Smart Technologies for Traceability in Organic Olive Production

Aglaia Liopa-Tsakalidi[1*]**, Helen Kalorizou**[1]**, Vasiliki Gana**[1]**,**
Vasileios Thomopoulos[2]**, Anastasios Giannaros**[2]
[1] *Department of Agriculture, University of Patras, Greece*
[2] *Department of Computer Engineering University of Patras, Patras, Greece*
aliopa@upatras.gr

Abstract

This study offers an online traceability framework for continuous monitoring of critical environmental factors, using IoT, smart sensors, drones and open-source technology, integrating real-time data in four organic olive groves. This data-driven approach promotes more sustainable agricultural practices and supports the acquisition of evidence for improved traceability. Supply chain steps include organic olive cultivation, olive fruit processing, standardization, and production of biofunctional foods. The software ensures adherence to EU organic agricultural laws by facilitating real-time data collecting on environmental conditions, soil management, irrigation, and harvesting procedures. For smooth user interaction, it combines a responsive Bootstrap 5 web user interface, a lightweight PHP framework (CodeIgniter 4), and a relational open-source database (MariaDB). The system's capacity to enhance farm management and decision-making is demonstrated. The platform maximizes resource use, improves product quality, and fortifies customer trust by automating data collection and guaranteeing transparency. The system ensures complete supply chain visibility of organic table olives by recording important traceability data, such as fertilization management, irrigation, harvesting and transportation specifics, fruit quality, and processing activities. According to preliminary results, the suggested system greatly enhances operational effectiveness, regulatory compliance, and traceability in organic olive farming.

Keywords: smart agriculture, data collection, data analytics, innovative technologies, organic table olives.

1. Introduction

Smart farming combines advanced technologies such IoT, smart sensors, drones, GIS, RFID, and AI to create connected, efficient farms. Sensors monitor and collect real-time data on crop health, soil conditions, weather, and pests, critical parameters for plants growth, transmitting it to cloud-based analytics for decision-making (Soussi et al., 2024). This involves on-farm dynamic management of irrigation, fertilization, pest development, and resource management. Major benefits from this include increased traceability, sustainability, food safety, and cost-effectiveness with reduced environmental impact (Pradeep & Tyagi, 2024; Kalfas et al., 2024; Mushtaque, 2024; Kalyani et al., 2024; Ali et al., 2024).

Smart sensor systems enhance agriculture by providing real-time data on soil, climate and crop health. They monitor moisture, temperature, humidity and weather, optimizing farm management, improving efficiency and enabling data-driven decision-making for better yields (Hassan et al., 2024).

New technologies provide opportunities for local food development. With the rise of state-of-the-art technology, a new range of food and agricultural solutions emerges through innovations in traceability technologies. The implementation of an organized traceability system helps to record and maintain all information related to the route followed by a product from the original supplier to the consumer (Vlontzos et al., 2024).

Integrated smart technology in agriculture allows the production process to be monitored and managed toward product quality and safety traceability. In this case, traceability ensures food safety (Charlebois et al., 2024). Traceability is, therefore, defined as tracking a product from the time it is grown on the farm until it reaches the consumer's plate, where it involves several processes from QR codes to certifications and audits. The merits of traceability include food safety, quality control, consumer confidence, compliance with regulations, efficiency of operations, sustainability, risk management, and competitive edge (Tarjan et al., 2014; Le, 2024). This system builds trust and transparency, utilizes all the data available in a better way, and guarantees the provision of good-quality agricultural products, bringing along better standards and efficiency of operations (Victor et al., 2024). Organic production is a holistic system of farm management and food production, whereby environmental and climate policy, biodiversity, the conservation of natural resources, animal welfare, and high production standards are combined in order to meet the growing demand for foods from the ever-increasing population of consumers, produced by natural substances and processes (EU 2018/848, 2018). The basic principles of organic farming are in several aspects stricter than those of conventional agriculture.

Organic producers are a crucial group of operators on the platform, as they provide essential information about the first stage of the supply chain. Without their input, accurate traceability would not be possible. Therefore, a highly user-friendly platform is necessary to enable them to record information for monitoring and decisions making purposes, emerging dynamics for a mini, real-time, regulatory, consulting basis, digital agricultural extension which benefits all parts in the food chain (Li et al., 2024). Within this context, participatory footprint of the farmers, processors and distributors in organic production chain had always a high return on investment advantage in addition to potential peer leaning and co-evolving among the stakeholders (Lasdun et al., 2025; MacPherson et al., 2025).

This paper presents an initial concept of traceability for organic food, highlighting its key features and parameters related to organic farming and sustainability. The primary advantages of this platform lie in its transparency and full traceability. It provides consumers with clear visibility of the food produced by organic farmers and enables the rapid identification of any issues, allowing for swift recalls of affected products. In the EU, various information systems can capture traceability in the organic food supply chain. Their implementation depends on the specific requirements and complexity of the supply chain. Integration enhances management from production to consumption. Stakeholders range from small farmers to large companies, which require simple, cost-effective systems (Latino et al., 2022). Robust IoT and sensors functionality coupled with the preciseness of digital agriculture applications can secure the positive outcome for farmers and consumers (Mohapatra et al., 2025; Slettli, 2024).

Herein, we established and tested a reliable smart traceability system for the organic table olive production chain from farm to fork.

2. Methods

This study is aimed primarily at the conception and execution of an integrated platform conceived for organic table olive supply chains with the latest processes. In the platform, data collection moves through different stages requiring validation, and critical points of intervention mark information recording and retrieval throughout organic table olive production processes to support better and informed decision-making. The platform has been set to use new technologies, namely sensors and drones, while it gives end consumers direct access to a full and comprehensive range of information covering aspects from location to production and distribution processes along the entire journey from field to shelf.

The first step to establish an effective traceability system by which biofunctional foods safety and quality features will be elicited was to identify key stakeholders and set forth their roles, responsibilities, contributions, activities and interactions based upon experience. The Operational Team of Patras University, following Executive Regulation (EU) 2021/279 on traceability in organic production, conducted continuous discussions and interviews with all members involved in implementation. These stakeholders included the Agricultural Cooperative of Organic Olive Growers, the Agricultural Cooperative of Organic Products and the Processing Business.

The initial research phase involved organic table olive farmers participating in on-site studies to improve organic farming practices through innovative technologies. Four organic farms with different irrigation systems were selected for the study, where sensors were installed to record soil parameters, while meteorological stations monitored climatic conditions. Throughout the organic table olive chain, comprehensive data was collected from farm operations, cultivation, harvesting, olive processing techniques, etc. The Operational Team of the FP analyzed this data and proposed a list of functions that the application would offer for each user based on their role.

The platform development process involved extensive stakeholder engagement, with multiple rounds of discussions and exchanges of views on specific use cases and general functionality. This iterative process, including several redesign phases, led to the creation of the platform's final form. The system, built on PHP programming language, utilizes open-source technologies to ensure long-term sustainability through community-based updates and support and establishes trust to the stakeholders through code transparency. To be more specific, the open source accompanied software libraries that were utilized during the process of developing the web application are the CodeIgniter 4 framework, the MariaDB Relational Database Management System and the Bootstrap 5 framework that offers a responsive web user interface on the web application. Finally, the web application is hosted on an Ubuntu Server Operating System based cloud Virtual Private Server based in Germany, ensuring both compliance with GDPR and fast data transfer and access (being geographically in a central European country). The VPS's resources are comprised of 8 virtual CPU cores, 16GB of RAM and 240GB of Solid Storage Disk based storage ensuring more than enough computing power for the web application's real-time needs. Should the need for computational resources rise in the future, the server is fully scalable and can be upgraded in a manner of minutes via the web hosting provider's administration environment.

The data collection system includes various parameters, such as geographical location, soil management (humidity, temperature and salinity), meteorological data, and good organic farming practices, which include all aspects of plant nutrition, plant protection, pruning, irrigation, and harvesting. To guarantee traceability, each farm is assigned a Unique Global Location Number (GLN), with GLN barcode labels involved in enhancing the transparency of the supply chain. Organic farmers form an important part of the supply chain, producing organic table olives, keeping agricultural records, managing environmental conditions, and carrying out harvesting and transportation to the processing business.

The traceability system goes as far as harvesting and transporting; the table olives are hand-harvested and placed into traceable plastic crates.

A farm dispatch chart or harvest delivery note serves as a consignment note, recording essential information including the SSCC of boxes/pallets, date/card number, transport vehicle license plate, farm GLN, olive variety, quantity, weight, and the person responsible for loading. This system also addresses potential farm operation risks, including inferior-quality fruit harvesting, improper transport conditions, and incorrect quantity recording.

At the processing company's reception area, quality control procedures are implemented, with detailed reports recording consignment note numbers, GLN, SSCC packing list, receipt quantities, total batch quantities, and processed or rejected olives. Organoleptic characteristics, including appearance, color, smell, taste and texture, are carefully documented. The processing and packaging stage emphasizes the importance of high-quality raw materials for producing biofunctional foods, with comprehensive data recording of production orders, quantities, weights, tank usage, and batch characteristics. The development of biofunctional products using organic table olives involves careful documentation of mixing ratios and ingredient quantities.

The platform ensures complete traceability in the organic table olive subchain by recording key data, integrating with other distribution and production systems, and enabling sharing of files. This integrated approach tracks data from the farm right through to processing, ensuring consistent quality control and regulatory compliance along the entire supply chain. The adopted methodology implements a solid frame to provide traceability, quality assurance, and transparency to the organic table olive production, while novel technologies are embedded and stakeholder engagement is part of the production process.

3. Results and Discussion

In this work, a web-based application to aid traceability and streamline organic olive farming management processes is presented: Farm registration and cultivation practices are addressed by the tool, and supply chain steps involve organic table olive farming, processing, standardization, and the production of biofunctional foods. By integrating real-time data from sensors installed in four prototype organic table olive orchards, technology continuously checks critical environmental factors. In this way, the model puts the emphasis on more sustainable farming practices and supports informed decision-making for improved traceability (Visconti et al., 2020). The system is built using the PHP programming language and CodeIgniter 4 framework, using open-source technologies, with MariaDB Relational Database Management System behind and a user-friendly, responsive front-facing interface built with Bootstrap 5. Real-time sensor data is integrated step-by-step throughout the production process, from farming to final distribution. Preliminary experiments have shown that the platform could positively impact traceability, resource optimization, and offer compliance with global best practices. By automating data collection and increasing clarity throughout the supply chain, the system will develop implementation solutions for more sustainable and efficient organic table olive farming. Integrated monitoring allows the application to follow the olive fruits from farming, through processing to the distribution of biofunctional foods. In addition to implementing traceability practices that allow the tracking of the table olives' origin to their journey on store shelves, the system integrates measurement data coming from four pilots in organic table olive farms, ensuring openness at various cultivation stages and the reinforcement of sustainable organic farming practices.

3.1 Web Application

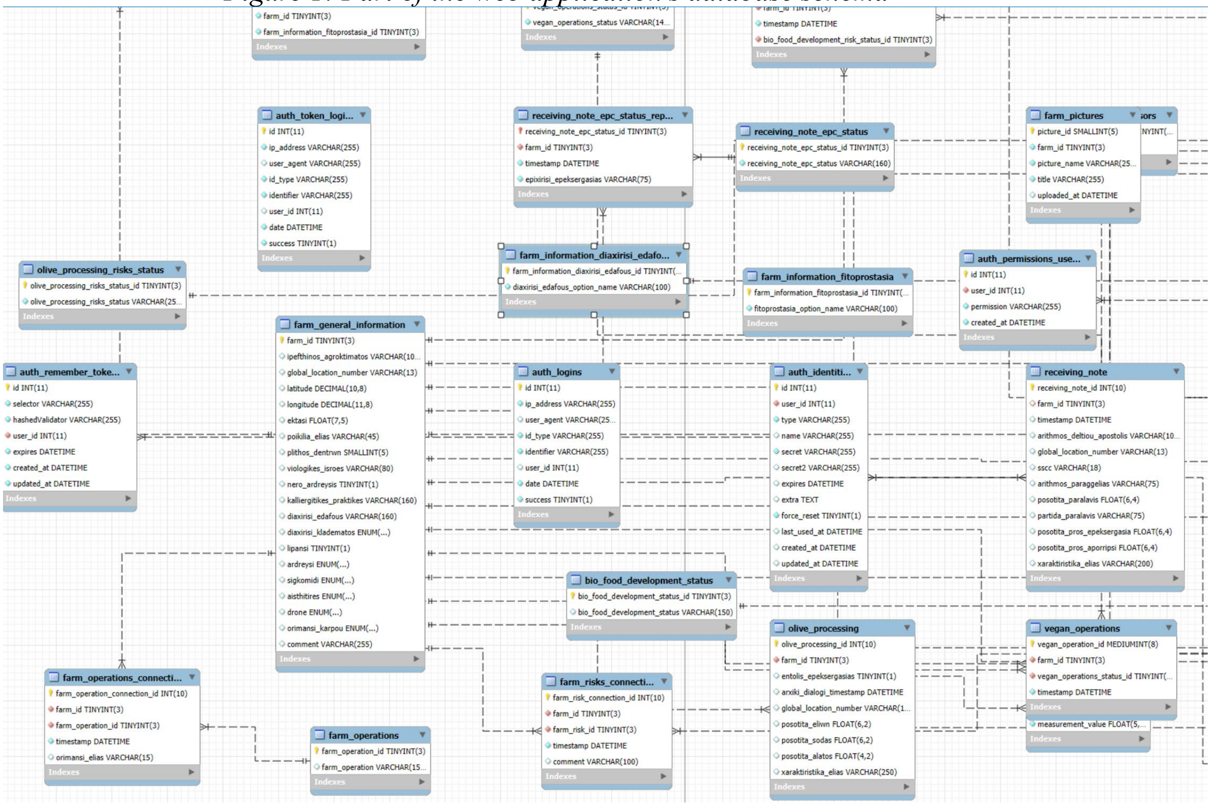
As aforementioned, the web application is built on PHP programming language accompanied by open-source software libraries and the MariaDB Relational Database Management System and is hosted on an Ubuntu Server OS powered cloud VPS (Figure 1).

PHP v8.1 was utilized, bringing several improvements in performance, security, error handling, debugging, and overall capabilities compared to earlier versions. PHP, originally released in 1995, is a reliable and still relevant choice to build web applications with having over 76% of the websites run on it (W3Techs, 2024), several Content Management Systems like WordPress, Drupal, and Joomla coded with it, and many companies like Meta, Wikipedia, Slack, and Etsy having their web applications (partially) written in PHP.

The CodeIgniter library works complimentary to the PHP programming language offering a Model View Controller developing environment. The MVC architecture offers a developing environment which provides distinct entities that handle different things throughout the web application: 1) the Models which contain the code that in charge of retrieving data from the database, 2) the Controllers which process the data passed by from the Models and 3) the Views that define the rendering of the user interface on the user's device. This type of architecture offers the developer extended scalability, efficiency and easy maintenance (Kalelkar et al., 2014).

Regarding data storage, bearing in mind the needs of this particular web application, a relational database management system was chosen. Considering the structured nature of the data, information of farms, traceability, and data acquired from the sensors installed on the organic farms, a relational database was the chosen approach. To begin with, ACID transactions ensure no data inconsistencies. Furthermore, data can be acquired and joined from multiple database tables when needed, ensuring an efficient retrieval of related data. Finally, SQL databases provide the ability to execute advanced filtering and aggregations (Jatana et al., 2012).

Figure 1: Part of the web application's database schema

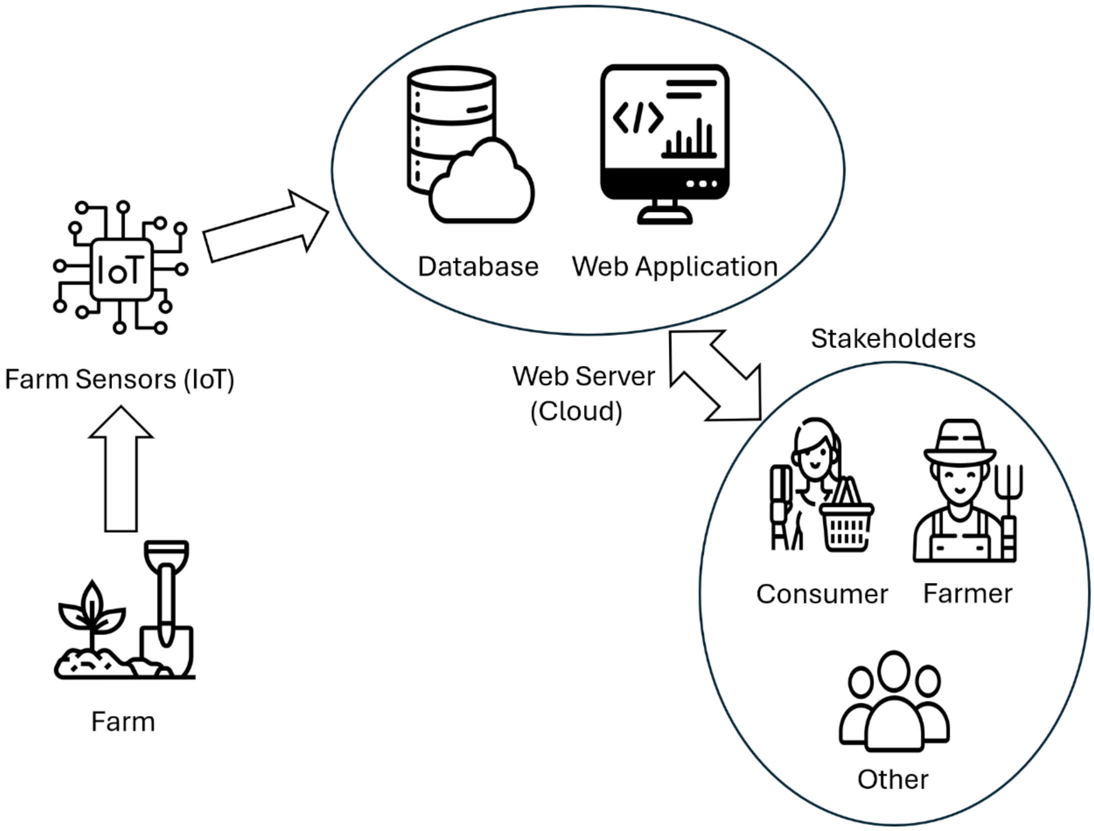


3.2. System Architecture

The system consists of these elements (Figure 2):

- Organic Farms where olives are grown.
- Sensors collect real-time data on organic farms.
- The Web Server hosts the web application which consists of the database and the digital user interface which the users utilize to interact with the system.
- The Stakeholders, namely producers (organic farmers), consumers, and others (e.g. logistics companies or olive processing unit).

Figure 2: System Architecture



In a more detailed manner, farm sensors, based on the Internet of Things technology, are installed on various organic table olive farms to collect real-time data such as humidity, temperature and salinity, and send this information to the web server. This data is sent every ten minutes to the web server. The web server stores the data on the database alongside the organic farm details, the traceability data (tracking information), and details on the user accounts (user authentication system). Finally, the stakeholders can access the web application through a web user interface which enables them to do various tasks according to their user role. Multivariable roles and multilevel data analysis secure avoidance of quantitative and qualitative risks in the production chain as previously projected in smaller group of farming processes (Dwivedi & Sherly, 2025).

To be more specific, the organic farmer registers their farm on the platform and documents cultivation processes which enable them to initiate the declaration of traceability records for their harvest. Inclusion of these processes and data analysis lead to minimalization of organic olive fruits heterogeneity in space and time converting strict agroecological management into financial advantage (Zhang et al., 2025). Optimization of micro-service irrigation and fertilization schemes coupled with climate monitoring resulted in successful resources management tactics in our case as it shown in high density olive orchards for conventional, non-organic olive oil production and other horticultural crops (Jamshidi et al., 2025; Massaoudi et al., 2022).

Then the logistics company that has taken on the task of transferring the yield from the organic farm to the processing company delivers the organic table olives for processing. The processing company receives the olives and transforms them into the final product. The actual tracing pattern of pre- and post- harvested organic olives, conceptualized and realized in this work, guarantees food authenticity improving transparency for the consumer (Liu et al., 2025).

Every single step of the process is registered and documented on the traceability platform ensuring that the consumers have the ability to verify and validate the product's authenticity tracing every step of its way from farm to fork; joint comprehensibility by the farmer and consumer leads to business resilience in the market and sustainable quality trust of the final product (Kirikkayis et al., 2024; Seo, 2025).

3.3. Challenges

During initial stages of system design and deployment, sensors had limited or unstable internet connectivity which was one of the first major challenges to overcome. In areas where 4G connectivity was not stable enough, LoRa radio technology was utilized to transmit the sensors' data to a central gateway installed inside the farmhouse (Suji Prasad et al., 2021). Caching mechanisms and asynchronous uploads were also deployed to enhance data transmission (Bouras et al., 2019).

Sensors integration on the system was an additional challenge for the development of monitoring process. Log files from sensors activities did not provide records in an easily human-readable format. The information was not readable and capable of being sorted by the database structure. The research group solved these compatibility problems by developing PHP script to transform the output's data towards appropriate format; imported data were integrated smoothly into the functional database.

The final major challenge was not a technical one; stakeholders expressed their hesitation towards actual technological advancements. Some of them expressed their skepticism about adopting the system; projecting the argument of a non-justifiable burden for their entrepreneurial activities. This type of behavioral response was expected in people with low technological adaptation profile. The lack of digital skills temporarily decreased the social acceptance of smart technologies (Qian & Zhang, 2022). Training sessions helped to emerge in public the importance of the current work and push further gradual change in olive farming.

3.4. Future Work

Despite the challenges faced, while the system was greatly appreciated by the testing groups, there are some advancements that could be made to further enhance the user's experience, namely Blockchain integration, AI-powered Data Analysis, and interoperability with existing systems. This approach will enhance farm-based profit predictability and robust food quality standards via sustainable water, soil and olive resources governance (Parra-López et al., 2025).

Literature reviews suggest that the integration of Blockchain technology can have a great impact on the ecosystem. As a decentralized and distributed ledger technology, Blockchain introduces redundancies and reduces the risk of a single point of failure while at the same time ensures that no central authority has total control over the system and the data it holds (Kamilaris et al., 2019; Bhat et al., 2021; Salah et al., 2019; Kamble et al., 2020).

Furthermore, AI can be integrated in the system in an effort to utilize the data acquired from the IoT sensors placed on the farms to generate predictive insights on farm conditions, crop yields, and potential risks, helping the farmers in their decision-making process (Filippi et al., 2019, Kamilaris et al., 2017; Muangprathub et al., 2019). Moreover, the vast amount of data stakeholders (organic farmer, logistics company, processing company, seller) generate and submit in the platform throughout the process can be utilized in conjunction with AI to provide a tech-augmented approach into business intelligence processes. Such a recommendation tool can provide alternative suggestions for re-organizing the processes of the whole chain in an effort to make the whole chain more efficient (Bharadiya, 2023; Paramesha et al., 2024).

Finally, the integration of AI in the system can offer compatibility with (future) national or even international food traceability systems to ensure broader adoption and compliance with European industry standards. To accomplish this, a component could be developed that adds interoperability functionality in the platform ensuring its data can be transferred in other (future) systems regardless of the way these systems store their data (Aydin & Aydin, 2020; Kadadi et al., 2014).

4. Conclusion

The developed traceability platform keeps track of the entire lifecycle of olive production, from cultivation and harvesting to processing and distribution. This enables the stakeholders to authenticate the final product's origins and procedures of processing and distribution alongside the conditions present at every step of the way offering transparency. The numerous tests that took place and the feedback received from various stakeholders suggest that the proposed holistic ecosystem offered through a web-based application has succeeded in achieving its purpose by providing traceability and assisting in the management of the operations of the chain from harvesting to sale of organic table olives. By automating data collection from IoT sensors installed on fields, the system provides holistic monitoring capabilities contributing to the efficiency and transparency of the chain. Utilizing contemporary technologies like Blockchain and AI can further enhance the trust and sustainability of the application by aligning it with best practices and the needs of the times. The system, entirely based on open-source technologies, is perfectly aligned with the EU regulations on food traceability, ensuring compliance and offering consumer trust.

Ethics Statement

Not applicable: This manuscript does not include human or animal research.

Acknowledgments

This study is funded by the European Agricultural Fund for Rural Development, Rural Development Program 2014-2020, Measure 16 – Action 2, Sub-Measure 16.1-2 Action II, the project "Partnership for smart organic olive farms & innovative products - SMART OLIVE FARM" (Project code: M6SYN2-00305).

References

Ali, G., Mijwil, M. M., Buruga, B. A., Abotaleb, M. and Adamopoulos I. (2024). A survey on artificial intelligence in cybersecurity for smart agriculture: state-of-the-art, cyber threats, artificial intelligence applications, and ethical concerns. *Mesopotamian Journal of Computer Science*, 53-103. https://doi.org/10.58496/MJCSC/2024/007.

Aydin, S. and Aydin, M. N. (2020). Semantic and syntactic interoperability for agricultural open-data platforms in the context of IoT using crop-specific trait ontologies. *Applied Sciences*, 10 (13), 4460. https://doi.org/10.3390/app10134460.

Bharadiya, J. P. (2023). A comparative study of business intelligence and artificial intelligence with big data analytics. *American Journal of Artificial Intelligence*, 7(1), 24-30. https://doi.org/10.11648/j.ajai.20230701.14.

Bhat, S. A., Huang, N. F., Sofi, I. B. and Sultan, M. (2021). Agriculture-food supply chain management based on blockchain and IoT: A narrative on enterprise blockchain interoperability. *Agriculture*, 12(1), 40. https://doi.org/10.3390/agriculture12010040.

Bouras M. A., Ullah, A. and Ning, H. (2019). Synergy between Communication, Computing, and Caching for Smart Sensing in Internet of Things. *Procedia Computer Science*, 147, 504-511. https://doi.org/10.1016/j.procs.2019.01.244.

Charlebois, S., Latif, N., Ilahi, I., Sarker, B., Music, J. and Vezeau J. (2024). Digital Traceability in Agri-Food Supply Chains: A Comparative Analysis of OECD Member Countries. *Foods*, 13(7), 1075. https://doi.org/10.3390/foods13071075.

Dwivedi, S. and Sherly, M. A. (2025). Multivariate assessment of digital agriculture and irrigation potential: Application to India. *Agricultural Systems*, 227, 104328, https://doi.org/10.1016/j.agsy.2025.104328.

EU (2018). Regulation 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007. *Official Journal of the European Union*, L 150. http://data.europa.eu/eli/reg/2018/848/oj.

Filippi, P., Jones, E. J., Wimalathunge, N. S., Somarathna, P. D., Pozza, L. E., Ugbaje, S. U., ... and Bishop T. F. (2019). An approach to forecast grain crop yield using multi-layered, multi-farm data sets and machine learning. *Precision Agriculture*, *20*, 1015-1029. https://doi.org/10.1007/s11119-018-09628-4

Hassan, E. S., Alharbi, A. A., Oshaba, A. S. and El-Emary A. (2024). Enhancing Smart Irrigation Efficiency: A New WSN-Based Localization Method for Water Conservation. *Water*, 16(5), 672. https://doi.org/10.3390/w16050672

Jatana, N., Puri, S., Ahuja, M., Kathuria, I. and Gosain, D. (2012). A survey and comparison of relational and non-relational database. *International Journal of Engineering Research & Technology*, 1(6), 1-5.

Jamshidi, B., Jolfaee, H. K., Mohammadpour, K., Seilsepour, M., Dehghanisanij, H., Hajnajari, H., Farazmand, H. and Atri, A. (2025). Internet of things-based smart system for apple orchards monitoring and management. *Smart Agricultural Technology*, 10:100715. https://doi.org/10.1016/j.atech.2024.100715.

Kadadi, A., Agrawal, R., Nyamful, C. and Atiq, R. (2014). Challenges of data integration and interoperability in big data. *IEEE International Conference on Big Data (Big Data),* Washington, DC, USA, pp. 38-40. https://doi.org/10.1109/BigData.2014.7004486.

Kalelkar, M., Churi, P. and Kalelkar, D. (2014). Implementation of model-view-controller architecture pattern for business intelligence architecture. *International Journal of Computer Applications*, 102(12), 16-21. https://doi.org/10.5120/17867-8786.

Kalfas, D., Kalogiannidis, S., Papaevangelou, O., Melfou, K. and Chatzitheodoridis, F. (2024). Integration of technology in agricultural practices towards agricultural sustainability: A case study of Greece. *Sustainability*, 16(7), 2664. https://doi.org/10.3390/su16072664

Kamble, S. S., Gunasekaran, A. and Sharma, R. (2020). Modeling the blockchain enabled traceability in agriculture supply chain. *International Journal of Information Management*, 52, 101967. https://doi.org/10.1016/j.ijinfomgt.2019.05.023.

Kamilaris, A., Kartakoullis, A. and Prenafeta-Boldú F. X. (2017). A review on the practice of big data analysis in agriculture. *Computers and electronics in agriculture*, 143, 23-37. https://doi.org/10.1016/j.compag.2017.09.037.

Kamilaris, A., Fonts, A. and Prenafeta-Boldύ F.X. (2019). The rise of blockchain technology in agriculture and food supply chains. *Trends in food science & technology*, 91, 640-652. https://doi.org/10.1016/j.tifs.2019.07.034.

Kalyani, Y., Vorster, L., Whetton R. and Collier R. (2024). Application Scenarios of Digital Twins for Smart Crop Farming through Cloud–Fog–Edge Infrastructure. *Future Internet*, 16(3), 100. https://doi.org/10.3390/fi16030100.

Kirikkayis, Y., Gallik, F., Winter, M. and Reichert, M. (2024). Improving Comprehensibility of IoT-Driven Business Processes through BPMN 2.0 Extension: A User Study. *Procedia Computer Science*, 239:19-26, https://doi.org/10.1016/j.procs.2024.06.141.

Lasdun, V., Harou, A., Magomba, C. and Guereña, D. (2025). Peer learning and technology adoption in a digital farmer-to-farmer network. *Journal of Development Economics*,103496, https://doi.org/10.1016/j.jdeveco.2025.103496.

Latino, M. E., Menegoli, M., Lazoi, M. and Corallo A. (2022). Voluntary traceability in food supply chain: a framework leading its implementation in Agriculture 4.0. *Technological Forecasting and Social Change,* 178, 121564. https://doi.org/10.1016/j.techfore.2022.121564.

Le, M. T. (2024). Fostering product quality and Brand Trust by QR code traceability and customer reviews: The moderating role of brand reputation in Blockchain. *The Journal of High Technology Management Research,* 35(1), 100492. https://doi.org/10.1016/j.hitech.2024.100492.

Li, L., Han, J. and Zh,u Y. (2024). Empowering sustainability: How digital agricultural extensions influence organic fertilizer choices among Chinese farmers. *Journal of Environmental Management*, 371: 123340, https://doi.org/10.1016/j.jenvman.2024.123340.

Liu, Z., Yu, X., Liu, N., Liu, C., Jiang, A. and Chen, L. (2025). Integrating AI with detection methods, IoT, and blockchain to achieve food authenticity and traceability from farm-to-table. Trends in Food Science & Technology, 158:104925. https://doi.org/10.1016/j.tifs.2025.104925.

MacPherson, J., Rosman, A., Helming, K. and Burkhard, B. (2025). A participatory impact assessment of digital agriculture: A Bayesian network-based case study in Germany. *Agricultural Systems*, 224: 104222. https://doi.org/10.1016/j.agsy.2024.104222.

Massaoudi, A., Berguiga, A. and Harchay A. (2022). Secure Irrigation System for Olive Orchards Using Internet of Things. *Computers, Materials and Continua*, 72: (3), 4663-4673. https://doi.org/10.32604/cmc.2022.026972.

Mohapatra, A. G., Mohanty, A., Mohanty, S. K., Mahalik, N. P., Nayak, S., Samantaray, S. and Patoshi, R. K. (2025). Harmonizing nature and technology: The synergy of digital twin-enabled smart farming. In "Digital Twins for Smart Cities and Villages", Eds: Iyer S., Anand Nayyar A., Paul A., Naved M., 407-442. https://doi.org/10.1016/B978-0-443-28884-5.00018-X.

Muangprathub, J., Boonnam, N., Kajornkasirat, S., Lekbangpong, N., Wanichsombat, A. and Nillaor, P. (2019). IoT and agriculture data analysis for smart farm. *Computers and electronics in agriculture*, 156, 467-474. https://doi.org/10.1016/j.compag.2018.12.011

Mushtaque, M. A. R. (2024). Integration of Wireless Sensor Networks, Internet of Things, Artificial Intelligence, and Deep Learning in Smart Agriculture: A Comprehensive Survey: Integration of Wireless Sensor Networks, Internet of Things. *Journal of Innovative Intelligent Computing and Emerging Technologies*, 1(01), 8-19.

Paramesha, M., Rane, N. L. and Rane, J. (2024). Big data analytics, artificial intelligence, machine learning, internet of things, and blockchain for enhanced business intelligence. *Partners Universal Multidisciplinary Research Journal*, 1(2), 110-133. https://doi.org/10.2139/ssrn.4855856.

Parra-López, C., Reina-Usuga, L., Garcia-Garcia, G. and Carmona-Torres, C. (2025). Promoting digital traceability in agriculture: A predictive approach to adoption and policy design in the olive sector. *Technological Forecasting and Social Change*, 215, 124077, https://doi.org/10.1016/j.techfore.2025.124077.

Pradeep, M. and Tyagi, A. K. (2024). Smart Sensor-Based Smart Agriculture for Better Crop Production in This Smart Era. In A. Naim (Ed.), *AI Applications for Business, Medical, and Agricultural Sustainability* (pp. 236-266). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-5266-3.ch009

Qian ,Y. and Zhang, W. (2022). The Current Situation and Causes of Farmers' Digital Literacy. *Advances in Social Science, Education and Humanities Research,* 664, 2334-2337. https://doi.org/10.2991/assehr.k.220504.422

Salah, K., Nizamuddin, N., Jayaraman, R. and Omar, M. (2019). Blockchain-based soybean traceability in agricultural supply chain. *IEEE Access*, 7, 73295-73305. https://doi.org/10.1109/ACCESS.2019.2918000.

Seo, Y. (2025). How robotics, processing techniques, food delivery apps and data technology enhance consumer choices. *Reference Module in Food Science*, https://doi.org/10.1016/B978-0-443-15976-3.00022-2.

Slettli, V. (2024). Smart Farming or Digital Agriculture. *Reference Module in Social Sciences*, https://doi.org/10.1016/B978-0-443-13701-3.00490-4

Soussi, A., Zero, E., Sacile, R., Trinchero, D. and Fossa, M. (2024). Smart Sensors and Smart Data for Precision Agriculture: A Review. *Sensors*, 24(8), 2647. https://doi.org/10.3390/s24082647.

Suji Prasad, S. J., Thangatamilan, M., Suresh, M., Panchal, H., Rajan, C. A., Sagana, C., … and Sadasivuni, K. K. (2021). An efficient LoRa-based smart agriculture management and monitoring system using wireless sensor networks. International Journal of Ambient Energy, 43(1), 5447–5450. https://doi.org/10.1080/01430750.2021.1953591

Tarjan, L., Šenk, I., Tegeltija, S., Stankovski, S. and Ostojic, G. (2014). A readability analysis for QR code application in a traceability system. *Computers and Electronics in Agriculture*, 109, 1-11. https://doi.org/10.1016/j.compag.2014.08.015.

Victor, N., Maddikunta, P. K. R., Mary, D. R. K., Murugan, R., Chengoden, R., Gadekallu, T. R., ... and Paek, J. (2024). Remote Sensing for Agriculture in the Era of Industry 5.0-A survey. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 17, 5920-5945. https://doi.org/10.1109/JSTARS.2024.3370508.

Visconti, P., de Fazio, R., Velázquez, R., Del-Valle-Soto, C. and Giannoccaro, N. I. (2020). Development of Sensors-Based Agri-Food Traceability System Remotely Managed by a Software Platform for Optimized Farm Management. *Sensors*, 20(13), 3632. https://doi.org/10.3390/s20133632.

Vlontzos, G., Ampatzidis, Y., Manos, B. AND Pardalos, P. M. (2022). Modeling for Sustainable Management in Agriculture. *Food and the Environment*. 1st ed. CRC Press. https://doi.org/10.1201/9780429197529.

Zhang, Y., Cui., R., Wei X. and Chen, T. (2025). How digital financial inclusion enhances agroecological efficiency: Impact effects and mechanism tests. *International Review of Economics & Finance*, 97: 103755. https://doi.org/10.1016/j.iref.2024.103755.