An integrated toolbox for improved verification and prevention of adulterations and non-compliances in organic and geographical indications food supply chain

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D.5.2: Report on the results of the THEROS pilot demonstrations

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Executive Summary

This deliverable, D5.2: Report on the results of the THEROS pilot demonstrations, presents the outcomes of the pilot demonstrations conducted within the THEROS project, focusing on the real-world deployment and assessment of its integrated toolbox for monitoring, verification, and traceability in organic and geographical indication (GI) food supply chains. The pilots represent the culmination of the project's validation activities, translating previously developed technical components into operational settings involving real actors, products, and supply chain processes.

The pilot activities were carried out in four countries—Serbia, Greece, Spain, and the Czech Republic—covering heterogeneous agricultural and food production contexts, distinct regulatory environments, and multiple supply chain configurations. Each pilot was designed to reflect concrete challenges related to food authenticity, compliance with organic and GI requirements, sustainability monitoring, and information transparency. Through these demonstrations, the THEROS project assessed the practical applicability, interoperability, and added value of its toolbox components when used jointly in end-to-end scenarios.

This deliverable presents a consolidated analysis of the pilot results, addressing both system-level performance and user-level experience. From a technical perspective, the demonstrations confirm that the THEROS components can be effectively integrated and operated as a coherent digital ecosystem, supporting the collection, harmonisation, and exploitation of heterogeneous data streams, including Earth Observation outputs, in situ sensor measurements, laboratory-based analyses, and supply chain event data. The pilots show that these data can be transformed into actionable information supporting verification, traceability, and sustainability-related assessments across different stages of the food value chain.

Equally important, the pilot demonstrations provide evidence of the operational relevance of the THEROS toolbox for diverse stakeholder groups. Farmers, producers, certification bodies, processors, distributors, and cooperatives actively interacted with the system during the pilots, validating its usability, clarity, and relevance to their day-to-day activities. Feedback collected throughout the demonstration phase highlights the contribution of THEROS tools in improving visibility over supply chain processes, supporting compliance checks, and enhancing confidence in the integrity of organic and GI products.

Special emphasis is placed on the validation of THEROS functionalities related to environmental monitoring and green accountability. The pilot results illustrate how sustainability-related indicators—derived from remote sensing, sensing technologies, and analytical tools—can be operationally embedded into digital workflows and presented through user-friendly interfaces. This enables stakeholders to access

structured, verifiable information linked not only to product authenticity but also to environmental performance and farming practices.

Overall, the findings reported in this deliverable demonstrate that the THEROS toolbox is capable of supporting integrated verification and traceability processes under real operational conditions. The pilot demonstrations confirm the maturity of the proposed approach and provide concrete evidence to support future replication, scaling, and exploitation of THEROS solutions. The insights gained through the pilots also inform recommendations for further refinement, wider adoption, and alignment with evolving regulatory and market requirements in the domain of organic and GI food systems.

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Abbreviations & Acronyms

Abbreviation / acronym	Description
D5.2	Deliverable number 2 belonging to WP 5
dDPP	dynamic Digital Product Passport
DNA	Deoxyribonucleic Acid
EC	European Commission

Abbreviation / acronym	Description
EO	Earth Observation
GAT	Green Accountability Tool
GI	Geographical indication
GMO	Genetically modified organisms
HRM	High Resolution Melting
IoT	Internet of Things
KPIs	Key Performance Indicators
MEMS	Microelectromechanical systems
PCR	Polymerase Chain Reaction
PO	Project Officer
PU	Public dissemination level
SMEs	Small and Medium-sized enterprises
WP	Work Package

1. Introduction

1.1 Purpose of the document

This deliverable presents the consolidated results of the pilot demonstrations conducted within the THEROS project, focusing on the practical validation of the developed toolbox in real operational environments. The purpose of Deliverable D5.2 is to document how the THEROS solutions were deployed, used, and assessed by end users across different supply chain contexts, and to analyse the outcomes of these demonstrations in relation to the project's objectives.

Unlike previous deliverables that describe system design, technical development, or evaluation methodology, this report focuses on evidence generated through real-life usage of the THEROS tools. It captures the extent to which the toolbox supports monitoring, verification, traceability, and sustainability assessment in organic and geographical indication (GI) food supply chains, when applied under realistic constraints and conditions.

The document aims to:

- report on the execution of the pilot demonstrations in the participating countries,
- summarise the observed technical and operational performance of the THEROS components,
- present feedback and observations from involved stakeholders,
- identify benefits, limitations, and lessons learned during deployment,
- and provide input for future replication, scaling, and exploitation activities.

By consolidating these elements, D5.2 serves as a key reference for assessing the overall effectiveness and maturity of the THEROS integrated approach.

1.2 Intended readership

Deliverable D5.2, "Report on the Results of the THEROS Pilot Demonstrations", is a public deliverable of the THEROS project and is addressed to a broad range of stakeholders involved in or interested in the validation of innovative solutions for organic and geographical indication (GI) food supply chains. Its primary audience includes the European Commission (EC), the Project Officer (PO), and the members of the THEROS consortium.

The deliverable is intended to provide these audiences with a clear and structured account of the pilot demonstrations conducted within the project, presenting evidence generated through the real-life deployment of the THEROS toolbox. It documents how the developed tools were applied in operational environments, the types of results observed during the demonstrations, and the extent to which the pilots addressed the targeted challenges related to traceability, verification, and sustainability.

Beyond the project's internal stakeholders, this document is also relevant to external actors such as control and certification bodies, producers and cooperatives, technology providers, policy makers, and researchers working in the fields of food authenticity, digital traceability, and agri-food sustainability. By reporting on concrete pilot outcomes, the deliverable offers insights into the practical use of advanced digital technologies in quality-labelled food systems.

In line with its Public (PU) dissemination level, D5.2 has been written to be accessible to a wider audience, while maintaining the technical depth required to support transparency and credibility. The document contributes to a broader understanding of how integrated digital toolboxes, such as THEROS, can be operationally applied to strengthen trust, compliance, and sustainability in organic and GI food supply chains.

1.3 Document Structure

This deliverable is organised to guide the reader from the overall context of the pilot demonstrations to the presentation of their concrete results and concluding remarks.

Following the Executive Summary, **Section 1** introduces the scope and purpose of the document and positions it within the validation activities of Work Package 5.

Section 2 provides an overview of the THEROS pilot demonstrations, outlining the general objectives, participating pilots, involved stakeholders, and the main THEROS tools deployed in each pilot context. While **Section 3** presents the testing iteration of the THEROS toolbox.

Section 4 summarises the main outcomes of the pilot demonstrations, highlighting the functionalities that were successfully demonstrated and key observations derived from the implementation of the THEROS toolbox across different operational settings.

Section 5 constitutes the core of the deliverable and presents the results of the pilot demonstrations. The section is structured per pilot, describing the specific context, setup, demonstration activities, and observed outcomes for each country where THEROS solutions were deployed.

Finally, **Section 6** concludes the document with overall remarks on the pilot demonstrations and their contribution to validating the THEROS integrated approach.

2. Overview of Pilot Setup

2.1 Short recap of the pilot objectives and use cases per country

2.1.1 Serbian Pilot

The Serbian pilot was designed to showcase the application of THEROS toolbox components for supporting large-scale monitoring and verification of organic food products. The demonstration focused on illustrating how integrated digital tools can be used across complex organic supply chains, involving a broad range of stakeholders, including farmers and producers, transporters, wholesalers, control and certification bodies, consumers, and policy makers.

The main objectives and expected outcomes of the Serbian pilot demonstration included:

- supporting farmers and producers with digital tools that assist in planning activities in line with organic farming requirements while improving operational efficiency;
- strengthening the monitoring of production units to identify potential non-compliances, including intentional breaches of organic regulations;
- reinforcing traceability and control mechanisms across multi-stage supply chains, covering production, transport, and processing activities;
- enabling the verification of processed quality-labelled products and supporting the identification of fraudulent practices such as dilution, substitution, and mislabelling.

In the real-life scenarios and validation of THEROS toolbox components, managed by Organic Control System Subotica as leader of WP5 and partner organization Univerexport, with technical support of Sinergise, AUTH, EVERIS, ICCS and EBOS, the following THEROS tools has been developed and tested within Serbian pilot:

- EO based ecosystem services
- MEMS based photonics systems
- Dynamic Digital Product Passport
- Blockchain based traceability system
- Green accountability tool
- Verification engine
- Data management and harmonization platform

2.1.2 Czech Republic pilot

The Czech pilot, coordinated by Šumavaprodukt and supported by WirelessInfo (WRLS), is focused on testing a regional Digital Marketplace for local organic and certified products and validating the integration of IoT transport-monitoring sensors and traceability workflows into short food supply chains.

The core use case addressed:

- the challenge of connecting small producers with consumers through a unified online platform,
- ensuring transparent product origin and quality,
- testing IoT-based monitoring of transport conditions (temperature, humidity) for perishable goods, and
- evaluating the feasibility of blockchain-enabled traceability for small-scale local supply networks.

The Czech pilot specifically targeted small regional producers with limited digital capacity, testing how the THEROS tools can reduce administrative burden, increase transparency, and support short food chain logistics.

2.1.3 Greek Pilot

Greek Pilot coordinated by BIONET and supported by BIOHELLAS. The organic farming sector faces many challenges, one of the most important being the compliance of organic products with European Regulations.

To ensure compliance of organic products with the requirements of European regulations, both producers and Certification Bodies should have tools in their hands that permit to

- The farmers to be aware of the environment surrounding their plots in order to be able to take the necessary measurements to avoid contamination of their cultivations by substances prohibited for the organic agriculture. They also need tools that will enable them to strengthen the documentation they provide during inspection process regarding their compliance with the requirements of the European Regulations
- To the Certification Bodies, whose main concern is the products they certify to comply to the requirements of the European Regulations, the tools should allow them to confirm the findings at the inspection site and, in the case that the findings during the inspection shows a discrepancy, to have the ability for an initial investigation, which may lead to a further investigation.
- At the same time a tracking tool, that allows the products monitoring throughout the supply chain from the plot to the final consumer, at retails points, enables the integrity of organic products to be ensured and food fraud to be avoided, while at the same time giving the certification bodies the opportunities to conduct detailed and in dept inspections.

2.1.4 Spanish Pilot

The Spanish pilot, coordinated by Consello Regulador da D.O.P. Mexillón de Galicia and Kiwa España SLU, was on the deployment and real-life validation of the DNA based authenticity kit and the blockchain-based traceability THEROS tools.

The Spanish pilot aims to demonstrate that the mussel cultivated in Galicia and which holds a PDO recognized and registered in the EU through the Commission Regulation (EC) No 1050/2007, could be differentiated from other mussel species (e.g *Mitilus chilensis*) at different stages of the value chain, ensuring transparency and traceability.

Kiwa España S.L.U., serving as the certification body, will verify the DNA testing results and product's traceability information using the blockchain system. The pilot incorporates few checkpoints along the value chain to ensure that the high risky points are verified using the 2 tools. The checkpoints include:

- Unload fresh mussels at the port.
- Depuration of fresh mussel.
- Canning mussel.

2.2 Deployment of THEROS Toolbox components per pilot

Greek Pilot

EO based Ecosystems Services

A variety of applications have demonstrated the critical role of Earth Observation (EO) services in enhancing transparency and traceability within organic supply chains. However, the current implementations have shown optimal results when monitoring large-scale, uniform agricultural fields, with limitation in accurately assessing highly fragmented landscapes and smaller organic farms. The integration of high resolution EO data into the THEROS system can significantly expand its capacity to monitor compliance across diverse agricultural environments, including smaller, irregularly shaped plots. This enhancement will facilitate more precise detection of non-compliance or fraudulent activities and support certification bodies in overseeing organic practices with greater accuracy, even in complex terrain.

With the EO based ecosystems services will be developed markers – insights about what is happening on the parcel by applying statistical and machine learning methods to satellite (or other aerial) imagery timeseries.

The experimental methodology for developing and evaluating the markers is as follows:

- Preprocessing of the reference data provided by the Certification Body
- Training models using reference data
- Evaluation of the models on the left-out set of reference data

- On the spot validation of the results

MEMS based photonic systems and mobile application

The use of portable spectroscopic solutions has shown strong potential for supporting quality assurance across agricultural supply chains. When incorporated into the THEROS ecosystem, MEMS-based photonic systems contribute to more effective monitoring of organic farming practices by certification bodies, support the identification of adulteration at retail level, and enable producers to assess soil conditions and product characteristics under a wide range of operational settings.

MEMS based photonic systems coupled with THEROS mobile application utilizes an on line spectral data base of soil and food. By deploying accurate machine-learning model, the system is able to provide real time estimations of food products' purity, indicate organic compliance and display key soil properties. During the pilot demonstrations, end users had the opportunity to interact with and assess the MEMS-based photonic system in use cases aligned with their operational needs. In particular:

- Producers (BIONET) used the MEMS-based photonic system to perform on-site scanning of soil samples, with reports on key soil properties generated and made accessible through the THEROS mobile application.
- Certification bodies (BIOHELLAS) applied the same system to scan agricultural products, such as oranges, in order to support the identification of potential non-compliances related to organic farming practices.

Blockchain enhanced traceability system /Dynamic Digital Passport for organic food assets.

There is an increased need for transparency in the food supply chain due to the existence of malpractices, such as adulteration of products. This traceability is difficult and expensive due to heterogeneity of systems in different businesses and industries.

By centralizing all this information in a single, shared repository such as the Blockchain enhanced traceability system all actors will converge in a common space where the information will be interoperable and readily accessible for all.

The Blockchain enhanced Traceability system:

- The system stores the following global standards: GS1 for data structure & CTR (Critical tracking events) to structure the events that products go through the supply chain
- By the use of the Verification Engine validates information. Receiving information from the other tool components (ie EO, MEMS, DNA & IOT) is validated with the business rules defined to ensure the authenticity of products traced by the system

- Allow participants to input their information in JSON format either through screens or through APIs

Dynamic Digital product passport for organic food assets

The use of the dDPP for organic products increases traceability as well and contributes to efficient communication of product related information contributing to more informed decision making for consumers.

The dDPP allows the users to obtain information about selected products through scanning QR codes or inputting the product code. The information comes from the harmonization platform and verification engine concerning specific product information, verification data certifications and possibly sustainability data.

The enhancement of traceability, transparency and security aspects through using the DPP (directly) and block chain traceability platform (through the DPP interfaces) is explored by supply chain actors such as transporters and wholesalers represented by BIONET

Green Accountability Tool

The Green Accountability Tool aims for effective monitoring and evaluation of agricultural practices by leveraging advanced technologies such as Earth Observation (EO) data, MEMS photonics and blockchain.

The GAT empowers farmers, policy makers and stakeholders by integrated insights from environmental factors like carbon footprint and soil health, alongside insights from spectral analysis for product authenticity and blockchain-based supply chain traceability. GAT leverage blockchain systems for tracking products, MEMS photonics for soil and product authenticity assessments and EO tools for compliance monitoring and agricultural optimization.

The GAT was demonstrated to different stakeholders such as producers and supply chain factors (BIONET) and Certification Body (BIOHELLAS) for real world evaluation.

Serbian pilot

The Serbian pilot focused on validating the THEROS tools to address several key objectives within sustainable agriculture and food traceability. The central aim was to demonstrate the clear distinction between organic and conventional farming activities. This included the monitoring and verification of Ecological Focus Areas (EFAs) and the maintenance of multiannual crop rotation plans, with an emphasis on intra-field analysis utilizing EO (Earth Observation) ecosystem-based services.

A key focus of the pilot activities was the identification of falsified labelling, with particular attention given to processed quality-labelled products such as powders and liquids. This was addressed through the use of MEMS-based photonic systems, supported by a dedicated mobile application enabling the detection of potential adulteration.

In parallel, the pilot included the validation of supply chain transactions through a blockchain-based traceability system, demonstrating how digital records can be used to support transparent and verifiable product flows. Interfaces were provided for use by inspectors, transporters, retailers, and consumers through a dynamic digital product passport, supporting transparency and accountability at every stage.

Additionally, the green accountability tool was deployed to enable the access and visualization of relevant resources. The data harmonization platform and verification engine played a crucial role in ensuring interoperability, addressing claims, and validating transactions across the supply chain. These combined activities supported the final goal of establishing a robust and trustworthy framework for sustainable food production and distribution.

Czech pilot

The following THEROS components were deployed and tested within the Czech Pilot:

Digital Marketplace

A fully functional multivendor e-commerce platform based on PrestaShop Marketplace Builder was deployed and made publicly available at https://trh.regionalnispeciality.cz.

Features tested and validated:

- vendor onboarding and product listing
- customer ordering workflow
- automated order state transitions
- product-level metadata including origin and certification
- integration endpoints for traceability event submission
- administrative dashboard for producer management

IoT Sensor Network

IoT-enabled “THEROS transport boxes” with temperature and humidity sensors were introduced and tested during simulated and real transport scenarios.

Participants evaluated:

- ease of use
- clarity of monitoring outputs
- trust in data transparency

Traceability Components (Blockchain Integration)

During the pilot, event-based traceability workflows were tested:

- generation of PRE-PROCESS → PACKED → SHIPPED → DELIVERED events
- transmission of events to THEROS traceability portal

automated completeness checks

Spanish pilot

The Spanish pilot focused on the Protected Designation of Origin (PDO) "Mexillón de Galicia", aiming to strengthen authenticity verification, prevent fraud and mislabelling, and enhance end-to-end traceability across the mussel supply chain. The deployment targeted a high-value geographical indication product characterised by multiple transformation stages and strong regulatory oversight, making it an appropriate context for testing advanced verification and traceability mechanisms.

Within this pilot, a selected set of THEROS toolbox components was deployed in an integrated manner, covering key stages from production and landing to processing, packaging, and certification. The core technologies implemented included the DNA-based authenticity kit, blockchain-enhanced traceability, and the Dynamic Digital Product Passport (dDPP), all aligned with PDO control requirements and certification workflows.

The DNA-based authenticity kit was applied at three critical checkpoints along the supply chain. Sampling and analysis were carried out at the landing port during mussel offloading, as well as at two processing stages corresponding to fresh and cooked canned products. This deployment enabled species identification and authenticity verification at multiple points, supporting the detection of potential mislabelling or substitution and reinforcing confidence in declared product characteristics.

In parallel, the blockchain-enhanced traceability system was used to record and manage supply chain events associated with production, transformation, shipment, and certification. Traceability data, documentation, and verification outcomes were uploaded and managed through the THEROS traceability portal, ensuring immutability and transparency of records. The system supported certification workflows by enabling control bodies to review traceability information, verification results, and supporting documents within a single digital environment.

The Dynamic Digital Product Passport (dDPP) acted as the main user-facing interface for accessing verified product information. It aggregated data originating from the DNA authenticity checks and blockchain traceability records and presented them in a structured and role-based manner. Through the dDPP, different supply chain actors-including producers, processors, certifiers, and end users-were able to access information relevant to their role, while maintaining clarity and avoiding information overload.

The deployment of THEROS tools in the Spanish pilot demonstrated a tightly integrated workflow linking authenticity verification, traceability recording, and information dissemination. By combining DNA-based verification with blockchain-backed traceability and a digital product passport, the pilot illustrated how the THEROS toolbox can support PDO control schemes, enhance transparency, and reduce opportunities for fraud in complex and high-value food supply chains.

3. Testing iterations of THEROS toolbox

3.1 EO-based monitoring services

The EO-based monitoring services were deployed and tested primarily in the Serbian and Greek pilots, where they supported parcel-level monitoring of agricultural activity and organic farming practices. During the pilot demonstrations, the services operated as a core analytical component of the THEROS toolbox, generating Earth Observation (EO) markers derived from satellite time series and making them available through the THEROS back-end infrastructure and user-facing interfaces.

In both pilots, EO services were configured to process parcel geometries provided by certification bodies and pilot partners. Satellite imagery time series were analysed to produce a set of monitoring markers capturing land-use consistency, vegetation dynamics, and cultivation patterns. These outputs were delivered through application programming interfaces (APIs) and visualised via integrated tools, enabling near real-time access to parcel-level indicators. The services were tested under realistic conditions, including heterogeneous parcel sizes, diverse crop types, and varying data availability.

In the Serbian pilot, EO-based monitoring services were used to demonstrate support for organic certification and land declaration verification. Stakeholders explored markers related to parcel homogeneity, crop presence, greening and harvest cycles, bare soil periods, and indicators differentiating organic and conventional cultivation signals. The pilot demonstrated how such markers can assist inspectors in identifying inconsistencies between declared and observed parcel characteristics, as well as in prioritising on-site inspections. The ability to visualise seasonal dynamics and detect anomalies at parcel level illustrated the added value of EO services for enhancing traditional inspection workflows.

In the Greek pilot, EO services focused on citrus crops. Testing activities involved reviewing time-series indicators capturing vegetation behaviour and comparing parcel-level signals across different cultivation practices. The pilot demonstrated how EO-derived information can complement field-level assessments and laboratory analyses, supporting a more comprehensive view of farming practices. Users were able to explore spatial and temporal patterns, facilitating discussions on compliance, sustainability, and land-use management.

Across both pilots, EO monitoring outputs were integrated with other THEROS components, including the Green Accountability Tool and the Data Management and Harmonisation Platform. This integration allowed EO markers to be viewed alongside certification status, traceability events, and, where applicable, additional analytical results. The combined visualisation reinforced the role of EO services as a foundational layer for environmental monitoring within the THEROS ecosystem.

Feedback collected during the pilot demonstrations indicated that stakeholders valued the objectivity and spatial coverage provided by EO-based monitoring. Participants highlighted the usefulness of parcel-level indicators for gaining rapid insights into land-use conditions and seasonal evolution, particularly when supporting inspection planning and verification activities. At the same time, users noted the importance of clear contextualisation and interpretation of EO markers, especially for more complex indicators. Overall, the testing confirmed that EO-based monitoring services are a robust and relevant component of the THEROS toolbox, with strong potential to support scalable, data-driven verification processes in organic and GI food supply chains.

3.2 MEMS photonics systems and mobile app

The MEMS-based photonics systems were deployed and tested in both the Greek and Serbian pilots as portable tools supporting on-site quality assessment, organic farming compliance verification, and soil analysis. During the pilot demonstrations, the photonics systems operated in conjunction with the THEROS mobile application, forming an integrated workflow for data acquisition, processing, and visualisation by different stakeholder groups.

In both pilots, MEMS devices were used to collect spectral measurements directly in the field or at relevant points along the supply chain. Testing activities included measurements of soil samples, agricultural products, and food commodities selected according to the pilot objectives. The devices enabled rapid, non-destructive analysis, allowing stakeholders to obtain indicative results without the need for laboratory-based procedures. The pilot demonstrations showed how MEMS-based sensing can support timely decision-making in inspection, quality control, and compliance-related workflows.

The THEROS mobile application served as the primary interface for operating the MEMS devices and managing the collected data. Stakeholders used the application to initiate measurements, associate results with specific parcels, products, or batches, and upload the data to the THEROS back-end infrastructure. The application guided users through the measurement process, helping ensure consistency in data collection while reducing the complexity of operating advanced sensing equipment.

Across both pilot implementations, the mobile application was actively used by diverse stakeholder groups, including producers, inspectors, retailers, and technical partners. Users highlighted the benefit of being able to view measurement outputs shortly after acquisition and to associate these results with other monitoring and traceability information available within the THEROS ecosystem. The demonstrations also offered useful insights into how users interact with the application, underlining the importance of intuitive workflows and clear visualisation of results when introducing advanced sensing tools into real operational settings.

Overall, the testing of MEMS-based photonics systems and the associated mobile application confirmed their suitability for field deployment and their relevance as complementary tools within the THEROS toolbox. The pilots demonstrated how portable sensing, when supported by user-friendly digital interfaces, can enhance evidence collection and support integrated verification processes across organic and GI food supply chains.

3.3 DNA authenticity kit

The DNA-based authenticity kit was deployed and demonstrated exclusively in the Spanish pilot, where it was used to support species identification and authenticity verification for selected food products. During the pilot demonstrations, the kit was tested as a verification tool providing evidence to support product authenticity claims within the THEROS toolbox.

Testing activities focused on the analysis of representative samples selected in collaboration with the pilot partners. The DNA-based kit was used to identify species-related characteristics and to support the verification of declared product attributes, particularly in cases where visual inspection or other sensing technologies alone would not be sufficient to confirm authenticity. The pilot demonstrated how DNA-based analysis can be applied in practice to address risks related to mislabelling or substitution.

In the Spanish pilot, the deployment of the DNA-based authenticity kit was linked to traceability and certification-related workflows. Results produced during the demonstrations were associated with specific product batches, allowing stakeholders to explore how DNA-based verification outcomes can be connected to digital traceability records. This illustrated the role of the kit as an additional source of evidence supporting control and inspection activities.

The pilot also enabled stakeholders to review and discuss the use of DNA-based verification results in an operational context. Participants examined how such results could complement existing control processes and enhance confidence in product authenticity, particularly for high-value and quality-labelled food products.

Overall, the Spanish pilot confirmed the relevance of the DNA-based authenticity kit as part of an integrated verification approach. The demonstrations showed its potential to strengthen authenticity assurance and to support supply chain actors and control bodies in addressing fraud-related challenges within organic and geographical indication food systems.

3.4 Blockchain-enhanced traceability system and dynamic digital product passport

The blockchain-based traceability solution and the Digital Product Passport (DPP) were deployed as integrated elements of the THEROS toolbox, enabling the trusted capture, validation, and display of product information throughout the food supply chain. During the testing iterations, these components operated as the backbone for managing traceability events and making verified information accessible to different stakeholder groups through digital interfaces.

The blockchain component was used to record key supply chain events related to production, processing, packaging, transportation, and certification. These events were generated automatically or semi-automatically by connected THEROS tools and were stored in an immutable and tamper-resistant manner. Through this process, the system demonstrated how traceability data originating from heterogeneous sources can be securely consolidated and made available for verification purposes without relying on manual data reconciliation.

The Digital Product Passport functioned as the primary mechanism for exposing verified traceability information to end users. It provided a structured digital representation of each product or batch, aggregating information related to origin, certification status, and recorded supply chain events. The DPP enabled users to access this information through a single reference point, ensuring consistency between the data stored in the blockchain infrastructure and the information presented to stakeholders.

Throughout the testing iterations, the integration between the blockchain infrastructure and the Digital Product Passport demonstrated the ability to support near real-time updates of product status. As new traceability events were recorded, corresponding updates became available through the DPP, allowing users to follow the progression of products along the supply chain. This interaction illustrated how verified data can flow seamlessly from back-end systems to user-facing applications while maintaining data integrity.

The combined operation of blockchain-based traceability and the Digital Product Passport highlighted their complementary roles within the THEROS ecosystem. While the blockchain ensured trust, immutability, and accountability of recorded events, the DPP translated this information into an accessible and user-friendly format. Together, these components supported transparency, facilitated verification activities, and strengthened confidence in the authenticity and compliance of quality-labelled food products.

Overall, the testing of these components confirmed their suitability as core enablers of digital traceability within the THEROS toolbox. Their integration demonstrated how secure data recording and intuitive information access can be combined to support trustworthy, efficient, and transparent food supply chains.

3.5 Green Accountability Tool

The Green Accountability Tool (GAT) was deployed and demonstrated in the Serbian and Greek pilots as the central visual interface for visualising environmental indicators, traceability information, and certification status. During the pilot demonstrations, the tool operated as a unified dashboard that brought together information from Earth Observation services, MEMS-photonics analysis, the blockchain-based Verification Engine, and the Data Management and Harmonisation Platform. Through this integration, pilot partners gained access to harmonised datasets that could be viewed in near real time.

In both pilots, GAT was deployed as a web-based interface supported by secure authentication. Its integration with the THEROS back end allowed the tool to retrieve parcel-level EO markers, spectral analysis results from MEMS devices (used in the Greek pilot), and verified traceability events issued by the blockchain infrastructure. Certification and compliance information was displayed using the traffic-light logic defined during development, enabling users to immediately identify certified, verified, or pending statuses for products and parcels. Throughout the pilot demonstrations, the GAT performed as the main visual layer through which inspectors, producers, and pilot partners could review monitoring data, environmental indicators, and verification-related outcomes.

In the Serbian pilot, the tool was used primarily for parcel-level environmental monitoring and support to organic certification activities. Stakeholders explored EO-derived indicators showing the condition of agricultural parcels, seasonal anomalies, and organic versus non-organic cultivation signals. This facilitated demonstrations of how remote monitoring could enhance inspection processes and support the verification of land declarations. The Serbian team also made use of the certification and verification view, which consolidated information relevant to ongoing certification processes, helping illustrate how an integrated interface could support both inspectors and producers.

In the Greek pilot, GAT was used to demonstrate the combined operation of environmental monitoring and MEMS-based assessments. User testing involved reviewing parcel-level EO information related to olive and herb cultivation, while also visualising MEMS spectral measurements for soil and selected product samples. In this context, the tool showed how the integration of environmental signals and purity assessments can support decisions related to sustainability, product quality, and compliance verification. Greek pilot participants also explored the supply chain perspective of the tool, focusing on how traceability events and certification results appear in the system and how they can inform control or inspection activities.

Stakeholder evaluation in both pilots indicated a generally positive response to the GAT's usability and usefulness. Participants appreciated having previously fragmented information consolidated into a single interface, and they highlighted the clarity of the traffic-light status indicators and the intuitive presentation of environmental data. Some users noted the value of being able to quickly compare parcel-level indicators during inspections or decision-making processes, while others pointed to the potential of MEMS and EO integration for improving the efficiency of verification workflows. At the same time, stakeholders also identified areas for further refinement, mainly relating to the level of detail shown in more complex environmental indicators and the need for continued guidance on interpreting specific metrics. Overall, the feedback confirmed the tool's relevance for inspection bodies and producers and its potential for wider operational adoption.

3.6 Digital Marketplace & IoT

The Czech pilot provided one of the most comprehensive demonstrations of how the THEROS Digital Marketplace, IoT sensor monitoring and blockchain-based traceability can operate as an integrated ecosystem supporting short and transparent supply chains. Throughout the pilot, producers, consumers, and regional stakeholders interacted with a fully functional multivendor marketplace and tested it in combination with IoT-enabled transport boxes and automated traceability event recording. This allowed the consortium to assess not only the technical performance of each tool, but also their combined value when applied in real regional food systems.

The Digital Marketplace played a central role during the pilot by acting as the primary interface between producers and consumers. Participants viewed the platform as intuitive and easy to use, a finding supported by consistently high KPI evaluations, which ranged between 4.3 and 5.0 across multiple workshops. Users particularly appreciated the clear visual structure of product pages, the transparency of origin information, and the ability to trace certification details directly from the listing. For producers, the platform offered a straightforward onboarding process and simplified product management, making it possible even for stakeholders with limited digital skills to join the system. The positive reception from both producers and consumers confirmed the marketplace as a key enabler of short food supply chains and direct sales.

Complementing the marketplace, the IoT Sensor Monitoring component provided real-time environmental information during product transport. The THEROS sensor boxes, equipped with temperature and humidity monitoring, were tested extensively during demonstrations and simulation exercises. Across all sessions, stakeholders rated the usefulness of the sensor outputs extremely highly, with average scores between 4.86 and 5.00. Participants highlighted the immediate value of being able to verify transport conditions, particularly for perishable foods. Several producers also identified additional potential applications beyond transport itself, such as continuous monitoring during farmers' markets or storage in temporary facilities. The ability to provide objective environmental data increased trust in product quality and encouraged producers to consider how such monitoring could enhance their transparency commitments.

The traceability and blockchain component further strengthened the ecosystem by enabling automated recording and verification of product lifecycle events. During the Czech pilot, every order placed through the marketplace triggered a series of traceability events—production, packaging, shipment, and delivery—which were transmitted to the THEROS traceability portal and recorded on the blockchain. This workflow achieved a traceability completeness of 100%, demonstrating the reliability of the integration. To validate performance in scenarios involving non-compliant products, WRLS conducted a simulated recall exercise. The system successfully identified all affected orders, blocked further sales of the product, notified relevant stakeholders, and initiated corrective actions within 1 hour and 45 minutes, substantially outperforming the KPI threshold of 24 hours. This result confirms the viability of the THEROS solution for rapid incident response in real operational environments.

Taken together, the combined deployment of the Digital Marketplace, IoT monitoring, and blockchain verification demonstrated the full potential of the THEROS toolbox in the Czech regional context. The tools proved technically robust, well accepted by users, and mutually reinforcing their contribution to transparency, data integrity, and user confidence. The pilot experience shows that when integrated into a single workflow, these tools deliver a powerful foundation for trustworthy, efficient, and environmentally responsible local food supply chains.

3.7 Data Harmonisation Platform and verification engine

The Data Harmonisation Platform and the Verification Engine were tested as core backbone components of the THEROS toolbox, enabling the integration, standardisation, and verification of heterogeneous data streams generated by the different THEROS tools. During the testing iterations, these components operated continuously in the background, supporting the end-to-end flow of data from acquisition to verification and downstream consumption by user-facing applications.

The Data Harmonisation Platform functioned as the central integration layer of the THEROS ecosystem. It received data originating from multiple sources, including EO-based monitoring services, MEMS-based photonics systems and the mobile application, IoT sensor networks, DNA-based authenticity tools, and traceability systems. Through a set of dedicated connectors and translation mechanisms, incoming data were transformed into harmonised and standardised representations, ensuring consistency across datasets with different formats, semantics, and temporal or spatial characteristics. This process allowed diverse information streams to be managed within a unified data framework and made accessible to other THEROS components in a consistent manner.

Throughout the testing phase, the platform demonstrated its ability to support near real-time data ingestion and dissemination. As new measurements, monitoring results, or traceability events were generated, the harmonisation mechanisms enabled their structured storage and retrieval, ensuring that up-to-date information could be accessed by connected tools such as the Green Accountability Tool, the Digital Product Passport, and the traceability services. The testing confirmed that the platform could reliably support interoperability across the THEROS toolbox without requiring manual data reconciliation.

Complementing the harmonisation layer, the Verification Engine was tested as the component responsible for assessing incoming data against predefined verification rules. Based on the harmonised data received from the platform, the engine executed automated checks reflecting business and compliance requirements defined within the THEROS framework. These checks resulted in verification outcomes that were recorded as part of the product or parcel lifecycle and could be consulted alongside other traceability information.

The interaction between the Data Harmonisation Platform and the Verification Engine was a key focus of the testing activities. The combined operation demonstrated how only relevant and structured data are forwarded for verification, while preserving data integrity and traceability. Verification outcomes were generated consistently and made available to other components, reinforcing transparency and trust across the system.

Overall, the testing iterations confirmed the role of the Data Harmonisation Platform and Verification Engine as essential enablers of integrated verification within the THEROS toolbox. Their combined operation ensured that data produced by diverse monitoring and sensing technologies could be reliably harmonised, verified, and reused, supporting coherent and trustworthy traceability workflows across organic and geographical indication food supply chains.

4. Demonstration Activities

Serbian pilot

Over the past three years, the Serbian pilot of the THEROS project has actively promoted and demonstrated the project across a range of events and activities. Representatives from OCS introduced the THEROS project and its toolbox at fairs and informational sessions targeting the Serbian agrifood sector. These events, which included Innovative4Climate, the FoodTech and Agricultural Fair in Novi Sad, Biofest in Subotica, and Organic Fest in Banja Luka, attracted a diverse audience of professionals such as producers, processors, inspectors, and consultants. The primary focus was on presenting the THEROS toolbox for demonstration and testing throughout the duration of the project in Serbia.

In addition to public presentations, targeted demonstration activities were conducted in Novi Sad. Here, the first iteration of the dDPP (Dynamic Digital Product Passport) tool was tested among employees of Univer and OCS, as project partners. This testing group comprised producers, supply chain participants, food technologists, IT professionals, certification bodies, and consumers. The goal was to introduce the implementation of dDPP within the company and gather participant feedback to inform further development of the tool. This collaborative testing phase yielded valuable insights into the practical application of the dDPP, benefiting both the tool developers and participants.

Feedback from these activities emphasized the importance of tailoring user roles within the system to the specific needs of each user group. For consumers, participants recommended that only essential product information—such as product owner, lot number, production and expiration dates, country of origin, and certification status—be displayed. To provide a clear visual indication of valid certificates, they suggested adding a green check mark next to certificates before download, while still allowing downloads as needed. Participants also proposed displaying the product's organic status and the traceability steps leading to the final product, along with further differentiation in the app's visual design for various product types. These suggestions guided the development of dDPP into a user-friendly, purpose-built application for product traceability.

The Serbian pilot also participated in international demonstrations during plenary meetings in Prague and Santiago de Compostela. In Prague, the MEMS tool was tested using organic flour from Univer, where the detection of the purity index was observed in practice. In Santiago de Compostela, the dDPP tool was used to visualize and trace the journey of products such as organic wheat flour, organic sunflower oil from production through to retail but also transformation phase of organic apple juice. The functionality of the THEROS toolbox was further showcased at the final plenary meeting in Athens, where the fully tested tools as implemented in the Serbian pilot were presented and demonstrated.

During the implementation phase, OCS inspectors conducted on-site visits with producers to test Earth Observation (EO) technology. These visits facilitated knowledge sharing about how satellite technology could be used to monitor plots and the benefits of applying such tools. OCS provided parcels for EO marker verification, with a strong focus on evaluating the crop group marker—a critical step in confirming organic status. More than 300 farmers were visited, checked, and informed about the EO tool and its applications. The EO model demonstrated strong capabilities for monitoring monocultures of major fruit crops, though further refinement is needed for mixed cropping systems. The confidence scores produced by the model served as valuable indicators of prediction reliability.

For the continued development and effective implementation of EO ecosystem services in Serbia, collaboration with the Ministry of Agriculture and involvement of all stakeholders in organic farming remains essential.

To further facilitate adoption and broaden the impact of the THEROS toolbox, the Serbian pilot organized Learning History workshops. These workshops engaged a wide range of stakeholders, including supply chain actors, technology providers, food technologists, certification and inspection bodies, regulatory authorities, and consumers. Two workshops were held—one in Novi Sad and another in Subotica—with a combined attendance of 29 participants.

The first workshop provided hands-on demonstration and training in the use of a MEMS-based photonic sensor. Using samples of organic wheat flour and organic apple juice, participants were guided through step-by-step analysis with the device and its mobile application. They scanned samples, observed experimental results such as the flour purity index and vitamin C content, and gained insight into the practical benefits of rapid on-site food quality and safety testing. The session also underscored the need for consistent user training and data interpretation methods.

The second workshop introduced attendees to the dDPP and the Green Accountability Tool Platform (GAT), utilizing examples like organic wheat flour, sunflower oil, and apple juice. Participants tested the dDPP app by scanning QR codes or entering product IDs to access user-specific data, whether as producers, consumers, transporters, or certifiers. The GAT platform was also demonstrated, summarizing THEROS project activities related to organic agriculture and the geographical origins of products. Stakeholders appreciated the transparency offered by QR-based traceability but highlighted the importance of simplifying application interfaces and providing more guidance for producers to enhance usability and encourage wider adoption.

Greek Pilot

The Greek pilot concentrated on the deployment and testing of THEROS tools in real operational settings, with the objective of strengthening organic farming practices, increasing supply chain traceability and transparency, showcasing participatory certification workflows, supporting informed decision-making by supply chain stakeholders, and advancing the evaluation of carbon footprint-related indicators. The Greek Pilot involved the Agricultural Cooperative of Organic Farmers of Western Greece – BIONET, and the Institute for Control of Organic Products – BIOHELLAS, as the Certification Body. The supply chain actors included producers who are members of BIONET, as well as BIONET itself with its facilities for receiving, sorting, packaging, and distributing fresh organic products in Gastouni. The activities of the Greek Pilot focused on the development and real-world validation of the individual elements of the THEROS toolbox.

The initial activity focused on the application of Earth Observation (EO)–based ecosystem services to differentiate organic from conventional farming practices, support the monitoring of ecological focus areas and perennial crop rotation schemes, and enable parcel-level analysis. Through these services, EO data were used to support the detection and verification of organic farming activities. Participating actors included farmers who are members of BIONET and the certification body (BIOHELLAS).

The implementation took place on one organic and two conventional citrus farms in the Agrinio area, Western Greece, covering a total of 40 hectares (17 organic and 23 conventional). During the pilot, the trained markers included homogeneity, greening, harvest, bare-soil, crop type, and organic/non-organic classification, covering approximately 13,000 plots in Greece. Observed crops in Western Greece mainly included tree crops such as citrus and olive trees, while in Central Macedonia, arable crops were included. Evaluation on the three plots was based on data collected through MEMS systems, which allowed for indicator verification and real-time monitoring of organic practices.

The technology supported the verification of organic farming practices, as EO services detect and distinguish organic from non-organic activities. They also verify crop rotation and monitor areas of ecological interest, supporting compliance with EU organic farming regulations. Furthermore, the use of advanced machine learning (ML) and hyper-analysis models enabled the monitoring of small and complex plots (>0.1 hectares), while in-field analysis highlighted local cases of non-compliance. Finally, biophysical parameters derived from EO and ML models provided management recommendations (fertilization, irrigation, yield estimation) and support for carbon footprint and carbon sequestration assessments on the plots. The second activity involved providing ML-based recommendations to farmers to support the adoption of best cultivation practices.

The next activity focused on the use of MEMS photonic systems and the corresponding mobile application to identify practices incompatible with organic farming, such as the use of pesticides and non-organic fertilizers during food production. The pilot implementation of the MEMS Photonic Sensor was conducted on BIONET farms in the Kalyvia Agriniou area. The implementation was organized in three phases: initial sampling of 240 oranges (60 organic samples and 60 control samples, 60 conventional samples and 60 control samples), a second shipment of 48 oranges (24 organic, 24 conventional), collection of 120 soil samples from the same farms where the oranges were collected, and on-site demonstrations on May 20, 2025. Participants included BIONET producers, Aristotle University of Thessaloniki (AUTH) providing technical support, BIOHELLAS for results evaluation, and ICCS for technical guidance. Additionally, an online workshop was held with 16 participants (farmers, BIOHELLAS and ICCS inspectors).

Spectral data (Vis–NIR reflectance) and chemical analyses were collected for 240 oranges and 120 soil samples (60 from two organic farms, 60 from one conventional farm). The data included detection of pesticides, non-organic fertilizers, and other chemicals, as well as organic/non-organic classification. Results were validated using accuracy and F-score for SOC, Clay, pH, and Organic/Conventional management, with accuracy values of 0.69–0.79 and F-score 0.63–0.78.

The pilot implementation of dDPP was conducted under real conditions for organic citrus in Greece, covering the entire journey from field production to retail. Activities included a mobile application for producers, distributors, certification bodies, and consumers. Two online workshops were organized with 20 participants, including BIONET members and BIOHELLAS inspectors and ICCS. Users accessed the application via lot numbers or QR codes. Traceability events (Production, Shipping, Transformation Events) were recorded with unique identification codes. The system enabled verification of the complete product journey, real-time compliance monitoring, reduction of necessary certificate and invoice printing, and improved transparency and connectivity among all involved actors.

Additionally, the blockchain-based traceability system was evaluated, operating along the interfaces exposed by the Digital Product Passport. During the pilot activities of the THEROS project in Greece, a blockchain-enhanced traceability network was implemented for fresh organic products. Tests were conducted under real operational conditions, covering the entire supply chain from production to distribution. Participants included BIONET producers, certification bodies and inspectors (BIOHELLAS), carriers, and consumers.

All critical traceability events for each batch were recorded: Test Status, Production Event, Shipment Event, Transformation Event, Transit Event, Aggregation Event. The data included information from producers, measurements from MEMS systems, EO observations, and certificates. Blockchain ensured tamper-proof traceability and immutable audit history, allowing automatic cross-verification from multiple independent sources, detection of potential fraud or non-compliance with organic farming standards, and full “farm-to-market” transparency.

Another activity involved the use of the Green Accountability Tool (GAT), which provided access to and visualization of relevant data and facilitated interactions between authorities and supply chain actors. In the context of the Greek THEROS pilot, two pilot demonstrations of GAT were carried out: the first in summer, with BIONET in an administrative role and BIOHELLAS, and the second in mid-November, with active participation of BIONET member-producers. Activities included training and on-site use of the tool on farms, as well as online navigation and data analysis via the platform. The tool integrates data from Earth Observation (EO), MEMS sensors, and in-field measurements, providing a comprehensive view of environmental indicators.

Data were collected on soil health, vegetation status, carbon footprint, and compliance with European Regulation for organic farming. GAT centralizes data, provides transparency and practical recommendations, and enables evaluation of environmental performance and decision-making support. The evaluation validated the accuracy and usability of the environmental indicators and recommendations provided by the tool. Next, the participatory model was applied, allowing organic farmers to provide evidence of compliance to certification bodies through measurements collected by photonic systems and leveraging the integrity framework of the Digital Product Passport. Finally, basic soil properties were produced, and a large-scale assessment of carbon footprint and carbon sequestration associated with the production of organic food resources was conducted.

Within the implementation of the Learning History Workshops, the tools were applied and evaluated under real conditions by supply chain actors and certification bodies. The evaluation showed that the used technologies can be applied in different environments, and the combination of digital tools can lead to best practices in organic farming, enhance the reliability of organic products regarding compliance with EU regulations, and provide a competitive advantage for organic products in international markets.

During the Greek THEROS pilot program, the engagement of all stakeholders was critical for the successful implementation and evaluation of the tools. Farmers, certification bodies, technical partners, and consumers actively participated in the trials, providing feedback and taking part in workshops, training, and pilot applications. Their involvement ensured that the technologies were adapted to the real needs of users and used effectively in practice.

Farmers and members of BIONET, together with the certification body BIOHELLAS, actively participated in activities based on Earth Observation (EO) services on farms in Agrinio. From the outset, users responded positively to the technology, primarily because it allowed them to monitor even small and fragmented plots, which had been difficult with traditional methods. Despite the initial positive reception, training was considered necessary to ensure that farmers fully understood the recommendations derived from machine learning (ML) techniques and could correctly interpret the results of the analyses.

In the pilot implementation of MEMS photonic technology systems and the Digital Product Passport (dDPP), BIONET farmers, BIOHELLAS inspectors, and technical partners from Aristotle University of Thessaloniki (AUTH) and ICCS participated. Active user involvement in this participatory model enhanced transparency in certification processes and reduced administrative and bureaucratic workload during inspections. Users accepted the tools positively, while training focused on the correct use of MEMS devices and understanding the collected spectral and chemical data.

The dDPP allowed all users to participate in a transparent and participatory system for monitoring product journeys. The pilot involved BIONET farmers, BIOHELLAS inspectors and ICCS, transporters, and consumers. Evaluation via questionnaires confirmed the positive reception of the technology by users. Additionally, the workshops provided an opportunity to present the functions and benefits of the system, train participants in proper use, familiarize them with the application, and demonstrate how to utilize the tools for product monitoring, certification, and transparency.

In the blockchain network, data were recorded by BIONET with the participation of farmers (who also acted as transporters) and BIONET's packing facility. Certification bodies BIOHELLAS and ELGO-DIMITRA, inspectors, retailers, and consumers accessed the data through the dDPP. The technology significantly improved reliability and transparency in product monitoring, as all data were readily available, up-to-date, and verified. This allowed all stakeholders to see the complete journey of the product from field to shelf, increasing trust in the quality and origin of organic products. Moreover, the system promotes the establishment of new reliability standards for the Greek organic market. Initial user acceptance was highly positive, showing interest and willingness to integrate the technology into daily supply chain operations.

For the GAT tool, BIONET farmers, and the BIOHELLAS inspectors participated. Farmers responded positively, especially due to the tool's ease of use and practical field application, which allowed them to view real-time data on their crops. Certification bodies used GAT to monitor compliance with organic farming standards and the environmental performance of farms, aiming for improved evaluation and assurance of product quality. The overall experience demonstrated that the tool can significantly improve crop sustainability, enhance transparency in production processes, and support decision-making for more responsible and efficient management of Greek organic products.

Overall, the engagement of all stakeholders was decisive for the successful implementation of the THEROS pilot program tools. Active participation, training, and feedback from farmers, certification bodies, and technical partners allowed technologies to be adapted to real needs, strengthened transparency and reliability of processes, and supported informed decision-making for the sustainable management of organic crops.

Spanish Pilot

The demonstration activities of the Spanish pilot were carried out in Galicia and focused on the validation of THEROS tools in a real operational environment involving the PDO "Mexillón de Galicia" mussel supply chain. The activities were designed to demonstrate the practical deployment of authenticity verification and digital traceability solutions across multiple stages of production, processing, and certification, involving all relevant stakeholders.

On the 26th of May, 2025, a meticulously organized technical visit provided an in-depth exploration of the value chain behind one of Galicia's most emblematic seafood products: the Mejillón de Galicia, certified under the prestigious Protected Designation of Origin (PDO). A dedicated team of ten professionals, representing various entities involved in the Theros Project, embarked on this insightful journey, departing promptly at 8:00 a.m. from the Exe Peregrino Hotel in Santiago de Compostela. This marked the beginning of a comprehensive day devoted to understanding the intricate processes involved in the purification, processing, and genetic authentication of Galician mussels.

The first destination was Conservas Friscos in Catoira, where the group arrived punctually at 9:00 a.m. This leading cannery boasts decades of expertise in mussel preservation. Upon arrival, the team received a warm welcome from the plant's technical director and the company's CEO, a proud member of the fourth generation of the family that owns the enterprise. They provided an exhaustive explanation of the entire processing cycle. Participants were meticulously guided through each phase: from the initial reception of raw mussels to steaming, painstaking manual cleaning, careful selection, and precise packing. Special emphasis was placed on the artisanal techniques that remain integral to the process, the traditional preparation of flavorful sauces, and the rigorous hygiene and sterilization protocols that are strictly adhered to. Additionally, the group delved into the labeling standards that ensure consumers receive accurate information regarding the product's origin, a critical component under PDO regulations. This visit offered invaluable context, highlighting how quality and tradition harmoniously coexist within an industrial framework to produce a product renowned worldwide.

At 11:15 a.m., the team proceeded to the mollusk purification facility of Angulas Aguinaga in Cambados, where mussels undergo an essential depuration process before reaching the market. This state-of-the-art facility operates under stringent microbiological safety parameters, ensuring that mussels are thoroughly cleansed of sand, grit, and potential contaminants. The visitors had the opportunity to tour the advanced purification tanks, which utilize UV-treated seawater, and observe how environmental simulations facilitate the natural expulsion of impurities by the mussels. Plant officials elaborated on the robust traceability measures and strict regulatory controls in place, certifying each batch prior to its entry into the market or subsequent canning stages. This segment of the visit underscored the critical role that depuration plays in safeguarding food safety and fostering consumer confidence.

Subsequently, at 12:45 p.m., the group made a brief yet enlightening visit to the local port to witness the unloading of freshly harvested mussels from the iconic bateas (rafts) of the Rías Baixas. This stop provided a vivid, real-world context to the technical aspects explored earlier in the day, allowing participants to fully appreciate the logistical intricacies involved in transporting mussels from sea to shore.

The final stop of the day was at the headquarters of the Regulatory Council for the PDO Mussel of Galicia, also situated in Cambados. After lunch there was an engaging session of presentations and discussions. Representatives from the Council eloquently detailed the history, mission, and regulatory framework of the PDO, articulating the pivotal role it plays in preserving the integrity and enhancing the added value of Galician mussels in both national and international markets.

One of the most eagerly anticipated segments of the visit was the presentation on the genetic traceability protocol by the Theros Project’s partners. The technical staff delivered a clear, accessible presentation outlining the molecular analysis methods employed to verify the geographic origin of mussels through DNA markers. This groundbreaking tool empowers authorities to authenticate a mussel’s origin from Galician waters, even after processing and shell removal. The group observed the meticulous process of sample collection and analysis, gaining insight into how this system serves as a robust defense against fraud and mislabeling.

Following a dynamic round of questions and discussions, the group departed Cambados and made their way back to Santiago. The visit concluded with a profound sense of appreciation for the technical precision, commitment to sustainability, and cultural significance that define the Galician mussel sector. Through firsthand observation of every step in the value chain—from sea to cannery to laboratory—the participants left with a deepened understanding of why Mejillón de Galicia stands as a true emblem of authenticity and excellence.

In parallel, blockchain-enhanced traceability functionalities were demonstrated by recording key supply chain events related to production, transformation, shipment, and certification. Stakeholders interacted with the traceability portal to review lot information, supply chain flows, and verification outcomes. The demonstration also included the execution of certification-related actions, illustrating how traceability data and verification results can support digital certification workflows within the PDO control framework.

The Dynamic Digital Product Passport (dDPP) was demonstrated as the primary interface for accessing verified product information. Different user roles—including producers, processors, certifiers, and end users—were shown how to access role-specific views of the product passport, review traceability information, and consult verification results. This activity highlighted how complex supply chain data can be presented in a structured and user-friendly manner.

In addition to the on-site demonstration, Learning History workshops were organised to support stakeholder engagement and knowledge exchange. These activities included both on-site and remote sessions dedicated to the Dynamic Digital Product Passport and the DNA-based authenticity kit. Participants were introduced to the demonstrated workflows, engaged in discussions on practical use cases, and provided feedback through structured questionnaires.

Overall, the demonstration activities in the Spanish pilot provided a comprehensive showcase of how the THEROS toolbox can be applied in a PDO-controlled seafood supply chain. By combining on-site demonstrations with stakeholder workshops, the pilot ensured that both technical deployment and operational interaction with the tools were effectively demonstrated.

Czech Republic Pilot

Stakeholder engagement in the Czech pilot was consistently strong and played a central role in validating the relevance and usability of the THEROS tools in a real regional context. Across three workshop events, the pilot gathered a total of 102 participants, representing a wide spectrum of actors involved in short supply chains, including small and medium producers, technology providers, regional development organisations, tourism stakeholders, advisory bodies, and public authorities. Engagement levels remained high throughout the pilot, reflected both in active workshop participation and in the 61 completed evaluation surveys, which provided valuable quantitative and qualitative insight into user perceptions. The engagement

KPI threshold of 80% was exceeded, with the final workshop in Klatovy achieving 85% attendance, demonstrating sustained interest and commitment among stakeholders.

The diversity of participants allowed for a rich exchange of perspectives, and most stakeholders expressed strong support for both the Digital Marketplace and the IoT sensor monitoring solutions. Producers appreciated the new possibilities for visibility and transparency, while consumers and regional actors highlighted the potential for integrating the tools into broader regional development and tourism activities. At the same time, discussions also surfaced practical concerns that need to be addressed for successful long-term adoption. These included the high cost and organisational complexity of coordinating shared logistics for small producers, as well as the perceived administrative burden associated with blockchain-based traceability for very small farms. Overall, the level and quality of stakeholder engagement significantly contributed to shaping the pilot outcomes and provided essential guidance for refining the THEROS toolbox in line with real-world user needs.

Engagement was strong across all activities:

- Total workshop participation: 102 participants across 3 events
- Survey responses: 15 + 26 + 20 = 61 respondents
- Engagement KPI: ≥80% achieved (85% attendance in workshop 3)

Stakeholders included:

- small and medium producers
- technology providers
- regional development actors
- advisors
- tourism organisations
- public authorities

Collectively, they confirmed strong support for the marketplace and sensor solutions, while expressing concerns over:

- logistics coordination costs
- administrative complexity of blockchain for small farms.

5. Results per Pilot

5.1 Country-specific findings

5.1.1 Technical validation results

Pilot demonstration in Serbia

EO based ecosystem services component utilizes satellite imagery and machine learning to monitor agricultural activities and compliance with organic farming practices. Data exchange between the GeoSerbia portal and Sentinel satellites via EO based ecosystem services and machine learning has facilitated identification and verification of fields and crops under organic production. Over the course of the project, more than 3,000 plots were analyzed, covering upwards of 5,000 hectares in conventional and organic agriculture practices. The observed crops included grains such as wheat, corn, barley, rye, oats, millet, but also sunflower, soybeans, alfalfa and oilseed rape, as well as a variety of fruits and berries including raspberries, blackberries, cherries, apples, plums, peaches and other. Key markers include homogeneity, greening, harvest, bare-soil, crop type, and organic/non-organic classification markers. These enable large-scale and efficient monitoring of farming parcels.

Significant outcomes and insights were obtained during this period, demonstrating the practical value of these tools. It was observed that conventional and organic practices in arable crop production exhibit high similarity, making differentiation between them—particularly among grain types—challenging. Satellite detection can also be hindered when crops are dry; for example, wheat nearing harvest but not yet collected may be misclassified as bare soil. Additionally, distinguishing between similar crops such as wheat and rye remains difficult. Conversely, differences in organic practices are much more readily identified within fruit production.

However, the EO ecosystem services demonstrated that fields and crops can be accurately observed and delineated. This tool has been validated as particularly beneficial for inspection bodies and certifiers, enhancing their preparation for inspections and enabling the immediate identification of non-conformities. Additionally, it offers significant support to payment agencies in detecting fraudulent claims related to plots or crops submitted for subsidies. The positive impact of this tool was confirmed during the testing phase, and there is potential for its further development and implementation at a national level.

The MEMS portable spectrometer identifies the unique spectral signatures of foods—such as wheat flour and apple juice, as demonstrated in the Serbian pilot—to check their purity and ensure they meet organic standards. Data from the spectrometer is analyzed by a mobile app, which allows for real-time assessment and instantly confirms whether the food is authentic. This approach is designed to make food authentication practical, affordable, and easy to use for both consumers and businesses, ultimately improving food safety and transparency.

The MEMS consortium selected organic wheat flour and organic apple juice as reference materials for mobile application development within the project. For analytical purposes, 60 organic and 60 conventional 200 ml apple juices in their original packaging were tested during the initial iteration, while an additional 30 organic apple juice samples were evaluated in the second iteration. Regarding organic wheat flour, 5 kg samples (packages of 100 grams) were submitted for testing in the first stage, with another set of 3kg samples sent for the subsequent phase.

These sample results contribute to the development of a MEMS-based application, intended to rapidly and accurately detect adulteration, thereby reducing potential economic losses resulting from counterfeiting.

Dynamic Digital Product Passport (dDPP) for organic food assets tracks the product's journey through supply chain. It allows users to verify key tracking events, such as production, shipping, packaging, transformation and certification of the product, providing real-time information on the product's status and compliance.

This mobile application enables users to choose which roles they would like to track – producer, consumer, distributor, certifier - avoiding at the same time information overload.

The mobile app was piloted in Serbia with the organic wheat flour and organic sunflower oil products from field production to the retail store. Additionally, samples of apple juice were also tested as transformed products from concentration to juice as a final product.

The dDPP app showed its validity for consumers and retailers, but also certifiers by demonstrating product's path from field to plate with possibility of reducing fraud in organic products significantly.

Finally, the interconnection between all systems and utilized by all actors is Blockchain technology. It includes producers, packagers, transporters and certifiers and supports THEROS dynamic digital product passport (dDPP) and green accountability tool (GAT).

In Serbian pilot the organic wheat flour and organic sunflower oil was interconnected with the ERP and **Blockchain traceability system** allowing product data to be automatically collected and displayed across designated mobile applications and platforms. Summarizing the numbers 9060 organic oil products (3060 pieces in 250 ml doze and 6000 pieces in 750ml doze) and 3002 organic wheat flour products in package of 1 kg were transferred trough this traceability system via ERP integration. The integration between the two systems encountered minor challenges, which were addressed promptly, thereby demonstrating the functionality of the system.

Additionally, samples of organic apple juice were manually entered into the Blockchain system as raw materials and subsequently recorded as transformed final products. In overall 25 different LOT numbers transforming liters of juices in pieces of bottles in 200ml. This enabled both automated and manual processes to be evaluated during the project period.

Blockchain provides traceability, transparency, and security for actors in complex organic food supply chains, supporting the effective operation of related tools.

At the final core of data collection, integration, and harmonization lies the **Green Accountability Tool platform (GAT)**. By centralizing all relevant information in one secure digital environment, GAT significantly simplifies inspection and auditing processes while increasing transparency and trust among stakeholders. Because all data is systematically recorded, traceable, and verified, it becomes easier to demonstrate compliance and accountability across the entire value chain.

The platform enables stakeholders to view purity levels and chemical analysis results digitally, eliminating the need for fragmented reports or manual record-keeping. This not only saves time, but also supports certification processes by providing reliable, standardized, and readily accessible documentation. In many cases, GAT makes visible critical information that is otherwise difficult or time-consuming to obtain, helping stakeholders gain a clearer understanding of field conditions and inputs.

When farmers, inspectors, and other stakeholders can clearly see and interpret data related to their fields, they are better equipped to reduce waste, protect soil health, and make informed, data-driven decisions. Integrating these results alongside other operational and environmental data enables faster responses to potential issues, supports continuous improvement, and helps ensure ongoing organic compliance. Altogether, this data-driven approach strengthens transparency and contributes to more sustainable and resilient farming practices.

Pilot demonstration in Greece

The pilot activities carried out in Greece produced meaningful outcomes, illustrating how the combined use of THEROS tools—including Earth Observation services, MEMS-based sensing systems, the Dynamic Digital Product Passport (dDPP), blockchain-enabled traceability, and the Green Accountability Tool (GAT)—can enhance traceability, transparency, and environmental oversight when applied in real operational contexts.

More specifically, the Earth Observation (EO)-based ecosystem service enabled the technical verification of organic farming practices across various crops, even on small and fragmented Greek plots. The implementation covered fresh organic and conventional products, including oranges, tangerines, grapefruits, kiwis, olive trees, and arable crops. In total, markers were collected for approximately 13,000 plots, 120 soil samples and spectral measurements were conducted, and small plots larger than 0.1 hectares were monitored. Validation included accurate classification of organic and non-organic products, verification of crop rotation, and monitoring of Ecological Focus Areas (EFAs).

The pilot implementation of the MEMS photonic technology system, combined with a mobile application, demonstrated the capability to distinguish between organic and conventional oranges and to perform immediate in-field soil property assessments. Overall, 240 orange samples and 120 soil samples were collected. Evaluation showed accuracy and F-score values as follows: SOC 0.75/0.71, Clay 0.79/0.76, pH 0.69/0.63, and Organic/Conventional management 0.76/0.78. Validation included the detection of prohibited substances, assessment of purity, identification of hidden adulteration, and correct product classification.

The pilot implementation of the Dynamic Digital Product Passport (dDPP) demonstrated its ability to record and monitor the complete journey of organic products, supporting transparency and certification across the supply chain. The application covered organic citrus fruits, including oranges, tangerines, and grapefruits, and was tested by 20 participants via a mobile application. Validation included real-time verification of production, shipping, and transformation events, ensuring full transparency and connectivity among all involved actors.

The blockchain-enhanced traceability system further strengthened trust in the integrity of Greek organic products. It recorded all critical supply chain events, ensuring an immutable audit trail and allowing automatic cross-verification of information from EO, MEMS, and certificates. Validation demonstrated full traceability, tamper-proof recording, and timely alerts for potential fraud or non-compliance with organic farming standards.

Finally, the Green Accountability Tool (GAT) demonstrated its capability to accurately monitor the environmental performance of Greek organic farms. GAT provided information on soil health, vegetation status, and carbon footprint, while generating charts and maps that highlighted spatial variability and enabled sustainability assessments at the plot level. The recommendations provided to farmers were practical and easily implementable in daily farming operations.

Pilot demonstration in Spain

The technical validation activities of the Spanish pilot focused on assessing the correct operation and integration of the THEROS toolbox components deployed for the PDO Mexillón de Galicia mussel supply chain. Validation was carried out through real-world demonstrations covering multiple stages of production, processing, and certification, with emphasis on authenticity verification, traceability completeness, and system interoperability.

From a technical perspective, the DNA-based authenticity kit was successfully validated as a tool for species identification at different points along the supply chain. The application of the kit at the landing port and at two processing stages (fresh and cooked canned products) confirmed that the system can operate consistently across heterogeneous environments and product forms. The testing verified that authenticity results could be generated and documented in a structured manner and associated with specific product batches, supporting technical reliability in multi-stage verification workflows.

The blockchain-enhanced traceability system demonstrated robust performance in recording and managing supply chain events. During the pilot, traceability records covering production, transformation, shipment, and certification were successfully created and stored in an immutable manner. The technical validation confirmed that traceability events could be retrieved, visualised, and cross-referenced with verification data without data loss or inconsistency, supporting end-to-end transparency for PDO-controlled products.

The Dynamic Digital Product Passport (dDPP) was technically validated as the main interface for aggregating and presenting verified product information. The system correctly reflected updates originating from the traceability infrastructure and authenticity verification processes, ensuring consistency between back-end records and user-facing views. Role-based access mechanisms functioned as intended, allowing different actors to access relevant subsets of information while maintaining a coherent representation of the product lifecycle.

Integration between the DNA-based authenticity kit, blockchain traceability, and the dDPP was a central aspect of the technical validation. The Spanish pilot confirmed that verification results produced by the DNA-based tool could be linked to corresponding traceability records and made available through the digital product passport. This end-to-end linkage demonstrated the technical feasibility of combining analytical verification tools with digital traceability infrastructures within a single operational workflow.

Overall, the technical validation results of the Spanish pilot confirm that the deployed THEROS components operated reliably and coherently in a real PDO supply chain environment. The successful integration and operation of the tools provide evidence of their technical maturity and readiness for deployment in similar geographical indication food systems requiring strong authenticity and traceability guarantees.

Pilot demonstration in Czech Republic

The technical evaluation of the Czech pilot demonstrated that all deployed THEROS components operated with a high level of reliability, performance, and interoperability. Across the Digital Marketplace, IoT sensor monitoring, blockchain-based traceability, and the SensLog telemetry backend, the system consistently met or exceeded all relevant technical KPIs. Users experienced a stable and responsive marketplace interface, which maintained low response times even under simulated high-load scenarios with up to 500 concurrent users. The traceability workflow achieved complete event recording accuracy, confirming that the underlying blockchain integration is robust and capable of handling real operational conditions, including simulated product recall situations. Similarly, IoT telemetry tests showed that the SensLog backend can process large volumes of sensor data at high throughput with minimal latency, providing the technical foundation required for scalable environmental monitoring across short food supply chains. Overall, the technical performance results demonstrate strong system maturity and confirm that the THEROS toolbox is ready for larger-scale deployment.

Technical results for Digital Marketplace

- Ease of use: 4.36–4.86
- User satisfaction: 4.41–5.00
- Workflow integration: 4.55–4.79
- Transparency: 4.70–4.79

IoT Sensors

- Ease of use: 4.57
- Usefulness: 4.86–5.00
- Transparency: 4.71–4.93

Traceability System

- Traceability completeness: 100%
- API response time: 1.9 s
- Scalability: 500 concurrent users (1.8 s response time)
- Recall efficiency: 1 h 45 min

IoT Telemetry Backend — SensLog

- stable throughput: 400 msg/s under both test cases
- latency: <50 ms

meets KPI thresholds for ≥500 devices (simulated)

5.1.2 Operational experiences

Pilot demonstration in Serbia

Operational activities included realizing all the benefits but also lacks and deficiencies that need to be improved during the testing period.

Lot of information needed to be included while THEROS tools development is in process. After gathering information and data entrance, testing period of Work Package 5 of pilot demonstrations brought a concrete insight.

Earth Observation (EO) deployment in Serbia has effectively integrated EO services, national geospatial data, and analytics, with GeoPortal Serbia consolidating spatial datasets and Copernicus Sentinel satellites providing essential imagery. This system supports agricultural monitoring and organic production verification by combining multi-temporal satellite images with machine learning classification models. Though still improving, the platform reliably aids compliance checks and monitors organic parcels, offering confidence scores to guide validation and risk-based controls. While further development is needed for mixed crops and cereal identification, the current EO system is a functional tool for large-scale, national agricultural monitoring and verification.

Figure 1 Parcel of organic raspberry.

Figure 2 Parcel of organic plums.

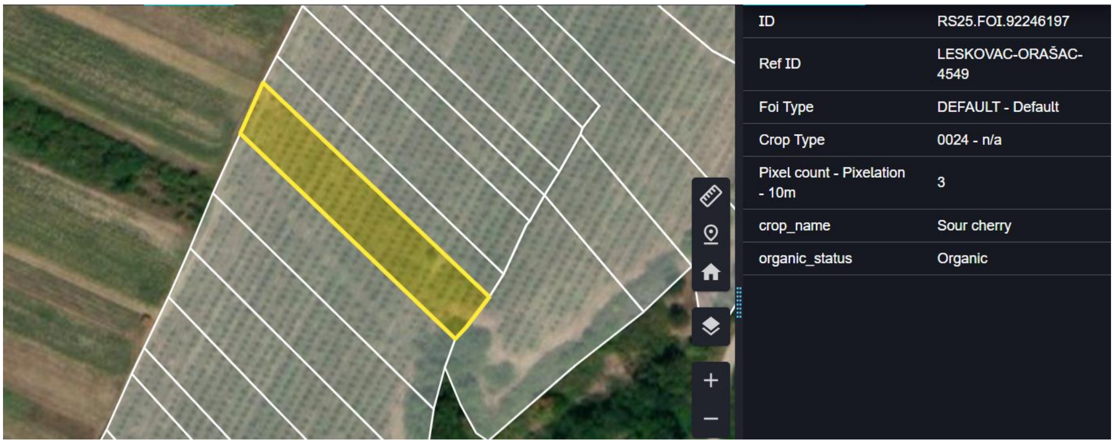


Figure 3 Parcel of organic sour cherry.

The Serbian pilot effectively demonstrated the application and operational readiness of MEMS-based portable spectrometry as an advanced instrument for food authentication within organic supply chains. The MEMS technology was evaluated under real-world conditions to determine its usability, analytical capability, and appropriateness for supporting organic integrity verification at multiple stages of the value chain.

Operational assessments showed that the MEMS portable spectrometer could accurately capture distinct spectral signatures of various food products, facilitating the differentiation between organic and conventional samples. For this pilot, organic wheat flour and organic apple juice were chosen as reference materials due to their significance in Serbia's agri-food sector and their vulnerability to adulteration. These products provided a comprehensive platform for assessing MEMS performance across both solid (wheat flour) and liquid (apple juice) matrices.

A major advantage of the MEMS system is its integration with a mobile application that processes spectral data in near real time. This enabled users to receive immediate feedback regarding product authenticity, substantially reducing the time and expertise required for food quality assessment compared to traditional laboratory methods. Findings from the pilot affirmed that the MEMS–mobile app workflow is intuitive and accessible for non-specialist users, aligning with the project's goal to make food authentication affordable, user-friendly, and widely available for businesses and consumers.

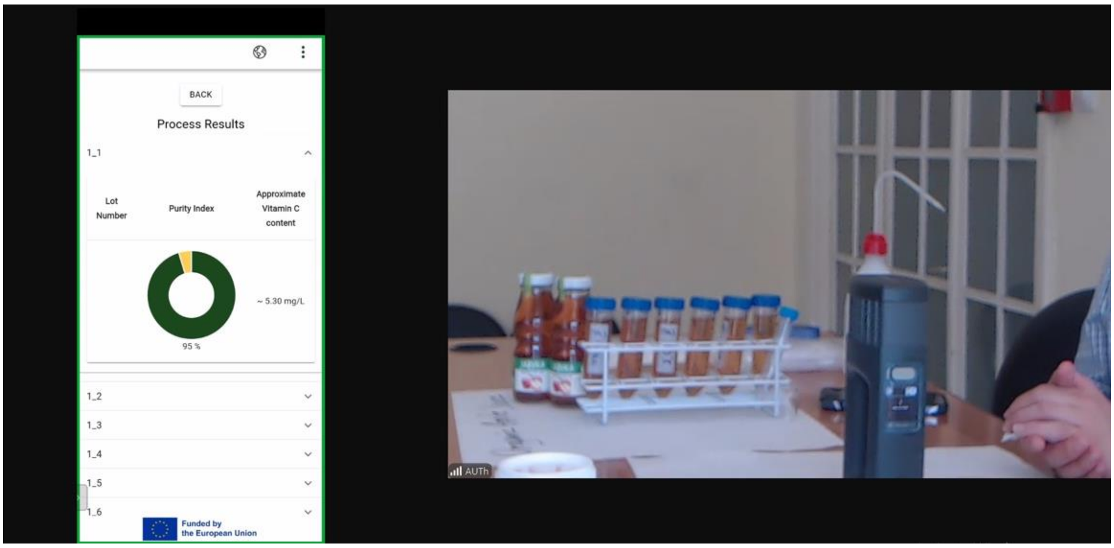


Figure 4 Analysing organic apple juice sample.

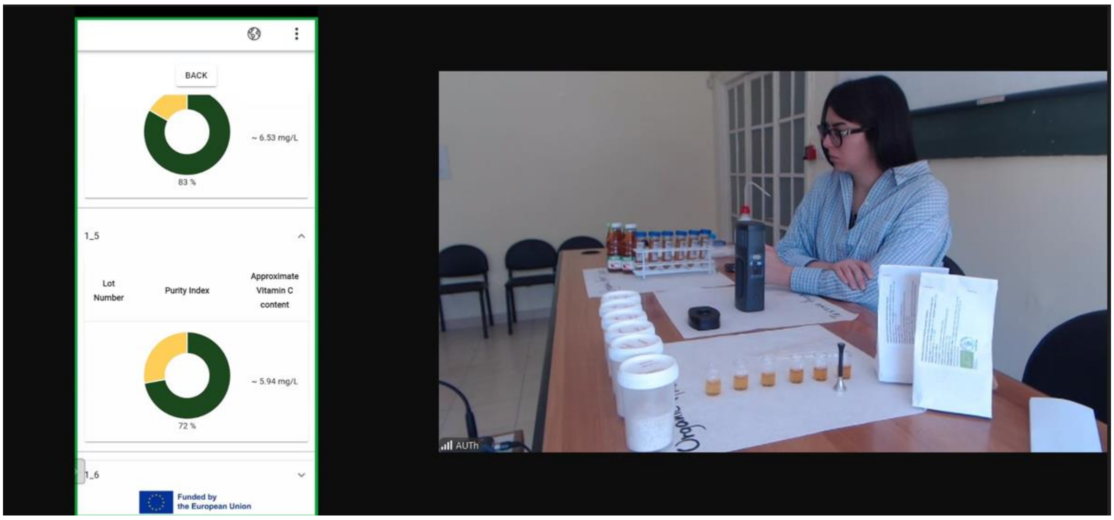


Figure 5 Analysing organic wheat flour sample.

The introduction of the dynamic Digital Product Passport (dDPP) in the Serbian pilot project demonstrated its significant operational effectiveness and practical worth across the agri-food supply chain. End users found the dDPP app easy to use, with a simple account setup and login system that allowed various stakeholders to quickly get started without needing much training.

Feedback from operations shows that the dDPP enables real-time tracking and verification by linking physical products to their digital profiles through product ID scans. This gives authorized users instant access to detailed information such as where the product came from, batch specifics, certifications, and verification records.

For transporters, the dDPP offers notable benefits at every stage of logistics. Scanning product IDs at pick-up or transfer points instantly checks batch and shipment data, helping prevent mistakes and misidentification. Every step—from loading to delivery confirmation—can be digitally logged and securely stored using blockchain technology, creating a trustworthy record of custody. These permanent logs serve as solid evidence to resolve any disputes over delivery conditions, timing, or authenticity, ultimately increasing stakeholder transparency and accountability.

From the consumer's viewpoint, the dDPP delivers clear and immediate value. By scanning a product, consumers can quickly see important details like certifications and verification histories, allowing them to independently confirm product genuineness and quality. This openness builds trust in both the product and its suppliers. Particularly in markets where tampering or fake documentation is common, the dDPP significantly reduces these risks by providing blockchain-backed proof of a product's integrity.

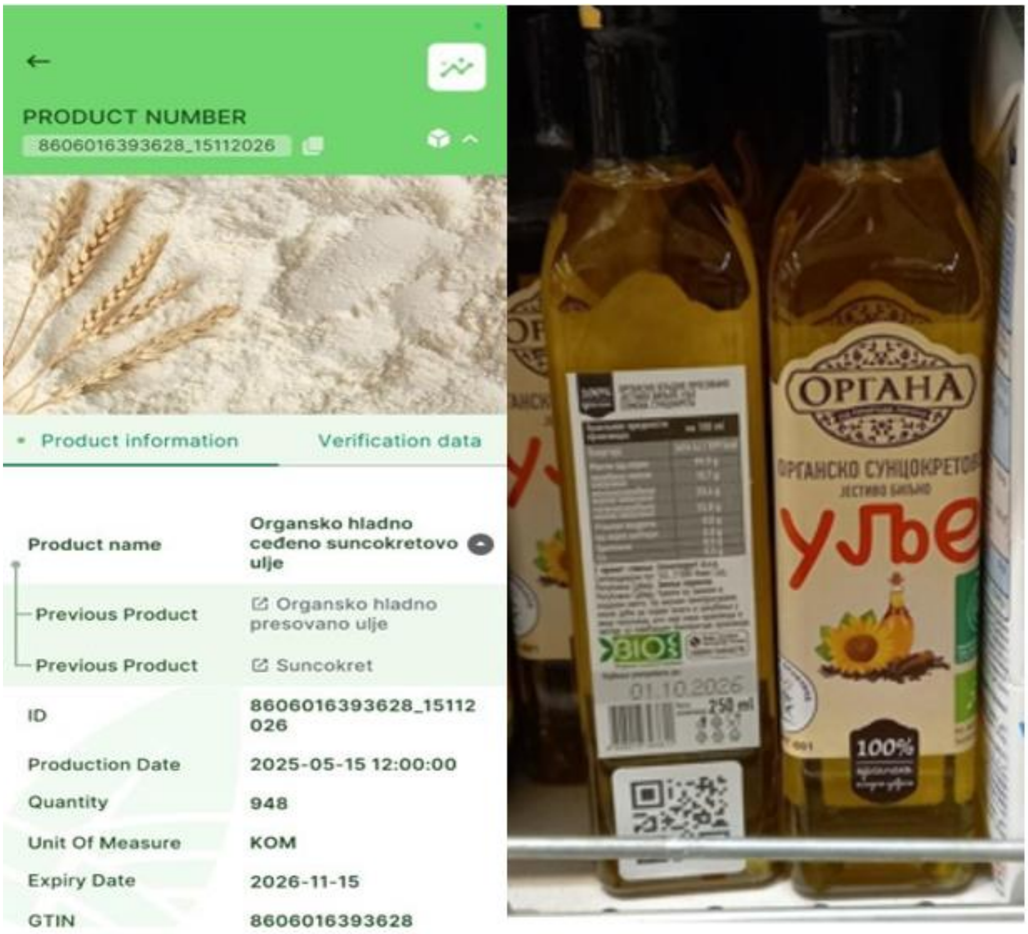


Figure 6 Organic Sunflower oil in the retail with QR code and overview in dDPP application.

Figure 7 Learning History Workshop held in Subotica.

The underlying blockchain infrastructure guarantees that all data recorded are immutable and securely stored, thereby significantly increasing trust and ensuring data integrity. While there were minor challenges integrating the ERP and blockchain systems, as well as issues related to manual data entry, these obstacles were ultimately resolved, resulting in operational functionality and real-time information display on the GAT platform.

In conclusion, the Serbian pilot validated that the dDPP component functions efficiently as a user-friendly, secure, and trust-enhancing tool. By uniting blockchain-based traceability, MEMS analytical verification, and consumer-facing transparency within a single application, the dDPP demonstrates robust operational readiness and substantial potential for scalability across organic and high-value agri-food supply chains.

Pilot demonstration in Greece

The pilot implementations of the THEROS project provided valuable real-world experiences, demonstrating how new technologies and digital tools can enhance oversight, data integrity, efficiency, and environmental management in Greek organic farming.

Initially, the application of Earth Observation (EO) technology on small and fragmented plots played a key role in monitoring and supervising organic practices. The use of machine learning (ML) techniques and hyper-analysis enabled the detection of localized non-compliances, i.e., areas or practices that did not meet organic farming standards. At the same time, these techniques provided targeted recommendations to farmers on proper fertilization, irrigation, and yield estimation, improving both productivity and crop sustainability. EO technology also supported the verification of crop rotation and the maintenance of Ecological Focus Areas (EFAs), ensuring that farms comply with organic farming standards and EU regulatory requirements.

Figure 8 Effect of organic farming practices on CO_2 sequestration and Soil Organic Carbon accumulation.

MEMS technology allowed for immediate, portable analysis of samples directly in the field, without the need to transport them to a laboratory. Both BIONET farmers and BIOHELLAS inspectors actively participated in these activities, strengthening collaboration and trust in the process. On-site demonstrations and sample shipment phases were organized to ensure data integrity and reliability, preventing potential alterations or errors during sample collection and transport. Meanwhile, farmers gradually became familiar with using MEMS devices, learning how to collect and interpret the data. This approach enabled the timely identification of potential non-compliances with organic practices and allowed for real-time evaluation of the physical and chemical properties of the soil, supporting more accurate and immediate crop management decisions.

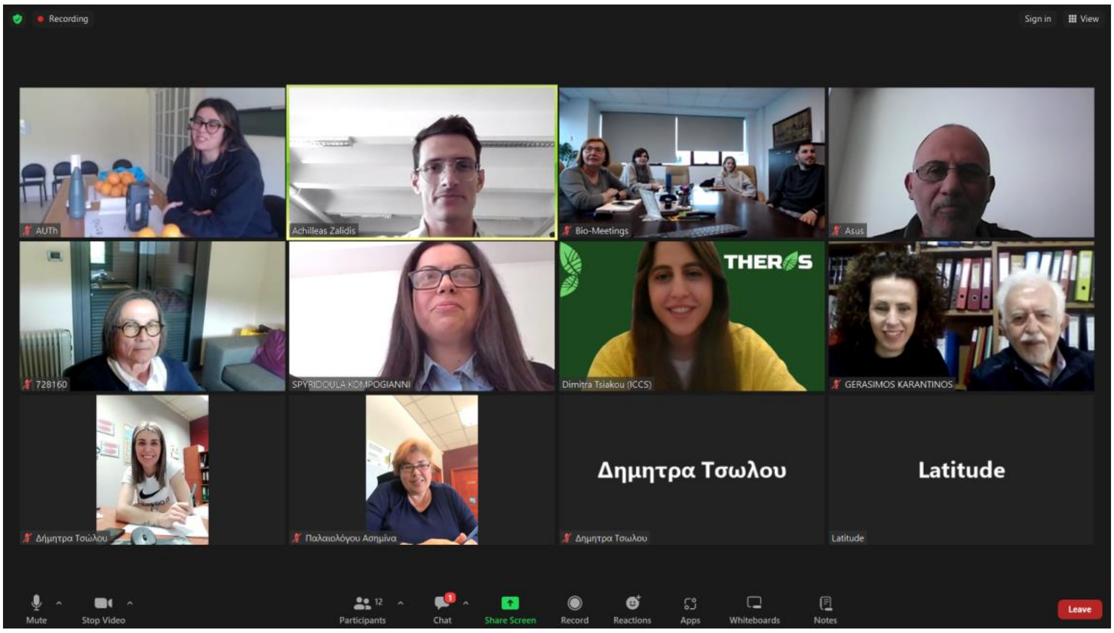


Figure 9 Online workshop for MEMS Photonic Sensor for Organic Citrus Differentiation.

Figure 10 Pilot implementation of the MEMS Photonic Sensor for real-time measurement of soil properties and the distinction between organic and conventional orange crops.

The implementation of the dDPP demonstrated successful integration across all stages of the value chain, improving operational efficiency and connectivity between producers, transporters, certifiers, and consumers. The dDPP allows inspectors, during the inspection process to examine any stage of organic product production, to check a larger number of batches and suppliers without the need to print certificates or transport documents, among other benefits, reducing the environmental footprint of the inspection process. The mobile application offered a user-friendly interface suitable for all roles.

The blockchain system strengthened the reliability of organic products by enabling full traceability and real-time cross-verification of data. The application reduced the risk of fraud, enhanced transparency for certification bodies and consumers, and supported interoperability among different data sources, including EO, MEMS, and certificates.

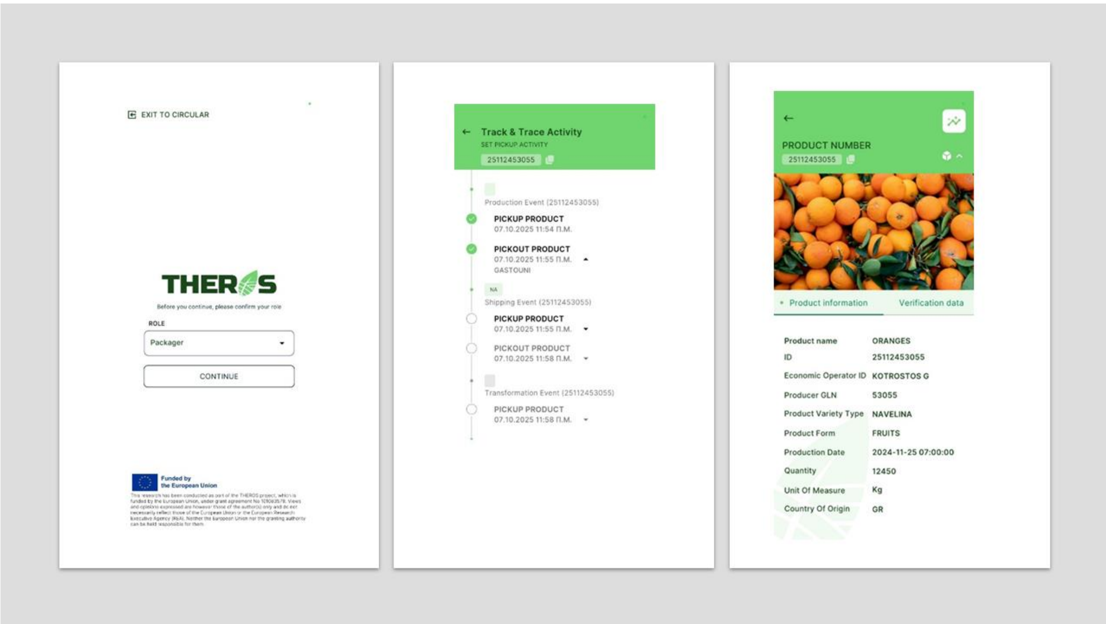


Figure 11 Organic Oranges with QR code and overview in dDPP application.

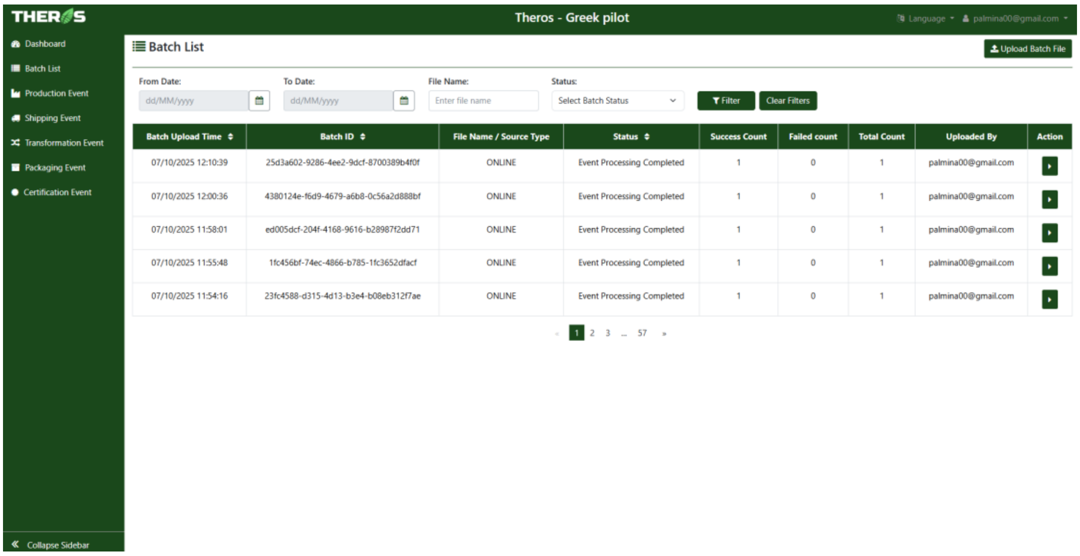


Figure 12 Inserted batches in the blockchain system.

GAT proved to be easy to use and highly accepted by farmers, providing an intuitive interface and rapid access to environmental data. Inspectors and certification bodies utilized the tool to monitor and assess the environmental performance of farms, improving informed decision-making, and supporting sustainable farm management.

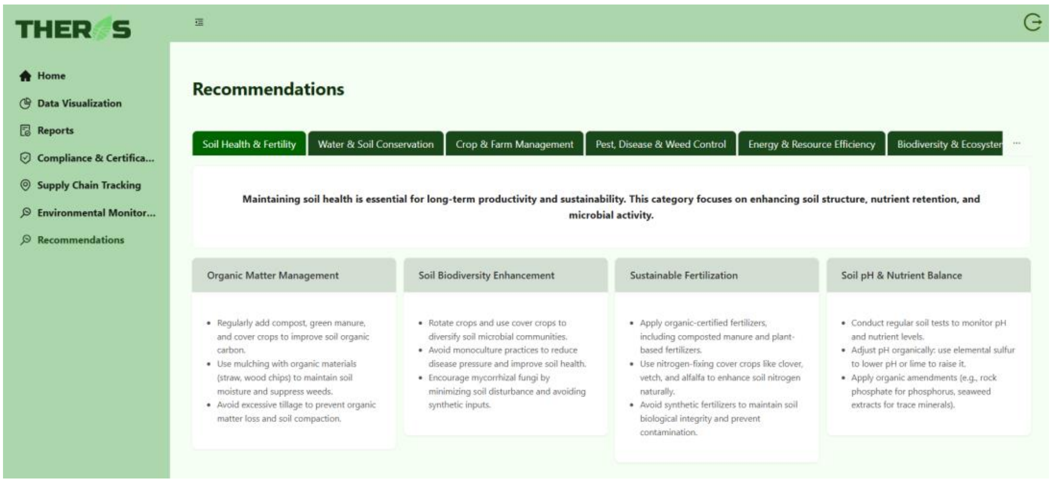


Figure 13 Recommendations tab and the pop-up suggestion functionality.

Pilot demonstration in Spain

The operational experiences of the Spanish pilot are illustrated through a series of visual materials captured during the on-site demonstration and testing activities. These materials document how the THEROS toolbox components were used in practice by different actors involved in the PDO Mexillón de Galicia supply chain, including producers, processors, certification bodies, and technical partners.

Figure 14 Photo at Friscos premises with Theros partners in Galicia.

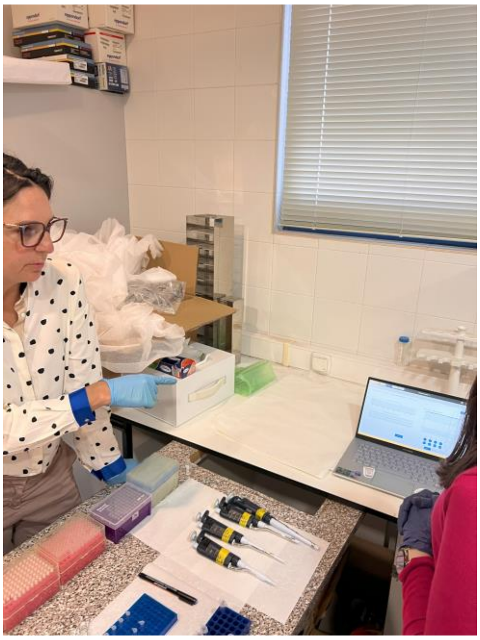
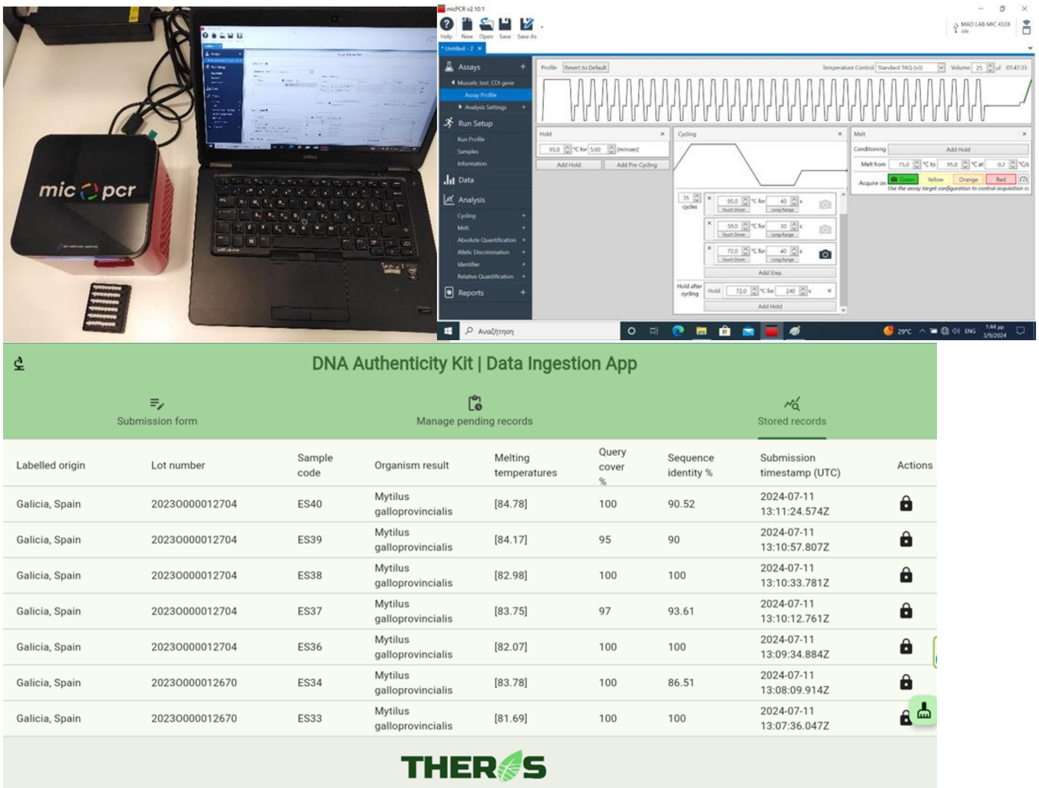


Figure 15 Demonstration of the DNA tool kit during the Spanish pilot.

The images presented below provide evidence of on-site deployment and interaction with the THEROS tools across multiple operational settings. They include examples of sample handling and authenticity verification activities, interaction with digital traceability interfaces, and the use of role-based views of the Dynamic Digital Product Passport during certification and inspection-related workflows.

Together, the visual material complements the technical validation results by illustrating how the THEROS solutions were embedded into real operational processes. The images highlight the practical aspects of tool usage, coordination between stakeholders, and the integration of digital verification and traceability mechanisms within existing PDO control procedures.



Labelled origin	Lot number	Sample code	Organism result	Melting temperatures	Query cover %	Sequence identity %	Submission timestamp (UTC)	Actions
Galicia, Spain	20230000012704	ES40	Mytilus galloprovincialis	[84.78]	100	90.52	2024-07-11 13:11:24.574Z	
Galicia, Spain	20230000012704	ES39	Mytilus galloprovincialis	[84.17]	95	90	2024-07-11 13:10:57.807Z	
Galicia, Spain	20230000012704	ES38	Mytilus galloprovincialis	[82.98]	100	100	2024-07-11 13:10:33.781Z	
Galicia, Spain	20230000012704	ES37	Mytilus galloprovincialis	[83.75]	97	93.61	2024-07-11 13:10:12.761Z	
Galicia, Spain	20230000012704	ES36	Mytilus galloprovincialis	[82.07]	100	100	2024-07-11 13:09:34.884Z	
Galicia, Spain	20230000012670	ES34	Mytilus galloprovincialis	[83.78]	100	86.51	2024-07-11 13:08:09.914Z	
Galicia, Spain	20230000012670	ES33	Mytilus galloprovincialis	[81.69]	100	100	2024-07-11 13:07:36.047Z	

Figure 16 Implementation of DNA-based authenticity kit in Galicia.

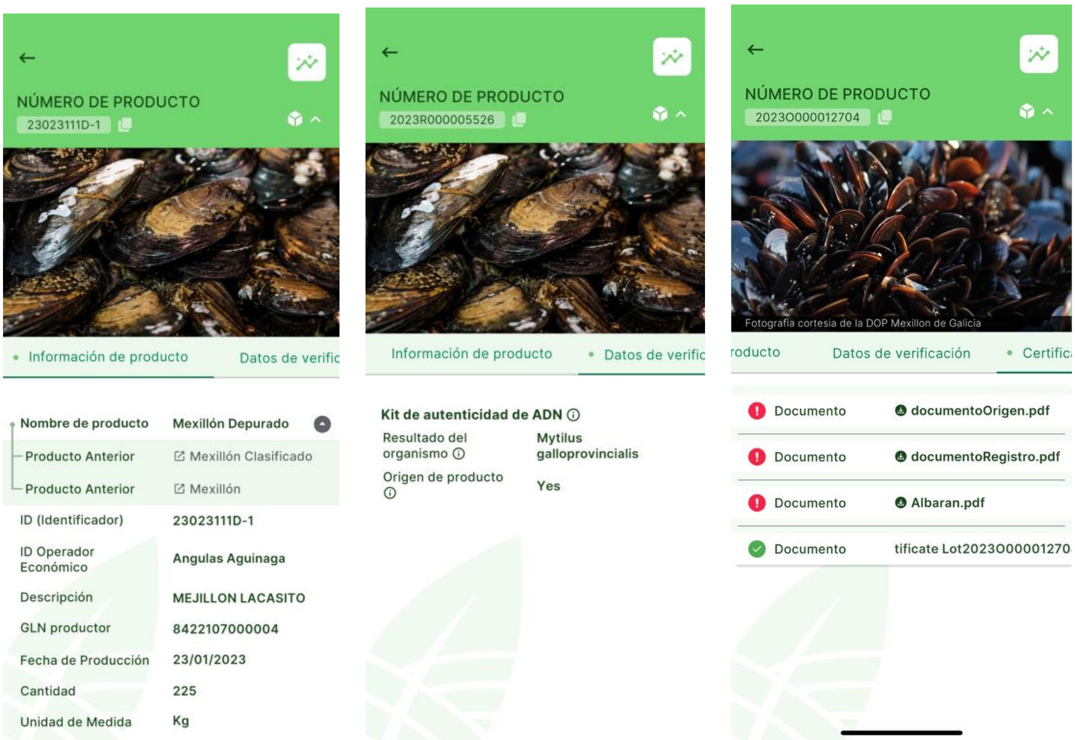


Figure 17 Screenshot from the DPP application of the mussel pilot.

The blockchain component was used by the certification body to verify the key supply chain events related to production, processing, packaging and transportation. These events were generated automatically or semi-automatically by connected THEROS tools and were stored in an immutable and tamper-resistant manner. Through this process, the records are securely consolidated and made available for verification purposes without relying on manual data reconciliation. At the end of the process, a certificate of authenticity can be obtained and uploaded to the blockchain and populated to the DPP application. See below for blockchain events and verification performed by the certificate body.

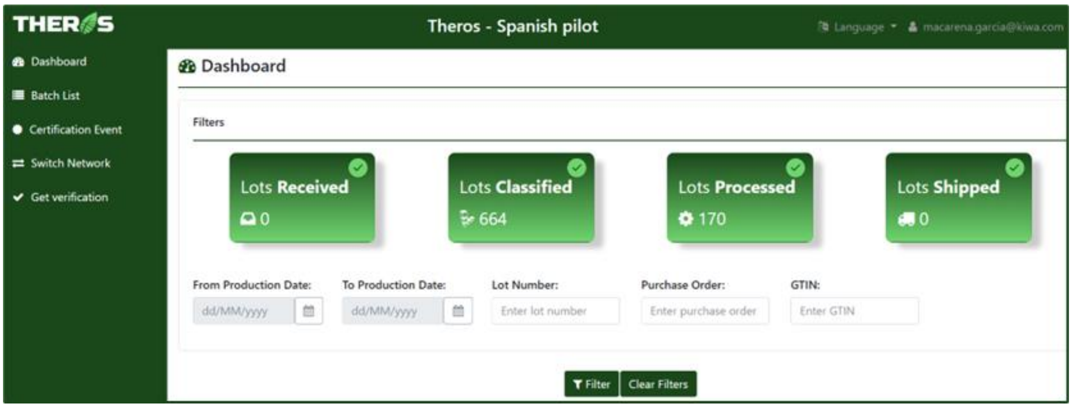


Figure 18 Blockchain platform Dashboard.

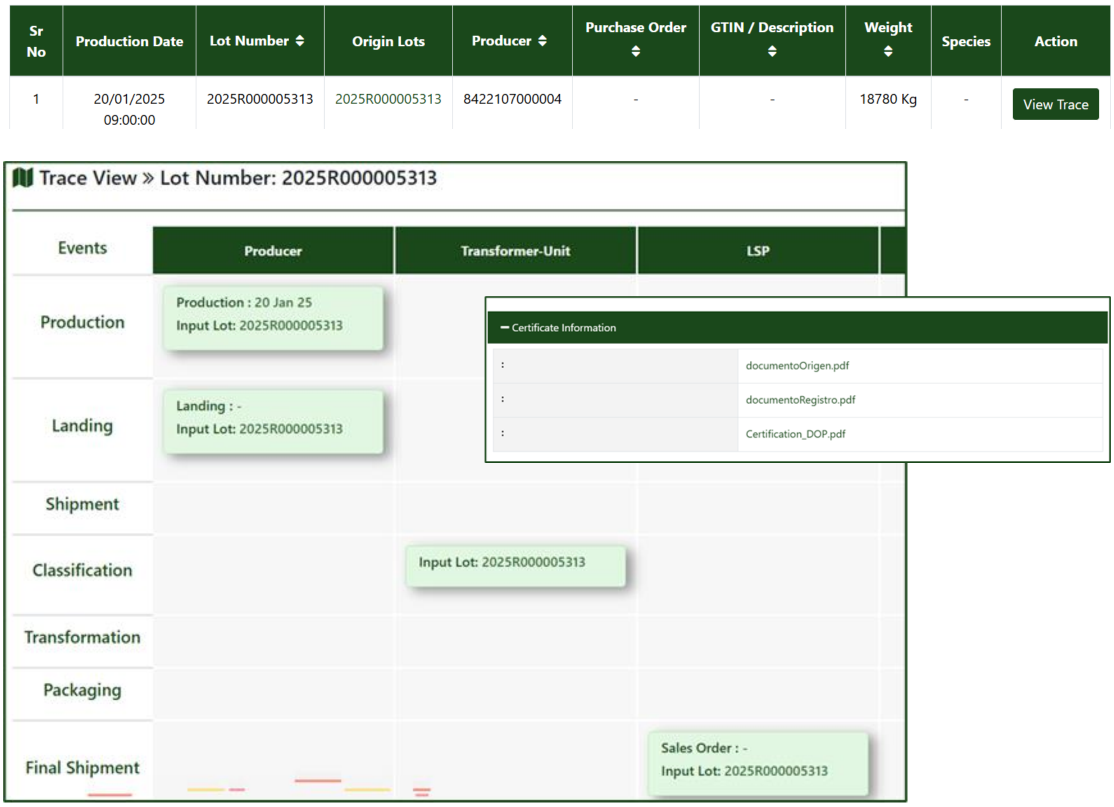


Figure 19 Blockchain platform workflow of a selected lot.

The last picture is from one of the workshops of different stakeholders from Kiwa and Consello Regulador.

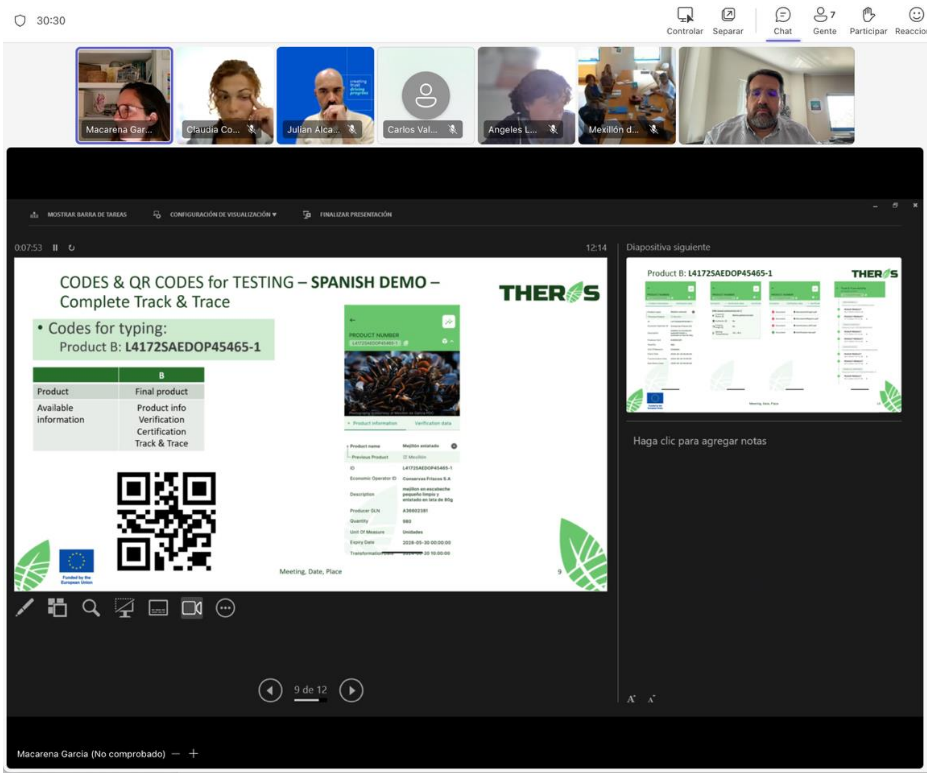


Figure 20 Online history workshop for dDPP.

Pilot demonstration in Czech Republic

The operational findings from the Czech pilot highlight how the THEROS tools were received by producers, consumers, and regional stakeholders when used in real or near-real settings. Participants consistently reported that onboarding to the marketplace was intuitive, allowing even small producers with limited digital experience to create product listings and manage sales with relative ease. Consumers responded positively to the transparency offered through the platform, valuing both the clarity of product information and the emphasis on local and regional supply chains. The IoT sensor boxes generated particular interest, especially among producers handling perishable goods, as they provided clear, trustworthy evidence of transport and storage conditions. At the same time, several challenges emerged during pilot operations. Producers noted the complexity of managing weight-based pricing, which requires additional configuration effort. Differences in digital literacy across producer groups affected onboarding speed and required varying levels of support. Cost considerations were also raised in relation to the IoT devices, particularly for very small farms. Finally, logistics coordination—especially shared deliveries and last-mile arrangements—was identified as the most significant practical barrier, underscoring that efficient physical distribution remains essential for fully realising the benefits of the digital tools. These insights provide valuable guidance for future refinement and scaling of the THEROS ecosystem.

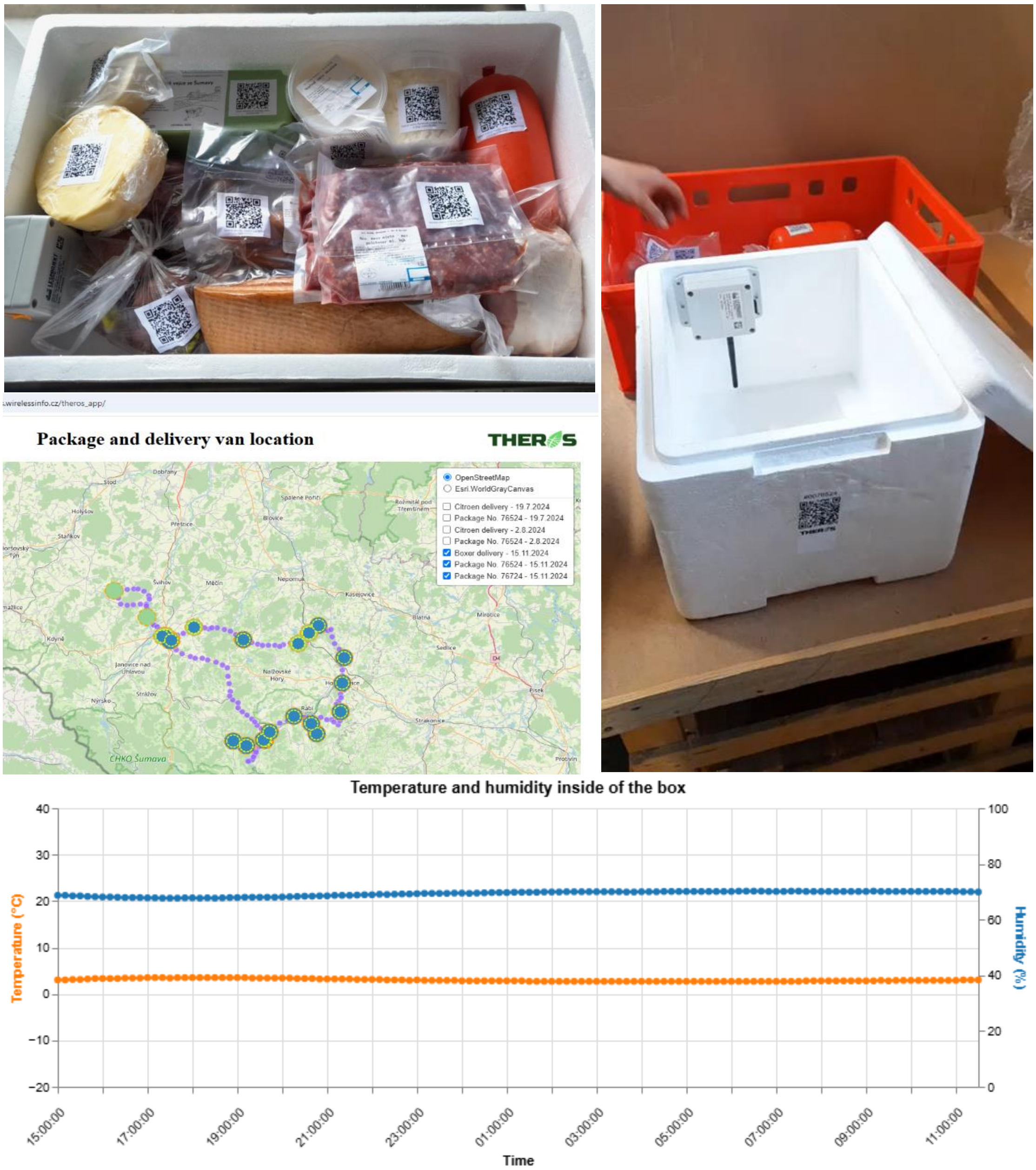


Figure 21 Ordered and marked products are transported in monitored boxes.

Positive operational findings:

- intuitive onboarding for producers
- consumers appreciated transparency and local product focus
- strong interest in integrating regional tourism (food trails, farm visits)
- IoT boxes considered highly useful for perishables

Challenges observed:

- complexity of weight-based pricing setup

- variability of digital skills among producers
- cost of sensor boxes for small farms
- logistics coordination (shared deliveries) identified as biggest barrier.

6. Conclusions

This deliverable has presented the results of the THEROS pilot demonstrations, focusing on the real-world testing and deployment of the project's integrated toolbox for monitoring, verification, and traceability in organic and geographical indication (GI) food supply chains. Through demonstrations carried out in diverse operational contexts, the project validated the feasibility of combining Earth Observation services, portable sensing technologies, digital traceability mechanisms, and harmonised data infrastructures into a coherent and functional ecosystem.

Across the pilots, the THEROS toolbox demonstrated its ability to operate effectively under realistic conditions and to support end-to-end supply chain transparency. Core components such as EO-based monitoring services, MEMS photonics systems supported by a mobile application, DNA-based authenticity verification, blockchain-enhanced traceability, the Dynamic Digital Product Passport, the Green Accountability Tool, and the Data Harmonisation Platform with the Verification Engine were successfully deployed and used by a wide range of stakeholders. Their combined operation confirmed that heterogeneous data streams originating from remote sensing, in-field measurements, analytical tools, and supply chain events can be reliably integrated and transformed into actionable information.

The pilot demonstrations highlighted several aspects that worked particularly well. The integration of EO services enabled scalable parcel-level monitoring and supported inspection and verification activities, even in complex and fragmented agricultural landscapes. Portable MEMS systems, combined with intuitive mobile interfaces, allowed on-site data collection and rapid access to indicative results, strengthening evidence gathering during inspections and quality control processes. Blockchain-based traceability and the Digital Product Passport provided a transparent and tamper-resistant mechanism for tracking products across the supply chain, while user-facing tools such as the Green Accountability Tool and the Digital Marketplace facilitated access to verified information for different actor roles.

At the same time, the demonstrations identified areas requiring further refinement. These include the need for continued user guidance and training for interpreting more complex indicators, optimisation of onboarding and workflow configuration for small-scale actors, and further alignment of digital processes with existing operational practices and regulatory procedures. The pilots also showed that non-technical aspects, such as logistics coordination and organisational capacity, play an important role in fully realising the benefits of digital traceability and monitoring solutions.

Overall, the results reported in this deliverable confirm that the THEROS toolbox has reached a high level of operational maturity. The demonstrated components and their integrations indicate readiness for deployment beyond pilot environments, with clear potential for scaling and replication in different organic and GI food supply chains. The insights gained through the pilot demonstrations provide a solid foundation for subsequent evaluation activities and support the positioning of THEROS solutions as viable tools for strengthening transparency, compliance, and sustainability in the agri-food sector.