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EDITED AND REVIEWED BY
Patrick Meyfroidt,
Université Catholique de Louvain, Belgium

*CORRESPONDENCE
Abdo Hassoun
✉ a.hassoun@saf-ir.com

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# Editorial: Food sustainability and Food Industry 4.0: unveiling the relationship

Abdo Hassoun[1]*, Fatma Boukid[2] and Fatih Ozogul[3]

[1]Sustainable AgriFoodtech Innovation & Research (SAFIR), Arras, France, [2]ClonBio Group LTD, Dublin, Ireland, [3]Department of Seafood Processing Technology, Faculty of Fisheries, Cukurova University, Adana, Türkiye

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Editorial on the Research Topic
Food sustainability and Food Industry 4.0: unveiling the relationship

Nowadays, the quest for food sustainability is becoming ever more urgent in the face of global challenges, such as climate change, population growth, outbreak of pandemics and conflicts, resource scarcity, biodiversity loss, and degradation of arable land. As the world strives to achieve the United Nations' Sustainable Development Goals (SDGs), ensuring sustainable food systems emerges as a pivotal concern for food producers, consumers, and all other stakeholders along the food supply chain. Traditional methods used in agriculture and the food industry are increasingly strained by the aforementioned pressures, necessitating innovative solutions that can enhance efficiency, reduce waste, and promote environmental sustainability (Kazancoglu et al., 2023; Mehany et al., 2023; Hassoun, 2024). Additionally, modern food processing and intensive agricultural methods are contributing to these pressures by prioritizing high production rates, often at the expense of long-term sustainability. Consequently, there has been increasing interest in recent years in applying technologies of the fourth industrial revolution (Industry 4.0) to the agricultural and food sectors. This approach, known as "Food Industry 4.0," has significant potential to transform food production, processing, packaging, distribution, and consumption (da Silveira et al., 2021; Hassoun et al., 2024a).

Food Industry 4.0 encompasses a range of digital, physical, and biological advanced technologies, including artificial intelligence (AI), big data analytics, the Internet of Things (IoT), smart sensors, robotics, and blockchain, among others, all integrated into the food supply chain to create smart, interconnected systems and enhance automation and digitalization (Liu et al., 2021; Hassoun et al., 2023a). These technologies enable real-time monitoring, precision agriculture, and smart food factories, addressing critical issues related to food security, safety, and sustainability. By leveraging these innovations, the food industry can significantly reduce its environmental footprint while enhancing productivity and ensuring a consistent supply of safe and nutritious food, ultimately enhancing food sustainability (Hassoun et al., 2022; Stefanini and Vignali, 2023). A particularly promising application of Industry 4.0 technologies directly linked to food sustainability is the reduction and valorization of food loss and waste in various food related industries, such as seafood (Hassoun et al., 2023c), the dairy sector (Hassoun et al., 2024b), and food packaging industry (Hassoun et al., 2023b).

Our Research Topic draws attention to the newly developed sustainable technologies and concepts in agri-food sector, emphasizing the potential of Industry 4.0 solutions to boost food sustainability and expedite the attainment of the SDGs.

Disease outbreaks, particularly the COVID-19 pandemic, have significantly disrupted global food systems. The pandemic has led to widespread lockdowns, labor shortages, and supply chain disruptions, exacerbating the already existing challenges, such as climate change and other environmental and societal stressors. The impact of COVID-19 has underscored the vulnerabilities in food supply chains and has accelerated the adoption of digital technologies within the agri-food industry to mitigate these disruptions. In their review paper, Hassoun et al. highlighted the importance of using various Industry 4.0 technologies, especially AI, big data, IoT, blockchain, smart sensors, robotics, digital twins, and virtual/augmented reality in overcoming challenges related to COVID-19, and discussed the barriers to their widespread adoption. The authors proposed four concrete recommendations to achieve an inclusive digital transformation and enhance food security and food sustainability, i.e., (i) transforming mindsets and developing digital skills, (ii) establishing adequate digital infrastructure and services, (iii) fostering interdisciplinarity and cross-border collaboration, and (iv) implementing effective data governance and cybersecurity strategies. The review concluded that while significant progress has been made, much work remains to fully leverage Industry 4.0 technological innovations in the agriculture and food industry.

Building on these insights, Ferguson et al. investigated the impact of digital agricultural technology on food security for smallholder farmers in Odisha, India, during the COVID-19 pandemic. Conducted collaboratively by Canadian academic researchers, 15 small-scale farmers from Odisha, and the Indian social enterprise eKutir, the study examined how eKutir's technology supports farmers in meeting their food security needs, sustaining livelihoods, and participating in local food systems before and during the pandemic. The main objective was to strengthen the adaptive capacity of smallholder farmers and their food systems during crises like COVID-19, affecting economic, physical, and social life aspects. The findings revealed that access to eKutir's platform (digital finance and payments, digital farm advisory, digital marketplace, and digital API; Application Programming Interface integrations) enabled farmers to stay connected to markets, continue earning income, and support local food systems during the pandemic. The authors concluded that designing these digital technologies to meet the specific needs of resource-limited farmers can significantly enhance their ability to withstand modern challenges and risks.

Transitioning from practical applications to conceptual analysis, Piot-Lepetit explored the possibility of fostering the convergence between digitalization and sustainability, termed digitainability, in the agri-food sector. The author emphasized the significance of sustainability and digitalization as key transformative trends, underlining the role of open innovation initiatives in promoting digital sustainability (digitainability) innovations within the agri-food sector.

To further advance the discussion in the context of precision agriculture, Zhou et al. established a foundation for achieving real-time control of mechanized trench fertilization in fruit cultivation and production. The authors developed a multi-source and cost-effective data acquisition system, to collect, construct point clouds, and store data related to the trench. The results showed the calculated width and depth had error ranges of 0–5.965% and 0–4.54%, mean value errors of 0.002 and 0.003 m, standard deviation errors of 0.011 and 0.017 m, and stability coefficient errors of 0.37 and 0.47%, respectively.

The journey toward digital transformation in agriculture and the food industry is laden with significant challenges, including technological barriers, financial constraints, and resistance to change, among others. Despite these hurdles, it is imperative to accelerate this transition to enhance efficiency, productivity, and food sustainability. Embracing advanced technologies such as AI, big data, IoT, smart sensors, and blockchain can revolutionize the whole food supply chains, addressing critical issues, such as food security, resource management, and climate change. Swift navigation through this transformative path is crucial to meet the growing global demand for food while ensuring environmental and economic resilience.

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AH: Writing – original draft, Writing – review & editing. FB: Writing – review & editing. FO: Writing – review & editing.

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## Conflict of interest

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