some Italian small companies that claimed to have implemented and passed a proof of concept of a blockchain system in real-world case scenarios in the agri-food sector.

According to recent reports by Ernst & Young [12], Bofrost Italia - a leading global company in the door-to-door sale and distribution of frozen foods to consumers - has selected EY OpsChain traceability platform blockchain solution to help track its products in the supply chain starting with two products: fillets of Northern cod and artichoke heart wedges that represent two fundamental categories (fish and vegetables) for this company. Customers can use their smartphones to scan the QR code on the package seen on Bofrost Italia's web page, or enter it manually, to follow the product's history from the origin alongside the supply chain until the table.

EzLab Blockchain Solutions [13] is an Italian SME specialized in advanced software solutions in the Smart Agri-food sector. AgriOpenData is an integrated Blockchain system that supports farmers in the traceability and in the certification of agricultural products by using the Blockchain technology and Smart Contracts. This system has been applied to several real cases, as reported by [13], to protect the quality of Made in Italy and the transparency of the supply chain.

Wine Blockchain is a project born with the purpose to control the wine production chain from the origin of grapes to the transformation into the bottle for fighting adulteration and forgery of Italian wines via a QR code on the bottle. This project of EzLab uses blockchain technology for building trust and transparency between the producer and the final consumer.

Rodolfi Mansueto S.p.A. - one of the main Italian operators in the processing of tomatoes and their derived products - with Compagnia Mercantile d'Oltremare Srl are two pilot companies associated with the ANICAV - the Italian National Association of Fruit and Vegetable Canning - involved in an experimental project called "Tomato Blockchain", whose software implementation has been entrusted to EzLab. The aim of the project is to develop the production of quality tomatoes using the blockchain technology for guaranteeing their origin, their health characteristics and the social values of the operators involved.

III. Traceability and Quality: A Strict Relationship in the Food Supply Chain

In this section we define the concepts of traceability and quality to which we referred in this paper for increasing consistency within our study. Generally speaking, to define the quality of a product is complicated because it depends on various factors and can take on different meanings depending on the point of view of the actors in the supply chain. The concept of quality is generally associated with products, in reality though the quality relates also to processes and material flows. Indeed, according to [14] quality refers both to the properties of the food itself and also to the ways in which those properties have been achieved. The ability to trace the whole path that allows to reach the final product is essential to guarantee its quality for example by identifying any errors in time and stopping the process in case of non-compliance with requirements.

A list of categories to formalize the quality standards or the quality control systems applied to agri-food production was identified in [14]. We adopt the basic definition provided by International Standards Organization (ISO), precisely ISO 8402:1994 [15] that defines the term quality as *"the totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied needs revolving around customer"*. In simpler word a product is known as a quality product when it satisfies various criteria and complies with the requirements specified by the user.

Here are some issues to consider when evaluating the quality of a typical food such as the Carasau bread. The aforementioned user in the specific case of the supply chain process of Carasau Bread manufacturing is each stakeholder involved in the chain. The chain is multi-actor and involves numerous, different and distributed actors, such as farmers, wheat producer, milling industry, retailers, consumers and so on. The perception of quality of bread changes along the supply chain in relation to point of view of involved actors and so intrinsic and extrinsic quality attributes. To better understand, for example from the point of view of the wheat producer the concept of quality will be linked to the varietal purity and the degree of germination of the seeds. Ingredients and processing contribute to consumer perceptions of bread, the quality of bread includes intrinsic attributes as the shape and extrinsic attributes such as labelling and nutritional facts.

For the milling industry, the quality will be dictated by the percentage of ash, the hectolitre weight, the uniformity and the size of the grain.

Quality is related to also recognition of provenance, in other words preserving information about the region in which the wheat was grown, and identity preservation that is preserving the story of the wheat as information about the individual farm. Usually information about where it is from and who produces it is lost as the product moves along the supply chain downstream from the farmer [16]. For this reason wheat is hardly traceable. [17] concluded in their study that quality and safety may indeed boost consumer confidence and they are both linked to traceability. Especially in Italy, the results showed strong links between traceability as a tool for the food safety by providing means for recall and for food quality. Another basic question needs be answered - what is the traceability of a product. In the literature several definitions of traceability and of traceability system can be found [18], [19], [20], [21], [22]. By combining the best parts of the existing definitions, Olsen and Borit [18] provide a generalized definition that can potentially be applied to traceability of any product that is *"the ability to access any or all information relating to that which is under consideration, throughout its entire life cycle, by means of recorded identifications"*.

Considering the definition given by the International Organization for Standardization in ISO 22005:2007, that is a specific standard for traceability in the food and feed chain, the traceability is defined as *"the ability to follow the movement of a feed or food through specified stage(s) of production, processing and distribution"* [23], a traceability system, based on product labelling, must contain information, both quantitative and qualitative, about the final product and its origin.

In Europe, food legislation is particularly strict and the implementation of traceability systems are mandatory. Unfortunately these system don't ensure consumers against fraud. Typically agri-food supply chain is less digitalized and trivially paper documents can be counterfeit or private databases tampered. Innovative and alternative methods for traceability systems based on product identification are needed.

According to [18] food product traceability is the ability to guarantee that products moving along the food supply chain must satisfy specific requirements.

IV. Internet of Things and Blockchain

With regards to our initial research question - *RQ1. How can Internet of Things be combined with blockchain technologies in order to address the potential issues in the agri-food industry with special reference to typical food product?* - we investigated in literature recent studies that adopted blockchain with Internet of Things in agri-food domain. The Internet of Things, abbreviated as IoT, is a group of physical devices that are able to collect data and communicate with each other via the internet. Sensors, chips, actuators are embedded into physical items and each of them transmits data to the IoT.

A. Traceability tools in the Internet of Things Era

In this subsection we mention RFID hardware architecture as an enabling factor for the IoT.

RFID is one of the major technologies in the field of identification of products and for traceability specially in the agrifood sector, ensuring food safety and quality. RFID stands for Radio Frequency IDentification that is a technology used to trace and track objects whenever in the supply chain using a wireless communication, particularly through electromagnetic waves emitted by special antennas to capture information loaded in suitable electronic devices (called tags), equipped with a chip - for instance microchip placed on a pallet or on a product - and a receveir able to read the information on the chip.

In GS1 [24] standard applications, a particular category of passive tags is usually used, on which the EPC codes of the products are inserted, and a defined range of frequencies of electromagnetic waves, called UHF, is exploited. EPC is acronym of Electronic Product code, that is a GS1 standard method of marking object by RFID Technology. Briefly EPC uniquely and unambiguously identifies individual products, captures the information along the movement into the supply chain and makes them available thanks to RFID.

A more detailed description about RFID technology and its usage can be found in [25]. The integration of sensors - components with electrical characteristics that connect the outside world with the digital world - to different typologies of radiofrequency smart tags able to ensure traceability and food quality and safety. Different types of sensors have been developed and we mention among others some food quality monitoring systems interfaced with RFID tags useful in our case study: i) Freshness indicators able to monitor the food quality in a packaging; ii) Biosensors monitor food quality for instance detecting the presence of degradation molecules; iii) Time Temperature Indicator used for measuring and recording temperature; iv) Humidity sensors for determining the amount of water vapor present in an atmosphere.

The combination of Internet of Things with blockchain technologies has become strategic to ensure traceability along the agri-food chain. Rejeb et al. [26] showed in their paper that the combination of Blockchain technology with IoT enhances supply chain integrity and Blockchain technology positively impacts the scalability, security, immutability and auditing, information flows, traceability, interoperability and quality of IoT solutions.

According to Aung and Chang [27] RFID and sensor based systems will be widely used both for tracking the goods in the supply chain and also for monitoring the quality of the products itself.

B. IoT with Blockchain in agri-food domain: a summaritazion of recent studies

In literature there are many studies focusing on enabling the usability of blockchain technologies and RFID in different sectors and among these also in agrifood supply chain. Therefore, for the purpose of our work, we cite the references in literature from the food industry.

Tian [28] proposes a decentralized traceability system for real-time food monitoring and tracing based on HACCP (Hazard Analysis and Critical Control Points), Internet of things and blockchain technology. Compared to the centralized systems, this system aims to provide an information platform for all the supply chain members with openness, transparency, neutrality, reliability and security.

F.Tian [29] establishes an agri-food supply chain traceability system based on RFID and blockchain technology with the aim of enhancing food safety and quality. The system covers the whole process of data gathering and management, for every transaction in the supply chain from farm to fork of two specific types of products such as fresh fruits and vegetables and meat. Moreover, the advantages and disadvantages of using RFID and blockchain technology in a agri-food supply chain traceability system are analyzed.

Zhang et al. [30] devoloped an intelligent traceability platform based on HACCP system to improve the quality control and safety transparency in waterless fish long-distance transportation. The presented system integrates QR Code with existing EPC (Electronic Product Code) traceability technology. The results of the experiments done on sturgeon delivery shown that this system can reduce the potential risks, implement quality control and improve the live fish transport volume at low-costly.

Huang et al. [31] propose a safe food traceable scheme based on Ethernet blockchain and smart contract to effectively execute transactions and encoding food by EPC technology. In addition, they propose a data management system structure combining on-chain and off-chain.

Demestichas et al. [32] provide an overview of the application of blockchain technologies for enabling traceability in the agri-food supply chain and then they discuss relevant existing commercial applications by highlighting challenges and future prospects.

The social technical constraints in order to realize a global food traceability system have been investigated in [33] and their findings have shown that boundary conditions should be met before blockchain can be used. Moreover blockchain technology requires standardization and data governance to improve the traceability information exchange in the dairy food supply chain.

Baralla et al. [34] designed and developed a blockchain oriented platform to guarantee the origin and provenance of food products in a Smart Tourism Region context. They proposed the smart contracts to guarantee transparency, efficiency and trustworthiness. In particular, the system interfaces with IoT network devices providing detailed information about data monitoring such as storage temperature, environment humidity, and other data suitable to manage cold chain.

This paper [35] proposed a generic agri-food supply chain traceability system based on Hyperledger Sawtooth Blockchain technology to reconstruct the product' history in order to verify product health and quality. They suggested RFID, IoT devices and sensors as sources of digital data and placed between the physical flow and the blockchain network.

In their review Galvez et al. [7] examined the potential of the blockchain technology for assuring traceability and authenticity in the food supply chain with regard to quality of data acquisition and management for their chemical analysis.

C. Enabling IoT with Blockchain

With regards to our second research question:
RQ2. How can Internet of Things be combined with blockchain technologies in order to implement a new decentralized traceability system in the whole agri-food supply chain?

Enabling the Internet of Things with Blockchain technology requires a great effort from all participating stakeholders. According to [36] some issues must be addressed:

- How to integrate the Blockchain platform combined with IoT devices in agri food supply chain;
- How to ensure the communication between devices and backs up the decentralized Blockchain platform;
- Which platform protocol to choose (e.g. Ethereum, EOS, NEO etc.) also based on private requirements that each organization should investigate;
- How to handle the massive amounts of data collected by a large network of sensors and potentially lower transaction processing speeds or latencies. This is a scalability issue.
- How to guarantee the reliability of IoT devices so that the measures provided are correct and cannot be altered by external interventions so that data recording and transactions are safe.

There are many potential uses of blockchain in food supply chain management on the basis of the requirements to be managed - technical, managerial and environmental [27]. The present study aims to focus on a specific use cases: traceability and transparency from technical perspective.

According to [27], the following key issues related to the traceability of our food supply chain from a technical point of view need to be managed:

- *Internet and Web technologies* - online tracking, monitoring, information exchange and retrieval over web etc.
- *Location based technologies* - Global Positioning System (GPS), Real-time locating systems (RTLS) etc.
- *Sensing technologies* - Wireless Sensor Network (WSN), Electronic Nose etc.
- *Identification technologies* - bar code, RFID etc.
- *Information and Communication technologies* - Information systems, computers and mobile networks.

Reyna et al. [37] offered an interesting evaluation of the feasibility of the interaction between blockchain technology and the IoT. They identified the strategic key points under which blockchain technology can help to improve IoT applications.

In the light of these studies, we assume that Blockchain technologies are able to keep records and traces but need the support of other digital tracking technologies. Their integration is useful in improving product quality in agri-food supply chain facing trust problems such as tampering, corruption and fraud. For instance Blockchain technology is with tamper-evident RFID tags to aid in the verification of the provenance of a product. Adapting innovative technologies such as blockchain and RFID technologies in our supply chain system is the key to address our research problems in the agrifood area. Moreover, combining blockchain with IoT is able to solve the issues of the centralized IoT architecture and exploit the benefits of both technologies.

V. CARASAU BREAD SUPPLY CHAIN: A MODEL PROPOSAL

Our selected case study represents a regional wheat to bread chain. In Italy about 90 per cent of bread is produced in artisan bakeries, and the 10 per cent remainder is industrial. There are more than 300 varieties of local breads having particular and unique characteristics due to wheat cultivar, flour class and raising method, baking, shape, size and so on. Carasau is a traditional flat bread of ancient origin from Sardinia obtained from the skilful processing of durum wheat semolina according to archaic recipe, which allows it to be preserved for a long time. This is one of the characteristics that allows this type of bread to be sold all over the world also through e-commerce channels.

To answer the last research question RQ3 - one of the most important parts of your research in order to implement a general-purpose architecture in a real scenario for a food traceability system - we combined the four requirements provided in [18] and the methodology presented in [38]. Consequently, we defined the following requirements (R) which correspond to a related major question (Q) needed to be answered:

1) R1: Ingredients and raw materials must be grouped into units with similar properties. (For a better comprehension, according to Aung and Chang [27] there are three types of traceable units: batch, trade unit and logistic unit. A batch is a quantity going through the same processes. A trade unit is a unit which is sent from one company to the next company in a supply chain, for example a box or a bottle. The logistic unit is a type of trade unit such as pallet, container and so on.) Q1: Which data are useful to be collected for traceability?
2) R2: Unique and never reused identifiers must be assigned to these units; Q2: Who is the owner of the information within every stage of the food supply chain?
3) R3: Product and process properties must be recorded and either directly or indirectly (for instance through a time stamp) linked to these identifiers; Q3: Which tools should be used for data collection?
4) R4: A mechanism must exist to get access to these properties; Q4: How should be managed data coming for instance from sensors network in order to make them accessible for all the supply chain actors?

As mentioned there are various ways to view traceability, though in accordance with Moe [39] it can be generally divided into two types: chain traceability called also external traceability and internal traceability. Internal traceability means to monitor internally in one of the steps along the supply chain the movement of parts or products within a limited area.

Chain traceability tracks a product batch through the whole production chain from procurement of raw materials to machining, distribution, and sales and follows its history forward, from the source to the consumer and backward, from the consumer to the source.

In this paper we apply the concept of chain traceability that in turn can manage information in two main ways [39]: i) information is stored locally in each of the steps in the chain sending only product identification information along with the product. ii) information follows the product all the way through the chain. We adopt the latter way since we desire to bring information from early steps in the chain, then from raw material, to the final consumer for better quality and process control.

We considered six main segments in the Carasau bread supply according to [16]: i) seed sector; ii) production and commercialization of grains; iii) milling; iv) baking; v) distribution; vi) consumption. These main sectors are described below:

1) The **seed sector** plays a crucial role in enhancing quality of raw material for food processing and promote territoriality. The certified seed is one of the keys for supply chain traceability.
2) **Wheat production** involves farmers and agricultural associations, cooperatives and producer associations. Traders operating in grain commercialization act as intermediaries between the farmers and the agricultural industry. Storage facilities represent a weak link in the supply chain in Italy. Italian production of cereals is difficult to organize into homogeneous lots, consistent in terms of qualitative characteristics and able to satisfy the needs of the processing industry so has to turn to foreign product.
3) The **milling industry** is a strategic sector in the Italian national chain of soft and durum wheat. In our scenario the processing stages of milling and baking must take place within the Sardinia region, while commercialization can be regional, national and eventually global.
4) The **bakery sector** involves a network of small artisan firms located all over Sardinia and it is oriented towards direct sale to the final consumer as well as to supermarkets. It includes bakeries located all over Sardinia. In our scenario the whole production process of Carasau bread has been standardized, from wheat breeds to packaging. This segment concerns the transformation of the primary product (wheat) into the secondary products (bread). It includes also a packaging phase where the product is uniquely identified through a production batch code containing information such as the production day and the list of raw materials used.
5) In this segment the **consumer** is the end user of the chain that buys the product and demands traceable information on the product quality, origin and so on.

A. A model proposal: an overview

In the context described so far, we propose an implementation model that contributes to the protection of quality productions by favoring the management of a large amount of data and by relating all the actors in the supply chain, from field to table.

Specifically, our model aims to represent a possible supply chain management system based on Ethereum blockchain, Radio-frequency identification (RFID), Near Field Communication (NFC), and Interplanetary File System (IPFS) technolgy.

Having conceived the Carasau supply chain as a chain of components/nodes from which batches/products enter and exit, the model proposal consists of:

- **sensors network** (IoT devices), to monitor for example the temperatures,
- opical cameras to monitor for example the storage points,
- **smart contracts** to store essential data of the batches and nodes,
- **an external database**, the IPFS, to store large amount of data, due to the significant costs of the on-chain storage.

This model is designed in such a way that:

- every IoT device connected to a Raspberry Pi board transmits data at predefined intervals, and interfaces with blockchain and IPFS;
- authorities can perform inspection online on every node and batch along the chain, by checking the uploaded documents on the IPFS system and interacting with the blockchain to store essential data on batch/node conditions and quality after their performed inspections;
- the hashes of the uploaded documents on the IPFS are stored on blockchain and are closely related to a precise batch/product, or to a precise component/node of the supply chain, such as the farm, the means of transportation used by the distributor, or the bakery;
- users and actors along the supply chain can trace every batch/product along the supply chain through NFC tags placed on every batch/product;
- system administrator, such as some regional bodies, provides to each actors the correct access permission.

Our model will be developed applying the ABCDE method [40], that is a software development process consisting of eight steps. The first three steps aim to collect the requirements of the system to be realized without assuming the use of a blockchain. The fourth step involves to divide the system into two subsystems. The fifth step involves to design of the blockchain system and the sixth that of the external system, making appropriate security assessments for both systems and following the main GAS optimization patterns during the design of the blockchain system. The last two steps involve the test of the two subsystems and their integration and release.

As above described the model provides for the components/nodes along the supply chain are equipped with adequate sensors/IoT devices. Specifically, every IoT device is connected to a Raspberry Pi board in such a way that it can interface with blockchain, transmitting data on the state/condition of the batches and nodes along the chain, listening events, and executing transactions that can also trigger events and lead to a change in the state/condition of the batches and nodes. This is because the model provides that essential data, that guarantees a transparent and auditable traceability of the batches and of the good working practices of each node, is stored in the Ethereum Blockchain implementing adequate smart contracts. Finally the model provides for a friendly Graphical User Interface allows actors along the chain to trace a batch, consumers to trace final products, and authority to perform online inspections on the products' quality and on the good working practices of each actors along the Carasau supply chain.

Hence the model provides for the implementation of two subsystems. One is the blockchain system composed of smart contracts (SC). It is the on-chain system. The other is the external system, the so called off-chain system. The first system will be developed in Solidity, that is an object-oriented, high-level language for implementing smart contracts The second one, that external, will be implemented in Javascript using the Node.js and Web3.js packages. Node.js allows to execute scripts to interact with our smart contracts, whereas Web3.js package provides a JavaScript API to interact with the Ethereum blockchain. These packages have to be installed inside each Raspberry Pi. To handle the events the websockets (WSS) connections in place of HTTP connection, by defining a websocket INFURA URL, will be used.

Note that every actor/device along the supply chain has to be authorized and identified by his/its Ethereum address in order to access the system and execute Ethereum transactions. To generate a transaction, the off-chain subsystem has to encode the transaction in order to obtain its Application Binary Interface (ABI). Then it has to create and sign the transaction with the private key of the actor/device generating the transaction. To implement this process the *ethereumjs-tx* package will be used. All packages above quoted are provided by *npm* that is the default package manager for the JavaScript Node.js runtime environment.

Figure 1 shows a schematic view of a possible use case of our implementation model taking into account for greater clarity only one node within the Carasau supply chain, specifically the leavening room within the bakery.

Smart devices constitute the sensing layer, hence two sensors S1 and S2, for the monitoring of environmental parameters (for example temperature and relative humidity in air, and concentrations of CO and CO_2, and two sensors (C1 and C2) for the optical monitoring for example of the hygienic-sanitary conditions of the leavening room within the bakery. These smart devices provide data to trace the quality of the Carasau production and the conditions in which this bread is produced. The system off-chain comprises a GUI, to trace batches/products and to make inspection on nodes/components, and also a software system for the automatic interaction with the IPFS. This is because data provided from sensors are stored into the IPFS and the hash, returned from IPFS, are stored in the blockchain.

VI. Conclusion and Future Works

This paper is part of a project under development and must be seen as a preliminary work for the entire project. According

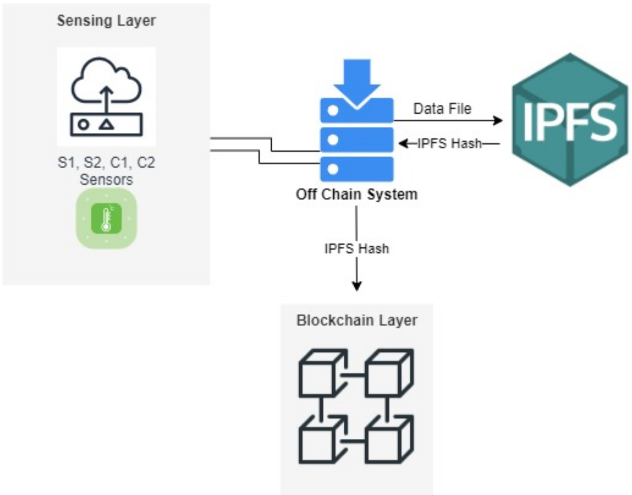

Fig. 1. Schematic view of a possible use case of the implementation model proposal taking into account the leavening room within the bakery.

to Behnke and Janssen [33] many blockchain projects remain at the piloting level because based on the results of their study they claimed that supply chain systems have first to be modified and organizational measures need to be taken to fulfill the boundary conditions, before blockchain can be used successfully. This paper aimed to contribute in the growing work on blockchain-based supply chains in agri-food domain and provide a possible solution.

Moreover, the purpose of this article was to examine the state of research on automatic traceability systems and further integrate it in the context of agri-food industry, especially bakery industries, in particular with regard to the typical and regional food product as in the scenario that we present here: the Carasau bread supply-chain. In this paper we tried to address some key issues and focused on three main research questions in order to improve knowledge on an important topic as traceability systems in the context of agri-food industry, especially bakery industries, in particular with regard to the typical and regional food product: the Carasau bread supply-chain.

In this preliminary paper we explored how Internet of Things can be combined with blockchain technologies in order to address the potential issues in the agri-food industry with special reference to typical food product and how to enable it. We concluded with the presentation of an implementation model proposal that combining the Internet of Things (IoT) technology - in particular RFID sensors and Near Field Communication (NFC) tags - with the Blockchain technology and the IPFS technology, can guarantee a transparent and auditable traceability of the goods from the farm to fork, providing at the same time data that demonstrate the quality of all intermediate products.

Finally, the presented system proposal will be object of our future work that will address the feasibility of the system, related technical issues, such as scalability and interoperability, and will try to solve the key challenges arising from current technologies related to the centralization of information.

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