Improving the supply chain management via Blockchain: an olive oil case study

Mariam Lahami[1,*], Faten Chaabane[2]

[1]ReDCAD Laboratory, ENIS, University of Sfax, Tunisia
[2]DESLAB, Data Engineering and Semantics Research Unit, Faculty of Sciences of Sfax, University of Sfax, Sfax, Tunisia

Abstract

One of consumers' primary concerns is verifying the traceability of sensitive foods, such as olive oil. Henceforth, recently, ensuring that olive oil supply chain is reliable and safe has become highly required. The current state of this supply chain involves a variety of stakeholders with different interests, often reticent to share traceability information. In this paper, we present BOOSCh, a fully decentralized olive oil traceability solution built on Ethereum blockchain. Compared to the existing approaches, the proposed work uses both the secure InterPlanetary File System (IPFS) for off-chain data storage, and smart contracts to manage interactions among stakeholders, insuring transparency and efficiency Through this combination, BOOSCh eliminates intermediaries, ensuring an immutable and trusted transaction history. We provide implementation details of the approach to show its effectiveness, offering a template for improving supply chain processes in other industries.

Keywords

Blockchain, smart contract, supply chain, traceability, olive oil, DApp

1. Introduction

The future of agriculture depends critically on the capacity to trace food. A food traceability system is required to retrieve any or all of the information relating to the product under examination, throughout its life cycle. Any traceable food or product in the supply chain is referred to as a Traceable Resource Unit (TRU), which is the object under investigation. The two goals of traceability are to track the transaction history and the TRU's current location.

Consequently, the food traceability system should guarantee food safety and quality control, permit authentication, prevent fraud, and be under the authority's control. It should also increase customer safety and confidence. One of the most important agricultural activities that requires an efficient track-and-trace system is olive oil production because of its potential health benefits, its delicious taste, and its nutritional and culinary advantages over other edible oils. Thus, it can be a target for fraud and adulteration during its transformation process due to its high prices and low production volume.

Many Mediterranean countries, Tunisia foremost among them, rely heavily on such industries to contribute to their socio-economic development. In fact, growing olives in Tunisia is one

TACC 2023: Tunisian-Algerian Joint Conference on Applied Computing, November 6 - 8, Sousse, Tunisia
*Corresponding author.
mariem.lahami@enis.tn (M. Lahami); faten.chaabane@isimg.tn (F. Chaabane)
0000-0002-2231-6917 (M. Lahami); 0000-0001-8136-3230 (F. Chaabane)

of the main activities in agriculture, and it is considered a strategic sector. Indeed, Tunisia is considered the most olive-growing nation in the southern Mediterranean, which is also the third-largest exporter of olive oil in the world (after Spain and Italy) and the fourth-largest producer of olive oil globally (172,000 t/year) [1]. As a result, this industry greatly helps the country to reach its objectives for economic development, food security, job creation, higher export profits, and the protection and improvement of natural resources. Although Tunisia has a long history of exporting olive oil, its growth strategy has always been centered only on increasing productivity, with the quantitative target of "produce more to export more" serving as the primary objective.

Traditional systems to handle the olive oil supply chain are complex and difficult to manage due to the involvement of several stakeholders [2]. They have to follow the production process of quality olive oil from the farmer through the oil factory to the final consumer while recording all these transactions in centralized databases. Consequently, tampering olive oil information is relatively easy and difficult to detect. Moreover, the use of various centralized databases may affect the scalability and interoperability of the proposed solutions.

In order to make olive oil supply chain secure, traceable and efficient, various recent efforts in the literature make use of the blockchain technology due to its numerous applications, particularly in supply chains and logistics, such as [3, 4, 5, 6]. Nevertheless, these solutions are not mature enough to be applied in the Tunisian market and suffer from missing some functional requirements, especially the inspection and certification of olive oil.

To overcome such limitations and to improve olive oil traceability, we present in this paper BOOSCh, the Blockchain-based Olive Oil Supply Chain, using the Ethereum platform. The local blockchain Ganache, Truffle IDE, web3js, and JSON-RPC features of the Ethereum blockchain are employed in this study. Smart contracts are developed using the Solidity programming language, which ensures the security of data provenance and the immutability of all stakeholder interactions. In addition, an off-chain InterPlanetary File System (IPFS) storage is adopted to store confidential data. As the only information maintained on-chain is the IPFS hash, this prevents sensitive information from ever being disclosed to anyone browsing the blockchain.

The remainder of this paper is organized as follows. Section 2 discusses a critical review of existing efforts with respect to the traceability of food supply chain, particularly to the olive oil case study. This is followed by a description of the olive oil supply chain in Section 3 and key concepts about Blockchain and its benefits in Section 4. Section 5 highlights the proposed Blockchain-based Olive Oil Supply Chain, followed by its implementation details in section 6. Section 7 concludes the paper, summarizing contributions and highlighting possible improvements for future work.

2. Related Work

To ensure the ultimate consumer's health and safety and to avoid fraudulent behaviour, several research works on integrating blockchain technology to ensure food traceability have been proposed in literature [7, 8, 9]. Regarding Olive oil Supply chain, we outline current initiatives aimed at resolving the issue of olive oil traceability and highlighting suggested anti-counterfeiting methods. We have included in this study both blockchain and non-blockchain-based solutions and categorized them accordingly.

2.1. Non-blockchain-based solutions for olive oil traceability

Authors in [2] proposed a platform based on Web and mobile technologies. All the stakeholders involved in the olive-oil supply chain can access to a Relational Database Management System (RDBMS) platform, built using MySQL Workbench. They may have different access rights (i.e., olive growers, transporters, oil mill managers, control authorities, analysis laboratory and final consumers). The proposed track-and-trace system used Django[1] to create the Web application and Flutter[2] for the mobile one. The latter is used by the final customer to scan the QR Code put on the product label. This QR code summarized all relevant data related to olive grower, oil mill manager, transporter and analysis laboratory. Nevertheless, this platform struggles essentially from the centralization issue caused by the use of a relational database which impacts its scalability and its performance.

The study in [10] suggested using smartphones equipped with NFC technology at every stage in the olive oil supply chain to deliver information to the final customer. The low cost and ease of the suggested method enabled its use in micro and small farms. The developed applications and the database architecture have been adjusted to the extra virgin olive oil process. However, this solution suffers from scalability issues since it is dedicated to micro and small farms and cannot be used for big ones. Similarly to [2], the use of centralized database makes it less secure and data related to olive oil, such chemical and organoleptic characteristics, can be easily tampered.

2.2. Blockchain-based solutions for olive oil traceability

Blockchain technology has proved its effectiveness in the development of supply chain management systems. Several research works are currently available in this regard.

Among them, we cited the study in [11] that introduced a blockchain-based application called BRUSCHETTA for the traceability and the certification of extra virgin olive oil. It supported track-and-trace of the olive oil from the plantation to the market by including several processes : the farming, harvesting, production, packaging, conservation and transportation. This solution exploited Internet of Things (IoT) technology to link sensors for extra virgin olive oil quality monitoring and enabled their operation on the blockchain. BRUSCHETTA uses Hyperledger Fabric as a private blockchain technology. This choice improves the scalability of the proposed solution but it may suffer from security and centralization issues.

The work in [6] discussed the importance of combining also blockchain with Internet of Things (IoT) to improve the visibility and avoid fraud in the olive oil supply chain. Authors proposed a new configuration for the olive oil supply chain while giving theoretical details about supported partners, collected and shared data however no implementation was done to prove the feasibility of the proposed system.

[5] suggested an embedded IoT-based agricultural system for keeping track of an olive field. Only two actors (i.e., farmers and vendors) were considered in this study and were connected

[1] https://www.djangoproject.com/
[2] https://docs.flutter.dev/

via a wireless sensor network. Collected data from sensors such as temperature, humidity and luminosity were saved on a real time database. To track-and-trace the different transactions, the blockchain technology is used with the aim of securing data which are encrypted using the Keccak 256 algorithm and cannot be accessed only by using the public key of the sender and the private key of the receiver. The final prototype was based on Ethereum Blockchain and was embedded on a Raspberry Pi 4 platform. Similar contributions were made by authors in [4, 3]. Three actors are involved in this blockchain-based system: the farmer, the producer (who handles production, processing, and packing, quality control, shipping, and logistics), and the consumer. Each component of this proposal was a Blockchain node, running on a Raspberry PI 3. Each transaction was recorded by the developed smart contract. The main problem within this solution is that all data are stored on-chain which leads transactions to be time consuming and more costly.

Another interesting work in [12] provided a general solution that facilitates the implementation of supply chain management systems and it illustrated its feasibility by the use of olive oil supply chain as case study. The idea here was to use Domain-Specific Graphical Language to represent supply chains. A simple graphical interface for making such representations, and a set of tools for translating the obtained graphical models into solidity smart contracts were offered by the proposed *-Chain Platform. However, the major issue with this platform is that its use is almost difficult for inexperienced administrators and the generated solidity code lacks validation.

3. Theoretical aspects about the olive oil supply chain

Traceability systems are used today to ensure the quality and safety of many different types of food items, including milk, fruit, vegetables, and meat. In this study, we concentrate on the analysis of extra-virgin olive oil traceability systems. According to [13], Extra-virgin olive oil (EVOO), virgin olive oil, regular virgin olive oil, and lampante virgin olive oil are the four categories of virgin olive oil. Due to its exceptional health benefits and organoleptic qualities, extra-virgin olive oil is regarded as the oil of the highest quality and price. Therefore, consumers are increasingly demanding authentic and high-quality olive oil and full transparency of its supply chain process.

The olive oil supply chain includes several stakeholders and several activities are carried out by each one of them as specified below :

- Farmer: He is in charge of farm management. He provides data about the ownership of the land plot, planting olive trees, cultivating and harvesting olives. The main factors that are collected by the farmer are the weather conditions (i.e., humidity, temperature, air pollution, etc.), the chemical composition of the land, and the harvesting method (i.e., by hand or by machines).
- Manufacturer: He is responsible for the transformation process of olives into olive oil. Moreover, he is charged with the packaging process and labelling details of every batch of product, etc.
- Inspector: Called also a certification entity, he takes samples of extra virgin olive oil to test organoleptic and chemical properties (i.e., acidity, fatty acid and sterol composition).

Then, he generates a digital certificate proving that the olive oil under inspection is an Extra Virgin Olive Oil.

- Distributor: also called a logistic supplier, he is charged with the transportation method used, and real-time data recorded about humidity, temperature, and other environmental conditions that may affect olive oil quality during the transportation period.
- Retailer: Data about the current stock of olive oil bottles, storage details, expiry date, and period at the market up to the consumer's purchase is provided by the retailers.
- End Consumer: he scans the QR code printed on the olive oil bottle to get all the information about this product from farm to store and get an idea about the safety and quality of this olive oil.

4. Key concepts on blockchain and its benefits

Blockchain was introduced for the first time by Nakamato et al. [14] as the technology underlying Bitcoin[3]. It is a decentralized and distributed ledger based on a peer-to-peer network. It is also considered a complex data structure that manages the flow of data without requiring central authority. The internal structure of a blockchain is composed of a linked list of blocks. Each block is linked to the previous one through the use of cryptographic hashes. It contains secure transactions signed with digital signatures and validated by several peers in the network according to a consensus protocol.

One of the most important features that has been proposed by several blockchain platforms is the Smart Contract (SC). Indeed, SC is a software program that was designed to develop business logic in order to make Blokchain suitable for several domains, either the financial one, especially eHealth [16] and supply chain management[9, 17]. Smart contracts are deployed on the immutable ledger and executed by specific types of transactions. They can be used to transfer digital currency, record information, and interact with other systems.

As mentioned in [15] and shown in Figure 1, the use of Blockchain technology in the context of food supply chain management presents several advantages. Firstly, food authentication, which is the compliance of foods with their label descriptions (e.g., geographic origin, production method, technology used in processing, composition, etc.) is guaranteed by Blockchain technology since all information and data are recorded in the immutable ledger. Second, due to the transparency feature of blockchain, there is no need to worry about food fraud. Any change made is visible to everyone in the network. Also, food safety and security are achieved because Blockchain transaction records are exceedingly hard to attack since they are encrypted. Furthermore, since every entry on the distributed ledger is connected to the previous one and so on, hackers would need to change the entire chain to change any record.

5. Development of Blockchain-based Olive Oil Supply Chain

The proposed Blockchain-based Olive oil Supply Chain (BOOSCh) is highlighted in Figure 2. The stakeholders that are involved in this work are: Farmer, Manufacturer, Inspector, Consumer.

[3]The first application of Blockchain that allows nodes to transfer digital currency without the need of a trusted third party like a central bank.

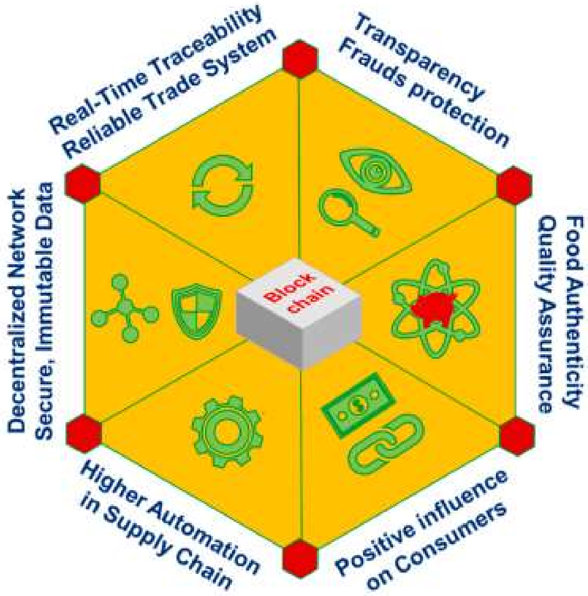

Figure 1: Blockchain benefits in food traceability and safety [15].

All their interactions with the developed smart contracts generate transactions stored on the blockchain. Each actor has a unique Ethereum address and has specific privileges to connect to the Dapp solution and perform its tasks. We use modifiers in the functions of the smart contract to apply restrictions to the unauthorized participants.

Figure 2: Blockchain-based Olive Oil Supply Chain System.

Figure 3 depicts interactions between various supply chain actors within the proposed system, and may be loosely separated into five phases that are described below.

Harvesting olives: The farmer initiates the process of the olive oil supply chain by adding a new record in the blockchain about the olive harvest at the suitable time. He provides harvest information such as the harvested land plot, location, variety, the time period required for the harvesting process and the weight of olives. Moreover, the harvesting technique (i.e., by hand or by machines) must be recorded because it may affect the acidity of the olives and, as a result, the quality of the extra virgin olive oil.

Milling olives: The manufacturer receives a notification when a given olive harvest is added to the system. Note that for simplicity reasons, the olive transportation from the farm to the olive factory is actually done by the farmer itself. The milling process starts and follows several tasks: de-leafing, washing, crushing, malaxing, decanting, and separation [11]. At the end of the milling process, the obtained olive oil is filled in containers with the aim of storing it before bottling. We assume that mixing olives obtained from different land plots, varieties and harvesting date is not possible. Each oil container stores olive oil obtained from a given harvest and a given land plot. A request is sent to the inspector from the manufacturer in order to obtain extra virgin olive oil certificate before bottling.

Inspecting olive oil: Once the inspector receives the certification request from the manufacturer, he starts the inspection and certification process. Its primary contribution consists of validating and documenting the final olive oil's specified qualities and characteristics using specific sample analysis. He conducts chemical-physical studies (involving acidity, peroxides, etc.) and organoleptic assessment by a test panel. The output of this phase is a digital certificate proving the compliance or not of the obtained oil with extra virgin olive oil, which is stored on the IPFS system. The obtained hash is then forwarded to the smart contract and recorded on the blockchain.

Packaging olive oil: Once the manufacturer receives the digital certificate of the olive oil under examination, he can proceed with the packaging and bottling activities. By adding an intelligent label with a QR Code to each oil bottle, the main objective is to enhance the food tracking process and to avoid fraud and ensure authenticity. The QR Code label adds value to the oil bottle by enabling the consumer to confirm the accuracy of the data on the label and defend the product's pricing. It summarizes all relevant information to this olive oil such as the land plot location, harvesting date, milling date, the oil quality certificate, the packaging date, etc. Once this step is completed, olive oil bottles are delivered to retailers and then to the market.

Consuming/Buying olive oil: The end consumer may verify the authenticity and quality of extra virgin olive oil by scanning the QR code attached to the oil bottle. Consequently, the use of QR code may increase the consumer's trust and is also useful to manage olive oil quality and safety from farm to market.

It is worthy to note that IoT smart devices and sensors to collect farm data (e.g., soil, water, temperature, and humidity) are not included in this current work. In the cultivation phase, the farmer provides manually collected data about land plots, olive tree varieties, fertilizing, and pesticides. A new transaction can be started when the farmer proceeds with olive cultivation and new records are created in the blockchain. Moreover, temperature monitoring is highly required either during the milling process or transportation process, therefore, temperature sensors should be deployed on the box containing the olives at the end of the harvest or on the

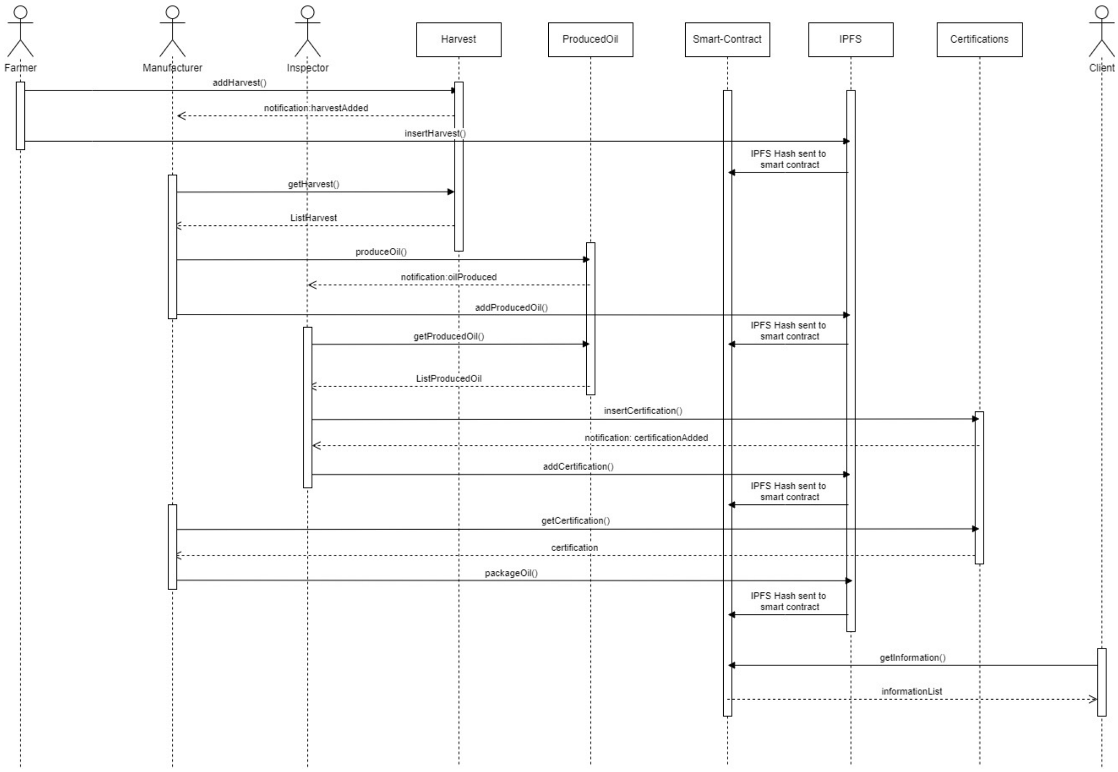

Figure 3: Sequence diagram showing the different supply chain stakeholders and their interactions through the smart contract.

olive factory especially on oil containers. Actually, this information is collected manually, and the use of temperature sensors is also out the scope of this paper.

6. Implementation details

The proposed solution is developed using a public Blockchain called Ethereum. To implement, deploy and test our solidity smart contracts, we use the truffle[4] Framework, which is a very familiar tool for Blockchain developers to create a smart contract project. It offers a project structure, files and folders that make easy the deployment and testing of Ethereum smart contracts.

Figure 4 presents the architecture of the olive oil Dapp which is made up of three layers. The front-end layer is implemented using the React[5] Framework, and each actor connects to the Dapp using the Metamask[6] wallet. The business layer is implemented in NodeJs and is composed of two kinds of APIs (Application Programming Interface). First, an API for blockchain access

[4]https://trufflesuite.com/
[5]https://fr.legacy.reactjs.org/
[6]https://metamask.io/

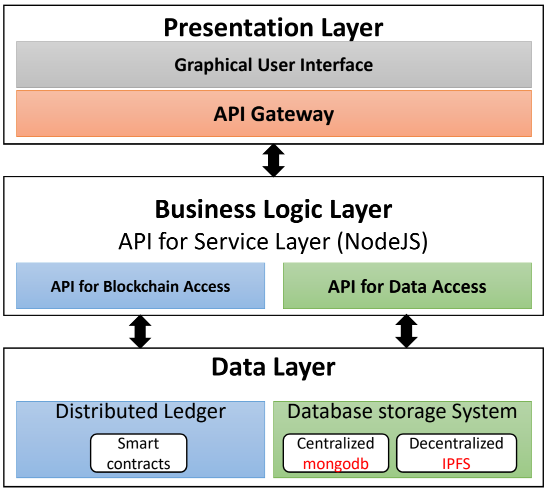

Figure 4: The architecture of the Olive Oil Dapp.

is responsible for invoking smart contracts deployed on the Ganache[7] local blockchain. The library web3.js[8] is adopted to perform actions like reading and writing data from smart contracts. Second, an API for data access is provided to manage data access and off-chain storage. Due to performance and compliance reasons, centralized (i.e., MongoDB) and decentralized (i.e., IPFS) database storage systems are used in the data layer. For example, olive oil certification details are stored off-chain, and the IPFS-hash of the generated document is stored on-chain.

Figure 5 illustrates the GUI interface used by the farmer to provide details about the harvesting activity. Also, the GUI interface of the inspector profile is depicted in Figure 6.

7. Conclusion

In this work, we have investigated the challenge of food traceability within the olive oil supply chain. To address this issue, we developed a decentralized solution based on blockchain technology, called BOOSCh. The latter is built on Ethereum blockchain and makes use of several promising techniques: smart contracts to easily manage interactions among stakeholders, IPFS for the off-chain storage and QR code to get detailed information regarding the olive oil's path to the store. Through BOOSCh, the traceability, security and scalability of the olive oil supply chain is achieved. Moreover, we demonstrated that the olive oil supply chain management becomes more practical and cost-effective. At the end, we provided the high level architecture of BOOSCh and its implementation details in order to show its effectiveness.

Although the functions in the developed smart contract were implemented for the olive oil supply chain, they can be easily extended to other supply chains like the drug supply chain and the seafood supply chain. Moreover, we think that further research and development are needed in order to apply Blockchain and IoT devices in supply chain. For instance, we can investigate

[7] https://trufflesuite.com/ganache/
[8] https://web3js.readthedocs.io/en/v1.10.0/

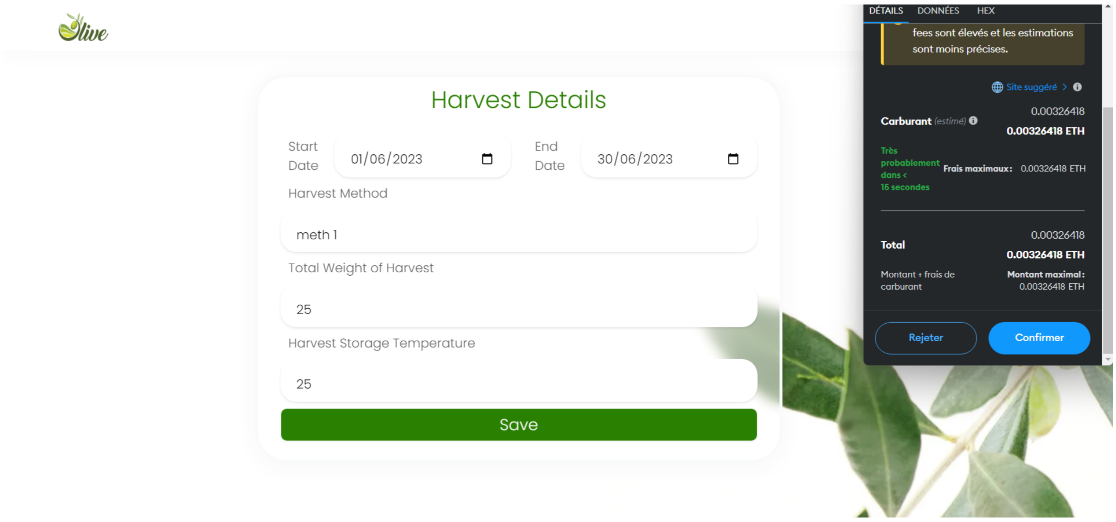

Figure 5: Screenshot of the GUI interface for adding olive harvest.

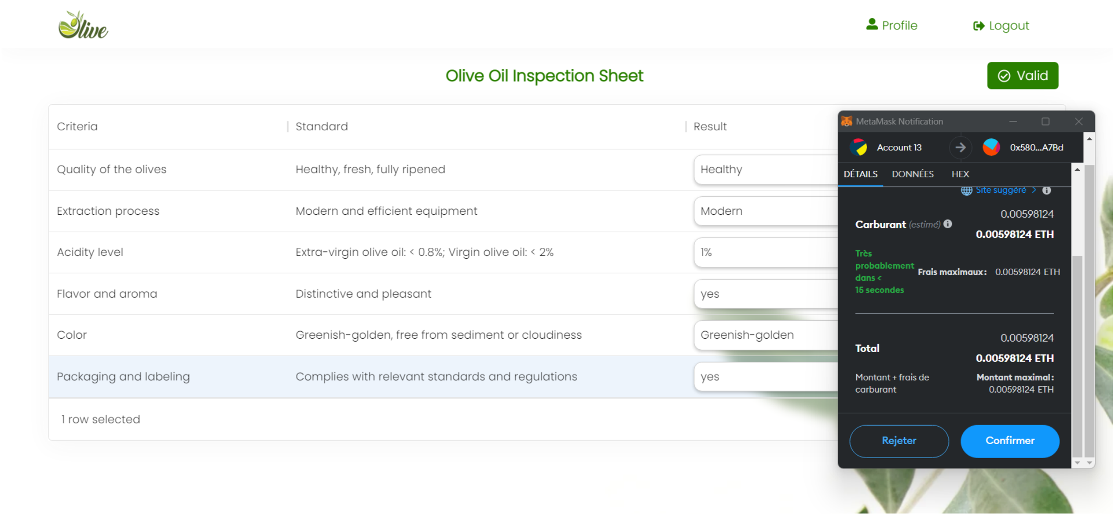

Figure 6: Screenshot of the GUI interface for inspecting olive oil.

the deployment of IoT sensors to collect real time data about temperature, humidity, etc. These sensors can be placed at the boxes containing the olives at the end of the harvest activity, at the oil container at the end of milling procedure or at courier trucks used for transportation. Despite the several advantages of blockchain technology, its development is still challenging and requires verification and validation efforts to obtain efficient, safe and secure blockchain-based solutions.

Acknowledgments

Thanks to the student Engineers Ibrahim Ben Lakhal and Abir Grati and Mohamed Ben Salah for the development of the olive oil Dapp solution in the context of their Second Final Year Project.

References

[1] L. Fernández-Lobato, Y. López-Sánchez, R. Baccar, M. Fendri, D. Vera, Life cycle assessment of the most representative virgin olive oil production systems in tunisia, Sustainable Production and Consumption 32 (2022) 908–923. URL: https://www.sciencedirect.com/science/article/pii/S2352550922001488. doi:https://doi.org/10.1016/j.spc.2022.06.002.

[2] R. Guido, G. Mirabelli, E. Palermo, V. Solina, A framework for food traceability: case study– italian extra-virgin olive oil supply chain, International Journal of Industrial Engineering and Management 11 (2020). URL: http://www.ijiemjournal.uns.ac.rs/images/journal/volume11/IJIEM_252.pdf.

[3] T. Frikha, J. Ktari, H. Hamam, Blockchain olive oil supply chain, in: S. Kallel, M. Jmaiel, M. Zulkernine, A. Hadj Kacem, F. Cuppens, N. Cuppens (Eds.), Risks and Security of Internet and Systems, Springer Nature Switzerland, 2022, pp. 101–113.

[4] J. Ktari, T. Frikha, F. Chaabane, M. Hamdi, H. Hamam, Agricultural lightweight embedded blockchain system: A case study in olive oil, Electronics 11 (2022). URL: https://www.mdpi.com/2079-9292/11/20/3394. doi:10.3390/electronics11203394.

[5] O. Ghorbel, T. Frikha, A. hajji, R. Alabdali, R. Ayadi, M. Abbas Elmasry, Blockchain-based supply chain system for olive fields using wsns, Computational Intelligence and Neuroscience (2022).

[6] R. Alkhudary, X. Brusset, H. Naseraldin, P. Féniès, Enhancing the competitive advantage via blockchain: an olive oil case study, IFAC-PapersOnLine 55 (2022) 469–474. URL: https://www.sciencedirect.com/science/article/pii/S2405896322002397. doi:https://doi.org/10.1016/j.ifacol.2022.04.238.

[7] J. Verny, W. Guan, Perspective chapter: Blockchain adoption in food supply chain, in: V. Chernyshenko, V. Mkrttchian (Eds.), Blockchain Applications, IntechOpen, Rijeka, 2022. URL: https://doi.org/10.5772/intechopen.106402. doi:10.5772/intechopen.106402.

[8] C. Cozzio, G. Viglia, L. Lemarie, S. Cerutti, Toward an integration of blockchain technology in the food supply chain, Journal of Business Research 162 (2023) 113909. URL: https://www.sciencedirect.com/science/article/pii/S0148296323002679. doi:https://doi.org/10.1016/j.jbusres.2023.113909.

[9] N. Ouled Abdallah, F. Fakhfakh, F. Fakhfakh, Overview of blockchain-based seafood supply chain management, in: Intelligent Systems Design and Applications, Springer Nature Switzerland, 2023, pp. 71–80.

[10] M. Conti, Evo-nfc: Extra virgin olive oil traceability using nfc suitable for small-medium farms, IEEE Access 10 (2022) 20345–20356. doi:10.1109/ACCESS.2022.3151795.

[11] A. Arena, A. Bianchini, P. Perazzo, C. Vallati, G. Dini, Bruschetta: An iot blockchain-

based framework for certifying extra virgin olive oil supply chain, in: 2019 IEEE International Conference on Smart Computing (SMARTCOMP), 2019, pp. 173–179. doi:10.1109/SMARTCOMP.2019.00049.
[12] S. Bistarelli, F. Faloci, P. Mori, C. Taticchi, Olive oil as case study for the *-chain platform, in: M. Pizzonia, A. Vitaletti (Eds.), Proceedings of the 4th Workshop on Distributed Ledger Technology co-located with the Italian Conference on Cybersecurity 2022 (ITASEC 2022), Rome, Italy, June 20, 2022, volume 3166 of *CEUR Workshop Proceedings*, CEUR-WS.org, 2022, pp. 94–102.
[13] R. A. Diego Luis García González*, R. Aparicio-Ruiz, Food Integrity Handbook: A Guide To Food Authenticity Issues And Analytical Solutions Chapter 19: Olive oil, 2018.
[14] S. Nakamoto, et al., Bitcoin: A peer-to-peer electronic cash system, 2008.
[15] A. Patel, M. Brahmbhatt, A. Bariya, J. Nayak, V. Singh, “blockchain technology in food safety and traceability concern to livestock products”, Heliyon 9 (2023) e16526. URL: https://www.sciencedirect.com/science/article/pii/S2405844023037337. doi:https://doi.org/10.1016/j.heliyon.2023.e16526.
[16] R. B. Fekih, M. Lahami, Application of blockchain technology in healthcare: A comprehensive study, in: Proceeding of 18th International Conference of The Impact of Digital Technologies on Public Health in Developed and Developing Countries, ICOST 2020, 2020, pp. 268–276.
[17] R. Mars, J. Youssouf, S. Cheikhrouhou, M. Turki, Towards a blockchain-based approach to fight drugs counterfeit, in: Proceedings of the Tunisian-Algerian Joint Conference on Applied Computing (TACC 2021), Tabarka, Tunisia, 2021, pp. 197–208.