Unveiling the Digital Food Product Passport Paradigm for Ensuring Traceability and Safety in the Global Food Ecosystem

Spyridon Evangelatos[†,‡], Paraskevas Bourgos[†], Nikoleta Tsampanaki[†], Nikos Kefalakis[†], Amalia Ntemou[†] and Pantelis Lappas[†,§] [†] Research & Innovation Development Department, Netcompany-Intrasoft S.A., Luxembourg, Luxembourg
[‡] Dept. of Electronic Engineering, Hellenic Mediterranean University, Crete, Greece
[§] Dept. of Statistics and Actuarial-Financial Mathematics, University of the Aegean, Samos, Greece
Emails: sevangelatos@netcompany.com, pbourgos@netcompany.com, ntsampan@netcompany.com, nkefalakis@netcompany.com, antemou@netcompany.com, plappa@netcompany.com

Abstract—Food supply chains are increasingly vulnerable to fraud and inefficiencies that impose substantial economic and environmental burdens. Food fraud is estimated to cost the global industry billions of euros each year while its consequences in terms of public health risks and erosion of consumer trust are equally profound. In response to these challenges, the concept of a digital food product passport has emerged as a transformative solution, capitalizing on well-established technologies that facilitate secure, real-time tracking and immutable documentation of the origin, composition and lifecycle events of a food product. This paper introduces the Digital Food Product Passport, a blockchain-based system that improves global food safety and traceability. It provides exhaustive, immutable records of a product's development cycle, from origin to packaging, aligning with major policies such as the recent European Green Deal. The Digital Food Product Passport targets to bridge the information gap that currently exists in supply chains and at the same time, empower consumers with reliable data for informed decisions on sustainable choices on food products. Its technical implementation involves several well-established technologies inluding distributed ledger technology, devices enabled by the Internet of Things (IoT), Artifical Intelligence, just to name a few, demonstrating how technology can address complex global challenges.

Index Terms—Traceability, transparency, food value chains, digital (virtual) food product passport, blockchain, smart contracts.

1 Introduction

The evolution of digital technologies, coupled with their application in the realm of food safety and traceability, has been an area of intense research and development [1]. Traditional systems often rely on manual or semi-automated processes, making them susceptible to errors and inefficiencies [2]. In addition, the growing sophistication of international food supply chains adds to this issue, as food products are more likely to cross many countries and many hands before they are consumed. This has led to rising difficulties in tracing the origin and path of food products, resulting in food safety and authenticity concerns. To solve this issue, various digital technologies have been explored, with solutions varying from barcodes and QR codes to RFID tags and IoT devices. Although these technologies offer improved tracking capabilities, they are not effective in providing end-to-end visibility and guaranteeing the authenticity of the collected data [3].

The emergence of blockchain technology presents a promising solution to such issues [4]. Its immutability, transparency, and decentralized nature make it particularly suitable to maintain data authenticity and integrity throughout the food value chain. Its applications in the supply chain of foods allow the entities involved, including producers, retailers, and consumers, to identify the origin and complete history of food products, and hence promote accountability and trust.

Despite these advantages, research on the integration of blockchain technology and digital food product passports remains limited. Although the application of blockchain has been widely explored to improve traceability and transparency in food supply chains, its specific use in the development of a standardized and interoperable digital food product passport is currently in an early stage. Existing studies primarily focus on isolated aspects such as traceability using blockchain or certification checks, instead of an end-to-end system that covers all phases of the food product life cycle. In addition, the lack of standardized solutions and regulatory alignment further hampers widespread adoption. Hence, further research is required to create robust models that harness the potential of blockchain to improve

This work has received funding from the European Union's Horizon Europe research and innovation programme through the WATSON and ALLIANCE projects under grant agreement No. 101084265 and No. 101084188. Views and opinions expressed are those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the granting authority can be held responsible for them.

the effectiveness, interoperability and scalability of digital food product passports [5].

In this context, our paper introduces the concept of a Digital Food Product Passport, a blockchain-based system that captures and provides access to comprehensive, trustworthy information about each food product's journey from farm to fork. Apart from the high-level architectural design, we also detail a prototype implementation, highlighting its core elements, including secure data capture, decentralized validation, and a user-centric interface that collectively enable real-time traceability and robust auditability throughout the food supply chain. The proposed system not only enhances food safety and traceability but also creates new possibilities for consumer empowerment and food industry innovation. Last, we present a detailed exploration of this paradigm, discussing its potential benefits and challenges, as well as the technical considerations for its implementation showcased in an extra virgin olive oil supply chain based on the EU funded WATSON project.

The rest of this paper is organised as follows: Section II reviews the related work and current approaches to digital product passports, emphasising on the technological gaps and challenges, particularly in the context of food supply chains. Section III presents the implementation details of the Digital Food Product Passport reference architecture, highlighting its robust, modular design and the integration of blockchain, IoT, and AI technologies to ensure secure, real-time traceability. Section IV demonstrates the practical application of the DFPP through a case study on the olive oil supply chain, including deployment details and initial validation results. Finally, Section V concludes the paper by discussing the potential benefits, limitations, and future research directions for enhancing transparency and safety in global food ecosystems.

2 Related Work

Recently, the European Union (EU) has published a set of policy initiatives such as the European Green Deal [6] and the Circular Economy Action Plan [7]. On top of these policies, EU proposed a new regulation, namely the Sustainable Product Regulation [8], that aims at improving EU products' circularity, energy performance and other environmental sustainability aspects, creating huge impact for the global trade. The digital product passport can be considered as a tool that bridges the data gap across different supply chains, integrating information from the whole life-cycle of a product collected from all the stages of the value chain. Each product needs to include this information and make it accessible via a data carrier through a unique product identifier (UID).

Digital product passports have emerged as a promising tool to enhance transparency and facilitate circularity across diverse industries. Several implementation frameworks have been developed, primarily targeting sectors such as electronic products [9] and critical raw materials for electrical and electronic equipment [10], as well as the building industry [11] and manufacturing [12]. These frameworks typically rely on sophisticated technologies most notably, blockchain networks, which provide an immutable, secure repository of product data [13]. In addition, many of these systems harness the capabilities of the Internet of Things (IoT), Big Data analytics [14], and Artificial Intelligence (AI) [15] to collect, process, and analyze vast amounts of information in real time.

Despite these advancements, the application of digital product passports to the food sector remains largely unexplored. To the best of our knowledge, this paper represents the first detailed attempt to describe the implementation of a digital product passport specifically tailored for food products, with the exception of a high-level traceability framework for organic and protected geographical indication food assets [16]. Our approach addresses the unique challenges associated with the food supply chain by offering a more versatile design that benefits all stakeholders, from producers and distributors to retailers and consumers [17], even though food products are currently excluded from the Sustainable Product Regulation. This work not only fills a critical research gap but also paves the way for enhanced transparency and accountability in food product traceability.

3 The DFPP Reference Architecture

The proposed Digital Food Product Passport (DFPP) solution is built upon a robust, modular architecture (illustrated in Fig. 1) designed to leverage blockchain and IoT technologies, aiming to enhance traceability, transparency, and accountability across the food supply chain. Designed to ensure seamless adoption and secure data exchange, the system contains multiple layers logically grouped into three elements, namely, Supply Chain Participant(s), Centralized Services, and User & Services Dashboards following a similar approach with [18].

In the following subsections, we provide a detailed breakdown of each of these elements. First, we describe the Supply Chain Participant(s) layer, encapsulating the blockchain technology and IoT devices and other data sources to aggregate, validate, and securely store data in an immutable ledger, ensuring real-time traceability and transparency. Next, we focus on the Centralized Services layer, which includes all services supporting the roles and responsibilities of the various stakeholders and the mechanisms they use for secure data access and authentication. Finally, we examine the User & Services Dashboards, which offer intuitive interfaces and analytical tools designed to empower end-users with actionable insights, thus facilitating informed decision-making.

3.1 Supply Chain Participants

The Supply Chain Participant module encompasses both data sources and localized services deployed at each participant's site within the food supply chain. The localized services within this module perform initial data validation and pre-processing at the source, thereby reducing latency and minimizing the potential for errors before the information is securely transmitted to the blockchain network.

The Data sources group various types of information critical for powering the system. This includes real-time data collected via IoT sensors, food scanning devices and authenticity control tools designed to monitor the product at each stage of production. Additionally, human-entered

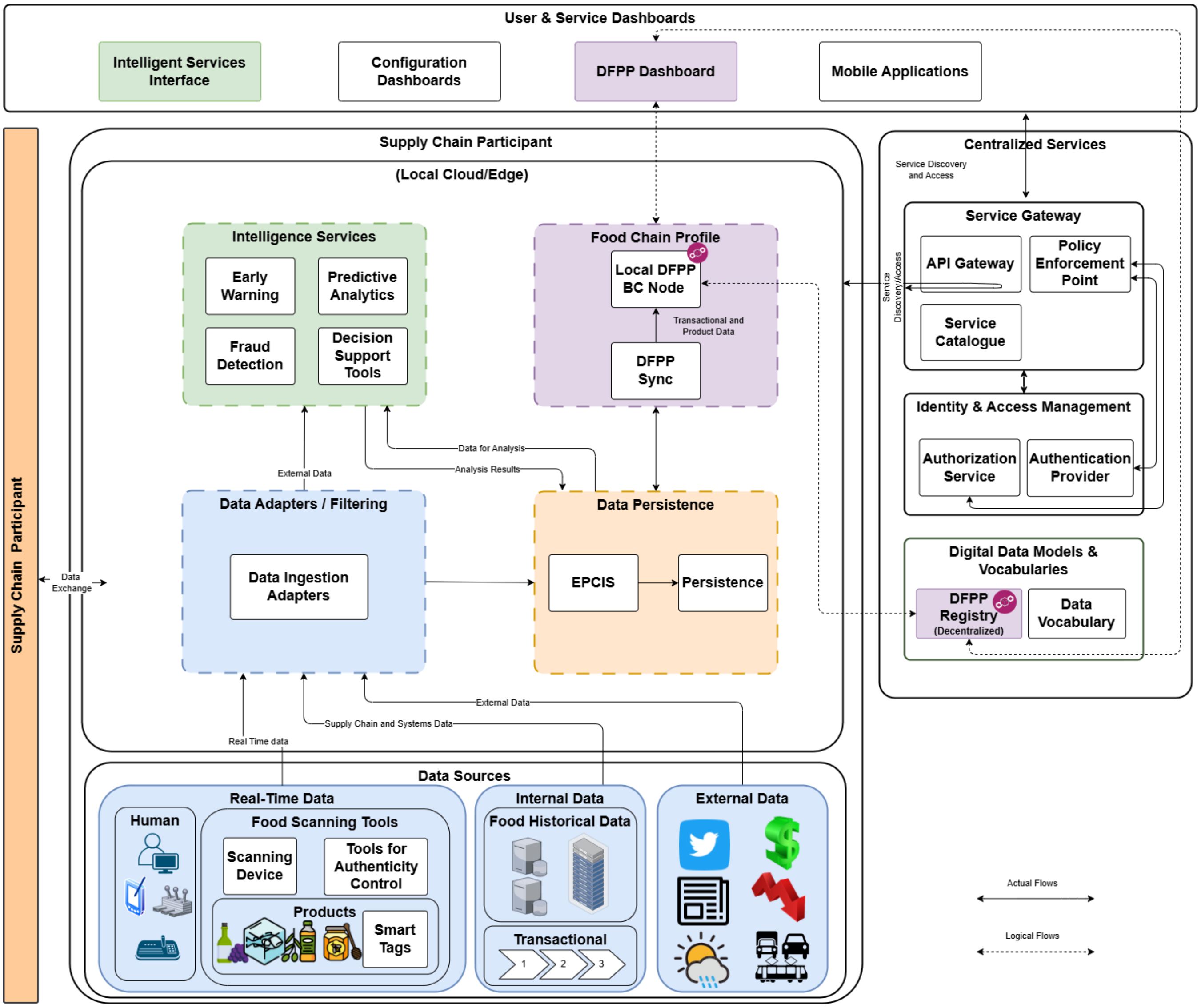

Fig. 1. Reference Architecture for the Digital Food Product Passport solution. A high-level overview of the proposed system.

data, such as quality checks or inspection results, are used. Internal Data generated by participants involved in the supply chain, such as production details, batch identifiers, or transaction data is also incorporated. Furthermore, external data sources like market information, environmental impact policies or assessments, and any regulatory policy updates, provide valuable context to support all stakeholders but especially consumers decision-making processes.

The local cloud/edge deployed services module of the Supply Chain Participant uses the data coming from the Data sources group to enable efficient collection, processing, secure storage and analysis at each participant's site within the supply chain. The module encompasses Data Adapters/Filtering, Data Persistence, Food Chain Profile and Intelligence Services modules, each having a critical role in ensuring optimal data management and decision support. More specifically, the Data Ingestion Adapters collect and process incoming data from the Data Sources, such as measurements from IoT-enabled devices. All data retrieved are standardized and stored in the Data Persistence module. The Electronic Product Code Information Services (EPCIS) component standardizes data exchange in the supply chain, providing a common language and format for the description of events related to the product lifecycle, such as shipping, receiving and quality inspections. The component processes the data, while performing data controls and checks to ensure that the collected measurements are within specified ranges. The Persistence component stores and manages the data collected and processed by the system into a repository, while allowing data sharing to the tools and services of the system, such as the Food Chain profile and the Intelligence services modules.

The Intelligence Services module in the DFPP architecture represents a set of AI-powered tools integrated throughout the supply chain, providing valuable insights and continuous monitoring at different stages of the food supply chain network. AI solutions include early warning systems in the upstream supply chain that assess and score suppliers based on qualitative and quantitative criteria [20]. Moreover, predictive analytics help detect fraud risks in

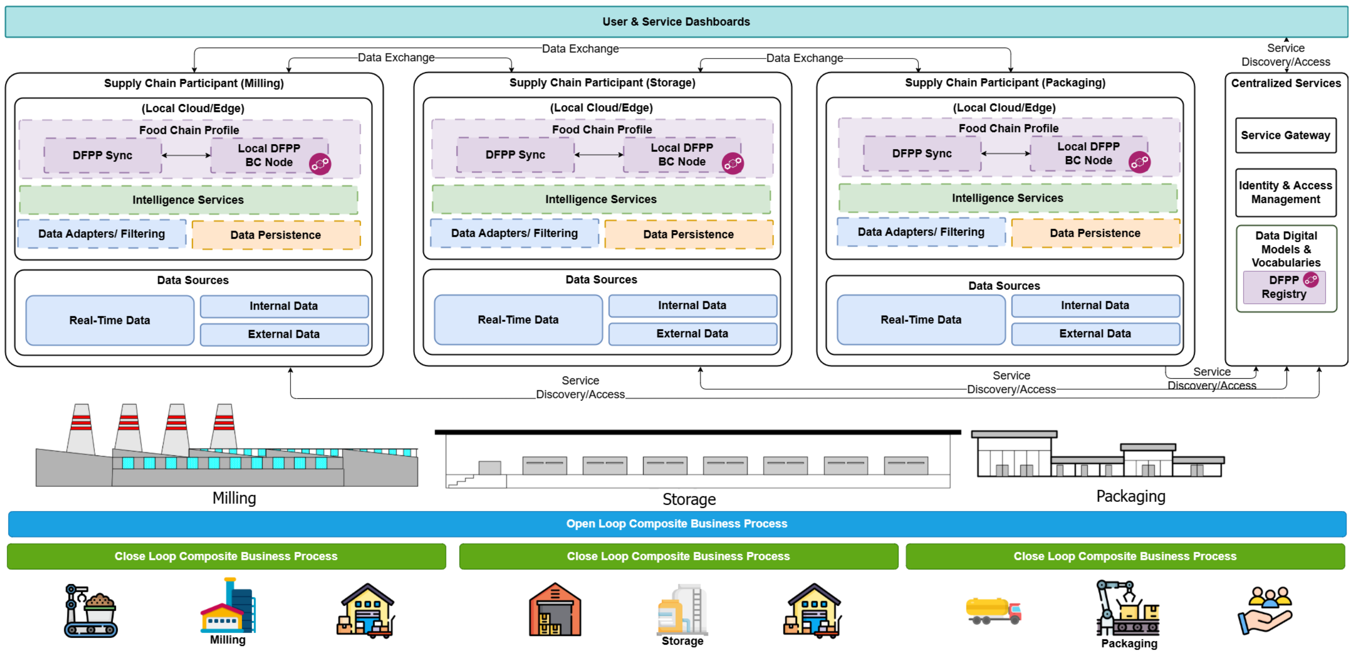

Fig. 2. DFPP architecture instantiation for the Olive Oil supply chain of three participants.

raw materials before production begins (e.g., analyzing pH levels and temperature readings in milk to compute a fraud indicator before cheese production). In addition to this, AI-driven recommendation engines support decision-makers by suggesting optimal mitigation strategies when fraud incidents occur. To achieve these capabilities, Intelligence Services employ deep learning algorithms for pattern recognition, exploratory data analysis for training predictive models on historical data, as well as optimization and fuzzy logic techniques to solve complex decision problems, ensuring food safety and supply chain integrity. Within the DFPP, these AI-driven insights are embedded into structured fields that balance accessibility for consumers with depth for experts. Public fields provide simplified fraud indicators, supplier risk scores, and traceability verification signals, ensuring that consumers receive clear and actionable information about food authenticity and safety. At the same time, private fields store more detailed AI analytics, such as Machine Learning model performance, fraud detection confidence levels, explainability metrics, and audit logs, offering deeper insights for regulators, food safety professionals, and supply chain managers.

The core module that supports and gradually builds DFPP is the Food Chain Profile module, which includes the Synchronization mechanism ensuring timely transfer of the product data and information related to the DFPP from the Persistence component into the Local DFPP blockchain node of the supply chain participant. The DFPP actually contains data that the participant intends to share with the rest of the supply chain. This data includes key identifiers, production details, quality assessments, environmental metrics and regulatory compliance records that collectively form a complete digital profile of each food product. The synchronization mechanism uses secure communication protocols and message bus architectures to ensure that any updates made at the local level are quickly and reliably propagated across the blockchain network, thus maintaining consistency and data integrity across all nodes. As a result, all stakeholders have access to real-time and immutable records of the history of the food product. This data sharing scheme reinforces transparency and traceability while at the same time, enables proactive measures for quality control and rapid response in case of safety concerns.

3.2 Centralized Services

The Centralized Services group offers end-to-end services necessary for the secure access of system services, both for internal and external users, and for seamless interactions among various components. The group comprises the Service Gateway module, the Identity & Access Management module, and the Digital Data Models & Vocabularies module, all of which are utilized to provide data security, interoperability, and structured access in the DFPP environment.

The Service Gateway module provides a secure way to access the system since it is the only access point for all stakeholders. The API Gateway service, for example, provides an integrated interface where the various functionalities and services are accessed. It exposes and orchestrates APIs and performs request routing, load balancing and caching for performance and to make it more dependable. Policy Enforcement Point (PEP) service is used for the enforcement of access control policies that have been established for all the stakeholders involved. The PEP analyzes and scrutinizes the access requests and verifies their compatibility with the policies and rules established earlier. PEP ensures that only authorized members and external parties gain access to the specific resources and features. It enforces policies concerning data sharing, data discovery and other blockchain-based interactions, enhancing data governance and security. The Service Catalogue module is a repository that holds a vsast list of services and functionalities,

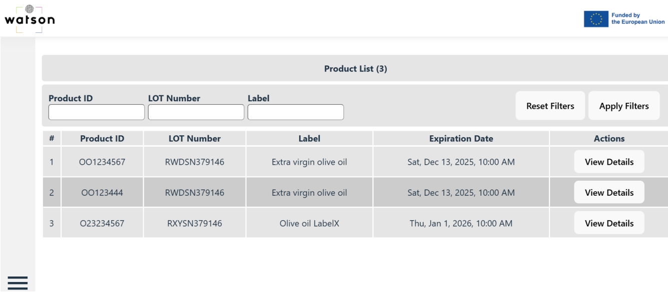

Fig. 3. The DFPP Dashboard

together with detailed descriptions of every service, such as API specifications, input/output data formats and access requirements, among others.

The Identity & Access Management group oversees the management of user identities, secure authentication mechanisms, and the enforcement of granular access control via its two core services, namely the Authorization Service and the Authentication Service. The Authentication Service verifies the credentials of users and system entities with strong cryptographic protocols and multi-factor authentication, ensuring that only authorized users are granted access to the system. Once a user is authenticated, the Authorization Service evaluates their permissions based on a set of roles and policies, and thus establishes the resources and operations that the user can access or execute.

The Digital Data Models & Vocabularies group consists of the DFPP Registry and the Data Vocabulary modules. The DFPP Registry is the access point for the Blockchain network supporting the DFPP solution. This service acts as the gateway for supply chain participants or end-users by allowing them to access the traceability data stored on the blockchain of a product. In parallel, the Data Vocabulary module standardizes the representation of product-related information by adopting globally recognized schemas and taxonomies (e.g., GS1 Core, GeoJSON), ensuring that data exchanged across different systems and stakeholders is interoperable and semantically consistent.

3.3 User & Service Dashboards

The User & Service Dashboards module provides stakeholders with user-friendly interfaces to access system functionalities and gain data insights. These dashboards serve as an entry point for end users to interact with the various tools and components of the system, guaranteeing ease of use and accessibility. The module includes the Intelligent Services Interface, which offers insights and data analytics, the mobile and web application for convenient service access, and Configuration Dashboards for managing system settings and workflows. At the core of these interfaces is the DFPP Dashboard, which offers a thorough view of the product's journey from farm to fork, the DFPP itself. This dashboard enables users to easily track and verify products at each stage of production. It is designed to primarily provide real-time product traceability visualization, allowing end-users to search a product and access its detailed DFPP information directly through the dashboard. The dashboard provides access to all available DFPPs within the supply chain, regardless of the production stage. Key features include advanced querying functionalities by product ID, lot number, or product label, which facilitate the tracing of specific product batches or individual items. These functionalities are particularly valuable for increased transparency, enhanced food safety and quality control, among other benefits.

4 Deployment and Performance Evaluation in the Olive Oil Supply Chain

In this section, we demonstrate how the proposed reference architecture is applied on a real-life use case for the Olive Oil supply chain, involving three key participants: a miller, a storage facility, and a packaging facility, as shown in Figure 2 Each participant represents a node in the supply chain, with their operations integrated into the architecture using Hyperledger Besu [21] as the blockchain technology. In the following part of this Section, we present a small-scale deployment, followed by initial validation results that showcase the effectiveness and potential impact of the system on the enhancement of food traceability and transparency throughout the supply chain.

4.1 System deployment

The blockchain network comprises three Besu nodes, each deployed on a separate virtual machine to simulate the decentralized nature of a real-world supply chain. This distributed setup ensures that each node independently records supply chain events and product information, providing redundancy and minimizing the risk of data tampering or system failure [22]. All recorded data is synchronized across the blockchain nodes, creating a unified, tamper-proof ledger that enhances overall traceability.

To maintain data integrity and achieve fast verification of transactions, the network employs the IBFT 2.0 consensus protocol [23]. This particular protocol, which is renowned for fast finality, ensures that once a transaction is validated, guarantees that once a transaction has been verified, it is recorded swiftly onto the blockchain and made irreversible. The application of distributed nodes along with a persistent consensus mechanism ensures not just the immutability and integrity of the data stored but also enhances the authenticity of the Digital Food Product Passport system throughout the whole food supply chain.

4.2 Data representation

An extensively used encoding standard for geographic data, GeoJSON, was used to encode product and geolocation data. This method makes it easy for the system to easily integrate accurate geographical data coupled with product life cycle events. In our olive oil illustration, for instance, every batch of olive oil is stamped with the precise coordinates of its place of origin when it is milled. From grinding to storage and finally packaging, the product's position is reflected in GeoJSON files as it traverses the supply chain. An accurate, real-time graphical representation of the product's path is provided in this format, enhancing traceability through the stakeholders' ability to immediately detect any deviations or bottlenecks in the supply chain.

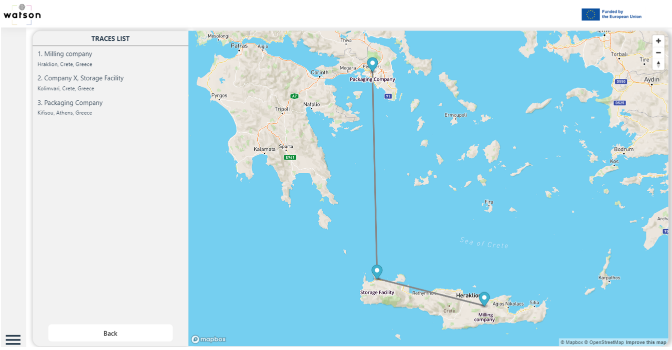

Fig. 4. The DFPP Dashboard - Traceability visualization

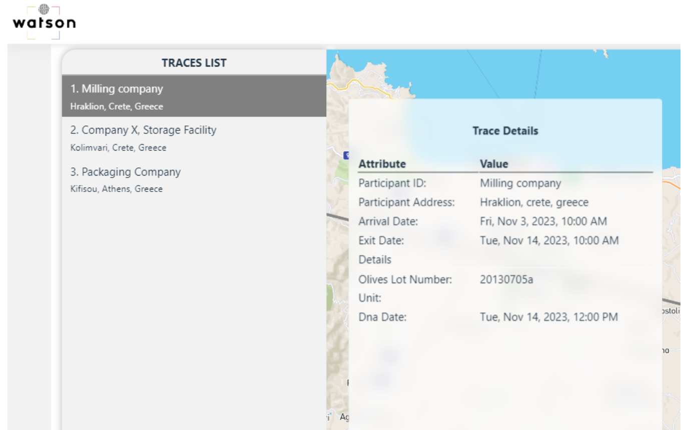

Fig. 5. DFPP Dashboard - Supply chain participant and production details visualization

4.3 Smart Contracts

Smart contracts serve as self-executing digital agreements that automatically enforce predefined rules on the blockchain, eliminating the need for intermediaries and ensuring consistency across the supply chain [24]. In our DFPP solution, smart contracts were developed to automate key supply chain processes, including:

- Product Registration where a digital twin [25] is created for each batch of olive oil with unique identifiers and metadata (e.g., origin, quality checks, olive varieties, etc.).
- Handover Events where ownership transfers between participants is being recorded with geolocation and timestamp data.
- Quality Assurance where the verification and storage of the results of the performed inspections or the authenticity checks are conducted at each stage [26].

Because of their modular nature, these contracts can guarantee data integrity along the supply chain and enforce business standards automatically without any human intervention. In the real-world tests, a smart contract generates a unique identity and associates metadata to create a digital twin for every batch of olive oil during product registration. In order to create an unchangeable audit trail, the contracts additionally securely log ownership transfers together with accurate geolocation and timestamp data. They also manage quality assurance by confirming and documenting the findings of authenticity checks or inspections at every production stage. These contracts include role-based access controls, stringent validation checks, and error-handling procedures to provide strong security and compliance. They also interface with IoT devices and external sources to integrate real-time data. [27].

4.4 DFPP Dashboard

The DFPP Dashboard offers a user-centric interface that enhances traceability by visualizing olive oil DFPPs through a multi-layered traceability map. Users can initiate a search using product identifiers such as ID, lot number, or label, as demonstrated in Figure 3, which directs them seamlessly to the traceability map interface. At the initial overview level, the dashboard displays a geospatial map that provides a macro-level perspective of all product traces, illustrating the movement and location of batches across the supply chain, as depicted in Figure 4. Once a user selects a specific trace from this overview, the dashboard transitions to a detailed view. This view presents critical information pertaining to the production stage and the respective supply chain participant, including precise geolocation data, timestamps and relevant production metrics (as shown in Figure 5). The dashboard's interactive filtering and querying capabilities enable stakeholders to drill down into the data for further analysis, ensuring that both high-level monitoring and granular investigations can be conducted effectively. This multi-tiered visualization framework supports continuous monitoring and rapid identification of potential issues and empowers consumers and industry professionals to make well-informed decisions.

With actionable information catered to their needs, the DFPP Dashboard is made to accommodate a wide range of stakeholders, from supply chain managers and regulatory bodies to end users [28]. Supply chain managers can take immediate corrective action by using the dashboard to identify irregularities or discrepancies in the product's path. When anomalies are detected, real-time analytics that are embedded within the dashboard allow the generation of notifications, promoting proactive risk management and enhanced food safety standards. Because of the natural toggle between the macro and micro viewpoints, users can monitor the overall dynamics of the supply chain and drill into the details for individual products as needed.

Additionally, the simplicity of use guarantee that valuable traceability data is available anywhere and everywhere, even on field operators' mobile devices. Ease of use is augmented and broad usage of the DFPP solution is encouraged by customizable settings that enable users to tailor the interface to display particular data points of value. Aside from data integrity, the fact that the dashboard is integrated with emerging technologies like blockchain, IoT and AI renders it a vital instrument in the future of food supply chain management.

5 Conclusion

This paper presented the one-of-its-kind DFPP, a blockchain-based system intended to improve traceability, transparency, and safety in international food supply chains. Its application provides an immutable history of a product's journey from farm to fork, addressing key food safety, fraud and sustainability concerns. To provide real-time tracking and verification of food products, the DFPP system leverages distributed ledger technology, Internet of Things and artificial intelligence-driven analytics. It makes verifiable, structured data about food provenance, quality, and compliance with sustainability policies like the European Green Deal accessible to all relevant parties, including farmers, regulators, retailers, and consumers. A real-world olive oil supply chain case study validated the effectiveness of the framework, demonstrating how smart contracts can automate key supply chain processes such as product registration, handover events and quality assurance. The study establishes DFPP as a scalable, tamper-proof and future-ready solution that bridges the digital gap in food traceability while fostering greater consumer trust and regulatory compliance.

Our future work will focus on scaling the DFPP framework to accommodate a broader range of food supply chains and food product types, even from shorter supply chain. Research efforts will also aim to develop standardized data schemas and protocols to improve interoperability with existing global regulatory systems, thus facilitating seamless integration with initiatives such as the Sustainable Product Regulation. Additional field trials and user experience studies across diverse operational contexts will be conducted to validate the system's robustness and refine its interface for greater usability.

References

[1] A. Kamilaris, A. Fonts, F. Prenafeta-Boldu, "The Rise of Blockchain Technology in Agriculture and Food Supply Chains," Trends in Food Science & Technology, vol. 91, 2019, pp. 640–652, ISSN 0924-2244.

[2] N. Kshetri, "Blockchain's Roles in Meeting Key Supply Chain Management Objectives," International Journal of Information Management, vol. 39, 2018, pp. 80-89, ISSN 0268-4012.

[3] V. Maritano, P. Barge, A. Biglia, L. Comba, D. Ricauda Aimonino, C. Tortia, P. Gay, "Anticounterfeiting and Fraud Mitigation Solutions for High-value Food Products," Journal of Food Protection, vol. 87, Issue 4, 2024, 100251, ISSN 0362-028X.

[4] V. Pandey, M. Pant, V. Snasel, "Blockchain Technology in Food Supply Chains: Review and Bibliometric Analysis," Technology in Society, vol. 69, 2022, 101954, ISSN 0160-791X.

[5] G. Chiaraluce, D. Bentivoglio, A. Finco, M. Fiore, F. Contò and A. Galati, "Exploring the Role of Blockchain Technology in Modern High-value Food Supply Chains: Global Trends and Future Research Directions, Agricultural and Food Economics, vol. 12, Article 6, 2024.

[6] European Commission, Directorate-General for Communication, "European green deal - Delivering on our targets,"In Publications Office of the European Union, 2021.

[7] European Commission, "Circular Economy Action Plan - For a Cleaner and More Competitive Europe," Brussels, Belgium, 2020.

[8] European Commission, "Establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC," Brussels, Belgium, 2022.

[9] Y. A. Gatchin, J. V. Donetskaya and V. I. Polyakov, "Implementation of a Digital Passport for an Electronic Product at an Enterprise," 2021 IEEE Wave Electronics and its Application in Information and Telecommunication Systems (WECONF), St. Petersburg, Russia, 2021, pp. 1–4.

[10] R. H. E. M. Koppelaar *et al.*, "A Digital Product Passport for Critical Raw Materials Reuse and Recycling," In Sustainability, vol. 15, no. 2, p. 1405, Jan. 2023.

[11] Q. Li and Y. Wang, "Blockchain's role in supporting circular supply chains in the built environment," *2021 IEEE International Conference on Blockchain (Blockchain)*, Melbourne, Australia, 2021, pp. 578–583.

[12] Gallina V., Gal, B. Szaller, Á. Bachlechner, D. Ilie-Zudor, E. Sihn, W., "Reducing Remanufacturing Uncertainties with the Digital Product Passport," In Kohl, H., Seliger, G., Dietrich, F. (eds) Manufacturing Driving Circular Economy, Lecture Notes in Mechanical Engineering, Springer, Cham, 2023.

[13] M. Zheng, S. Zhang, Y. Zhang and B. Hu, "Construct Food Safety Traceability System for People's Health Under the Internet of Things and Big Data," in IEEE Access, vol. 9, pp. 70571–70583, 2021.

[14] Q. Lin, H. Wang, X. Pei and J. Wang, "Food Safety Traceability System Based on Blockchain and EPCIS," in IEEE Access, vol. 7, pp. 20698–20707, 2019.

[15] N. N. Misra, Y. Dixit, A. Al-Mallahi, M. S. Bhullar, R. Upadhyay and A. Martynenko, "IoT, Big Data, and Artificial Intelligence in Agriculture and Food Industry," in IEEE Internet of Things Journal, vol. 9, no. 9, pp. 6305–6324, 1 May1, 2022.

[16] L. Lekawska-Andrinopoulou, D. Tsiakou, K. Chatzioannou, G. Tsimiklis, A. Amditis, "Towards dynamic digital product passport: The approach for food sector," E3S Web Conf., vol. 585, 08001, 2024.

[17] T. Adisorn, L. Tholen and T. Götz, "Towards a Digital Product Passport Fit for Contributing to a Circular Economy," In Energies, vol. 14, no. 8, p. 2289, Apr. 2021.

[18] M. Wiesner, J. Moreira, R. Guizzardi,P. Scholz, "A Reference Architecture for Digital Product Passports at Batch Level to Support Manufacturing Supply Chains," In: J. Araújo, J. de la Vara, M. Santos, (eds), Research Challenges in Information Science, RCIS 2024, Lecture Notes in Business Information Processing, vol. 513, Springer, Cham

[19] A. Tharatipyakul and S. Pongnumkul, "User Interface of Blockchain-Based Agri-Food Traceability Applications: A Review," in IEEE Access, vol. 9, pp. 82909–82929, 2021.

[20] F. Qi, L. Zhang, K. Zhuo, X. Ma, "Early Warning for Manufacturing Supply Chain Resilience Based on Improved Grey Prediction Model," Sustainability, 2022, vol. 14, 13125.

[21] C. Fan, C. Lin, H. Khazaei and P. Musilek, "Performance Analysis of Hyperledger Besu in Private Blockchain," 2022 IEEE International Conference on Decentralized Applications and Infrastructures (DAPPS), Newark, CA, USA, 2022, pp. 64–73.

[22] V. Singh, S. K. Sharma, "Application of Blockchain Technology in Shaping the Future of Food Industry based on Transparency and Consumer Trust," Journal of Food Science and Technology, vol. 60, pp. 1237—1254, 2023.

[23] R. Saltini, "IBFT Liveness Analysis," 2019 IEEE International Conference on Blockchain (Blockchain), Atlanta, GA, USA, 2019, pp. 245–252.

[24] P. Dudczyk, J. K. Dunston and G. V. Crosby, "Blockchain Technology for Global Supply Chain Management: A Survey of Applications, Challenges, Opportunities and Implications," in IEEE Access, vol. 12, pp. 70065–70088, 2024.

[25] J. Monteiro, J. Barata, S. Gentilini, "A Digital Twin-Based Digital Product Passport," Procedia Computer Science, vol. 246, 2024, pp. 4123-4132, ISSN 1877-0509.

[26] D. Shakhbulatov, J. Medina, Z. Dong and R. Rojas-Cessa, "How Blockchain Enhances Supply Chain Management: A Survey" in IEEE Open Journal of the Computer Society, vol. 1, no. 01, pp. 230–249, 2020.

[27] T. M. Hewa, Y. Hu, M. Liyanage, S. S. Kanhare and M. Ylianttila, "Survey on Blockchain-Based Smart Contracts: Technical Aspects and Future Research," in IEEE Access, vol. 9, pp. 87643-87662, 2021

[28] M. Rapezzi, G. Pizzi, and G. Marzocchi, "What You See is What You Get: the Impact of Blockchain Technology Transparency on Consumers," Springer Marketing Letters, 2024.