

Innovations in Agri-Food Plants

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1. Introduction

The global agro-food sector is navigating a pivotal transition characterized by the integration of Agro-Food 4.0 architectures and the pursuit of radical sustainability. This evolution is driven by the necessity to decouple industrial growth from environmental degradation while ensuring food security in a volatile global market. The current state of the art is defined by four intersecting technological domains.

The forefront of digitalization in food plants has shifted from basic PLC-based automation to Cognitive Manufacturing. Central to this is Digital Twin (DT)—a multi-physics, multiscale virtual representation of physical assets. Recent literature has highlighted how DTs allow for the real-time optimization of complex thermal and mechanical processes, such as spray drying and ultra-high-temperature (UHT) processing, by predicting the behavior of non-Newtonian food fluids under varying conditions [1,2].

Furthermore, the integration of Artificial Intelligence (AI) and Machine Learning (ML) algorithms enables the processing of massive datasets from Industrial Internet of Things (IIoT) sensors to achieve predictive maintenance and dynamic quality control [3]. These systems allow for “on-the-fly” adjustments to production lines, compensating for the inherent biological variability of agricultural raw materials, which is a major source of industrial inefficiency [4,5].

Sustainability has evolved from a regulatory requirement to a radical engineering philosophy centered on the Circular Bio-economy. Modern food plants are increasingly modeled as integrated biorefineries. In this paradigm, side-streams (e.g., pomace, whey, hulls) are not treated as waste, but as feedstock for the recovery of high-value compounds.

Advanced extraction techniques, including Ultrasound-Assisted Extraction (UAE), Microwave-Assisted Extraction (MAE), and Supercritical Fluid Extraction (SFE), are now the gold standard for isolating bioactive phenolics and proteins without the use of toxic solvents [6,7]. This holistic valorization approach ensures that every fraction of the raw biomass contributes to the economic and ecological viability of the plant [8,9].

A significant trend in process engineering is Process Intensification (PI), which aims to make industrial plants smaller, safer, and more energy-efficient. This is largely achieved through the electrification of processing via non-thermal technologies. Pulsed Electric Fields (PEFs), Cold Plasma, and High-Pressure Processing (HPP) have reached a level of industrial maturity that allows for the microbial stabilization of food with minimal thermal load [10,11].

These “green” technologies significantly reduce water consumption—a critical factor given that food processing is one of the most water-intensive industrial sectors [12]. Moreover, the integration of renewable energy microgrids (solar, wind, and biogas from plant waste) is transforming food plants into energy-autonomous units [13].

The digitalization of the agro-food plant is incomplete without considering its role in the global supply chain. Blockchain technology is being utilized to create decentralized,



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immutable ledgers that provide radical transparency from the farm to the processing plant and finally to the consumer [14].

When coupled with Smart Packaging and Intelligent Sensors (e.g., RFID and time-temperature indicators), blockchain enables a “dynamic shelf-life” model. This significantly reduces post-production losses and allows for more resilient supply chains capable of responding to disruptions in real time [15–17].

2. An Overview of Published Articles

The overarching synthesis of these studies suggests that the future of agri-food systems lies in holistic technological adoption. Whether through the optimization of electrical components, the implementation of smart irrigation sensors, or the chemical valorization of waste streams, the primary objective remains the same: the creation of a more resilient, resource-efficient, and sustainable food supply chain. These innovations collectively move the industry away from traditional, resource-heavy practices toward a more precise and circular bio-industrial model.

At present, innovation in food plants is no longer exclusively focused on volumetric efficiency or throughput. Instead, the emphasis has shifted toward “intelligent” and predictive system capabilities. The integration of Cyber-Physical Systems (CPS) and Digital Twins enables real-time monitoring and autonomous optimization of energy consumption, significantly reducing the carbon footprint of transformation processes.

In parallel, there is a clear consolidation of “green” extraction and processing technologies. The industrial implementation of non-thermal technologies—such as ultrasound, microwaves, and Pulsed Electric Fields (PEFs)—has proven effective in reducing processing times and eliminating toxic chemical solvents, while simultaneously preserving the integrity of thermolabile bioactive compounds. These systems are evolving from isolated units into components of integrated biorefineries designed for the total valorization of raw materials.

3. Conclusions

In conclusion, innovation in agri-food plants is evolving toward a systemic vision where technology serves as an enabler for environmental, economic, and social sustainability. The contributions gathered in this volume represent a fundamental step toward building more resilient, secure, and transparent food systems, prepared to address the global challenges of food security and resource scarcity. Moreover, “Innovation in Agri-Food Plants” is not merely about incremental mechanical changes, but about a holistic reimagining of how we produce, process, and preserve food in a resource-constrained world. These studies provide the technical foundation upon which a more sustainable and resilient global food system will be built.

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