Editorial: Advancing food processing: novel technologies and modeling techniques

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Editorial: Advancing food processing: novel technologies and modeling techniques

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Editorial on the Research Topic
Advancing food processing: novel technologies and modeling techniques

Introduction

In recent years, the food industry has witnessed growing interest in novel processing technologies driven by the need for improved sustainability, product quality, and process efficiency. Technologies such as Ohmic heating, ultrasound, and high-moisture extrusion offer significant advantages, from nutrient retention to reduced energy consumption. Simultaneously, modeling and simulation approaches—ranging from classical mathematical models to machine learning and Digital Twin systems—are transforming how these technologies are designed, optimized, and implemented.

This Research Topic brings together five cutting-edge contributions that explore how innovations in both physical processing and computational modeling can address persistent challenges in food manufacturing. These articles span process-specific advances to system-wide simulations, offering insights into future directions.

Understanding complex extrusion dynamics

In *"Modeling and experimental analysis of protein matrix solidification in cooling dies during high-moisture extrusion,"* Högg et al. offer an in-depth study of the cooling die section in high-moisture extrusion (HME) for plant-based meat analogues. Through a combination of experimental data and finite volume simulations, the authors examine how geometry, pressure, and flow behavior influence protein matrix structuring. Their use of inverse method to estimate unmeasurable parameters such as wall slip and viscosity exemplifies how simulation can address knowledge gaps in real-time process monitoring. This work significantly contributes to understanding protein texturization and provides a validated framework for optimizing HME processes—an area of growing importance for alternative proteins.

Digital twin applications in food processing

Abdurrahman and Ferrari's review, *"Digital Twin applications in the food industry: a review,"* presents a comprehensive synthesis of the state-of-the-art in Digital Twin (DT) adoption. The authors evaluate how DTs have evolved from static digital models to dynamic, real-time systems capable of monitoring, predicting, and optimizing food processing operations. They examine use cases and implementation challenges, with a particular focus on sustainability. By categorizing DTs based on application level, modeling technique, and functionality, this article provides a practical taxonomy and roadmap for future adopters. A key insight is the relative lack of DT deployment in food manufacturing compared to agriculture—a research gap they urge the community to address.

Simulation and machine learning for granular flow in food processing

In *"Simulation of granular flows and machine learning in food processing,"* Cui et al. investigate granular material behavior—an area of increasing relevance in food processing and transport operations. Using Discrete Element Method (DEM) simulations, combined with supervised machine learning approaches such as Random Forest and Ridge Regression, the study offers a dual pathway to predict granular flow behaviors. Their findings show that integrating DEM datasets with machine learning improves predictive accuracy while reducing computational costs. This combined approach holds strong potential for optimizing equipment design and operations involving powders and grains.

Optimizing UV-C disinfection through simulation and experimentation

Chen et al., in *"Maximizing the disinfection effectiveness of 254 nm UV-C light with a special design unit: simulation and experimental approaches,"* explore the combined use of simulation and experimentation to enhance UV-C disinfection efficiency for complex surfaces. The study presents a specially designed UV-C unit that achieves isotropic germicidal light distribution—essential for irregular, hard-to-sanitize surfaces found in food processing and healthcare environments. By integrating ray-tracing simulations with microbial inactivation tests using *E. coli* and *Listeria innocua*, the authors demonstrate up to 6.9 log CFU reductions. They also highlight how surface properties like roughness and hydrophobicity affect disinfection efficacy. The validated use of optical ray tracing for predicting fluence distribution, paired with microbial kinetics, presents a strong framework for developing future UV-C systems.

Hybrid solar drying of paddy grains using multiphysics simulation

Jha and Tripathy, in *"Performance evaluation and finite element modeling of heat, mass, and fluid flow inside a hybrid solar dryer during drying of paddy grains,"* present a rigorous computational and experimental study of a photovoltaic-assisted hybrid solar dryer (HSD) for paddy grain drying. They simulate heat and mass transfer within the dryer using finite element methods, validated by experimental results. The study evaluates system performance under varying thermal and airflow conditions, benchmarking the HSD against conventional tray and mixed-mode dryers. The model accurately predicts spatial distributions of temperature, air velocity, and moisture content. Results show up to 81% collector efficiency and 25%–33% reductions in drying time. This work supports the development of energy-efficient drying solutions in low-resource settings, underscoring the value of simulation-driven dryer design.

Synthesis and future outlook

A shared theme across these contributions is the integration of novel food processing technologies with advanced computational modeling. From finite volume, finite element, and discrete element method simulations to artificial intelligence and Digital Twins, the breadth of approaches illustrates the field's shift toward data-driven, predictive manufacturing.

Nonetheless, challenges remain. While modeling capabilities are growing, integration with real-time industrial operations—particularly for small and medium enterprises—remains nascent. More work is needed to standardize data collection and preprocessing for ML and simulation-based studies to enhance reproducibility. Moreover, multi-scale modeling—linking molecular transformations to macroscopic quality outcomes—remains underdeveloped, especially for complex materials like granular or fibrous foods.

The Digital Twin paradigm stands out as a promising avenue. As Abdurrahman and Ferrari highlight, DTs enable real-time decision-making and resource optimization. Yet, their deployment in food manufacturing remains limited. Future research should focus on scalable, modular DT frameworks that can integrate with existing equipment and data infrastructures.

Additionally, while many studies in this Research Topic focus on single technologies or processes, integrated models simulating full production chains would be valuable. These models should account for variability in raw materials, environmental conditions, and dynamic processing scenarios—key for building resilient, low-carbon food systems.

In summary, this Research Topic demonstrates the transformative potential of combining physical food processing innovations with advanced modeling and simulation tools. The featured studies offer robust examples of how interdisciplinary research can push the boundaries of sustainable, intelligent, and high-quality food production.

We thank all contributing authors for their outstanding work and hope this Research Topic serves as a valuable reference for researchers, practitioners, and policymakers in food engineering and related fields.

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