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Current and new Green Deal solutions for sustainable food processing

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Abstract
Food security, seen from a global perspective, encompasses both the sustainable production of high-quality food and the reduction of food waste. Food production needs to be resource efficient and contribute to economic growth through sustainable use of natural capital. Promising innovative processes have become internationally marketable applications based on research conducted over the last decades. The ultimate challenge is to define the niche applications for each breakthrough that will optimally fulfill the objective of highest quality food products with full environmental and economic sustainability. The aim of the article is to present and discuss the current and future perspectives of the food processing technologies, able to disrupt the food industry sector and consumer behavior.

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New technological solutions, Innovations in food engineering, Food preservation, Environmental challenges, Inventions, Sustainability, Circular bioeconomy.

The innovation aspect in food processing

Food preservation implies placing microorganisms in a hostile environment, with the aim to inhibit microbial growth or eliminate microbial survival. The feasible microbial response to any hostile environment defines the possibility to survive and potential ability to grow. Significant research is required in view of these responses; especially focusing on the response of specific spoilage and pathogenic microorganisms within the environment of a food product, affecting directly food quality and safety characteristics. The main consumer requirement is the production of high-quality foods, with high nutritional value, improved quality and longer shelf life. For this reason, research has been conducted for the evaluation of the homeostasis, metabolic exhaustion and stress reactions of microorganisms, by introducing the new concept of multitarget preservation for a gentle but most effective preservation of hurdle-technology foods [1]. Nowadays, the development of new food processing and packaging methods or novel combinations of existing technologies raises the interest of academia and industry and shows the potential to achieve significant quality improvement and shelf life extension of perishable food products, and thus improve management of the supply chain and subsequently reduce food waste. The current trend for novel food product design focuses on the development and application of minimal processing methods, mainly nonthermal processing technologies, such as high pressure, pulsed electric fields, and cold plasma. Furthermore, novel, biodegradable packaging materials and encapsulation of functional biomolecules are currently developed with the aim to inhibit microbial growth and physicochemical reactions and extend the shelf life of the packaged food products. The main advantage of novel processing over conventional (mainly thermal) treatment techniques is the better retention of sensory parameters and nutritional value.

Food processing is directly related to the human being and welfare. Global food production must be sufficient to meet human nutritional needs in the future. Under this context, novel food technologies, e.g. ultrasonic for emulsification *v.s.* high shear homogenization [2], combined application of rotor-stator and high pressure homogenization and spray drying for the microencapsulation of bioactive components in food matrices [3], electrospraying [4] and microfluidics [5], and food and feed ingredients [6] play a significant role in food security, safety, and sustainability. Climate change and environmental impact of any proposed industrial activity (including food industry) remain a significant threat to the European region and globally. To overcome these challenges, Europe requires a new growth strategy that will transform the Union into a modern, resource efficient and competitive economy [7]. The goals that have been set under this context lie within environmental (*i.e.*, elimination of net emissions of greenhouse gases by 2050), financial (*i.e.*, economic growth decoupled from resource use), and societal (no person and no place is left behind) activities. The European Green Deal is the overall plan to make the European economy sustainable. This can be achieved by turning climate and environmental challenges into opportunities and making the transition just and inclusive for all [8].

At the beginning of 2020, within only a few weeks, things had changed globally, due to COVID-19 disease caused by the coronavirus 2 (SARS-CoV-2). During the quarantine period, a dietary change has been reported towards the consumption of bakery products, dairy (cheese), pastry, eggs, and pulses, indicated by up to 300% frequency increase compared to the prequarantine period [9]. Up to the pandemic crisis, within the food related academic sector, the discourse had been dominated by the development and production of healthy and safe food products. The main issues considered were relevant to sustainability, circular economy, energy and water efficiency for product development and process design. Efficiency had been the main focus, with resilience not been considered as a significant issue [10].

In parallel to the problem of assuring high quantity and quality food for a growing world population, food industry has to satisfy today's consumers' needs. Consumers expect high nutritional value and biofunctional properties of nutritious foods, exceptional sensory characteristics, extended shelf life and ease of use, yet fresh like, minimally processed and with a 'clean label', sustainably developed in an environmentally and energy-efficient manner. These criteria create exceptional challenges for the continuous improvement of traditional processes and the creation of new products and design of advanced processes [11]. At the same time, consumers are often hesitant to accept innovations in food processing technologies, as the 'naturalness' of food currently influences consumer acceptance. Food neophobia has been reported towards innovations such as nanotechnology, cultured meat, and food irradiation. Considering the current challenges in food production, including crises caused by pandemics and population growth, disruptive food technologies are needed to progress towards a more resilient food system. Several food technologies have been considered as 'disruptive' innovations, as they fundamentally changed the food industry sector [12]. Representative cases are historically reported at BC era (e.g. 700.000 BC for fire, 10.000 BC for fermentation), and AD era (e.g. 1795 for canning, 1834 for refrigeration, 1945 for microwave ovens and 1995 for pulsed electric fields) [13].

The innovation challenges in food process engineering lie within potential advances in established technologies rather than novel processes. Innovation originates with the release of an idea, which after extensive analysis turns out to the concept and proposed solution, as it finally reaches the market and commercialization level. Each phase corresponds to a unique set of challenges and time-consuming actions within the innovation and creating value process. True innovations bring step changes in food process engineering and are actually rare events. On the other hand, innovations in food processing are mostly renovations or improvements of existing processes, which means taking smaller steps than the aspect of true innovation. A list of implications and opportunities of advance novel processing technologies and their potential to accelerate the food industry sector for the new Green Deal is presented in Table 1.

Thermal processing: 'I invent nothing, I rediscover'

The significance of the rediscovery of a well-defined idea and concept, so it can be applicable to the real life, has been emphasized by the French sculptor August Rodin (1840−1917) with his creation 'The Thinker'. During this period, at the beginning of the 19th century, the most important food processing achievements have been reported (Figure 1). Food preservation technologies, *i.e.*, refrigeration, pasteurization, and canning, are considered as the three most significant food inventions.

The first reference of thermal processing of foods took place at 1810 by Nicolas Appert with the invention of food canning [24], which was the result of the delivery of more than 200 prototypes by the inventor. Although the first applications were delivered in glass containers, the term 'canning' is considered as the most significant application of food thermal processing. Several applications have been reported and optimizations of the thermal processing of different food products. Data analysis and advanced mathematical modeling approaches have raised significant interest from the academia and industrial stakeholders, for process validation and optimization [25]. Nowadays, thermally processed foods may provide an excellent nutrition worldwide. Several alternative container materials have been developed that have the ability to protect canned food for longer periods, while at the same time having low greenhouse gas emissions.

Nonthermal processing: the case of high pressure − 130 years of technological progress

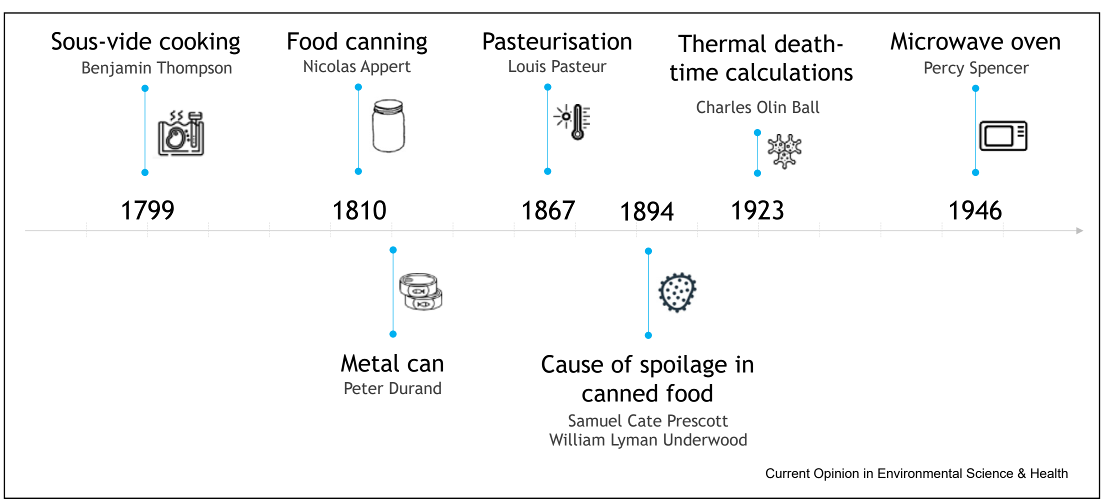
Based on the EU guidelines and recommendations, the produced food must be safe, nutritious, and high quality. In line with the EU Green Deal and the incorporation of the environmentally friendliness of the developed food systems, the global standard has

Table 1

Novel processing technologies for the acceleration of food industry to the new Green Deal.

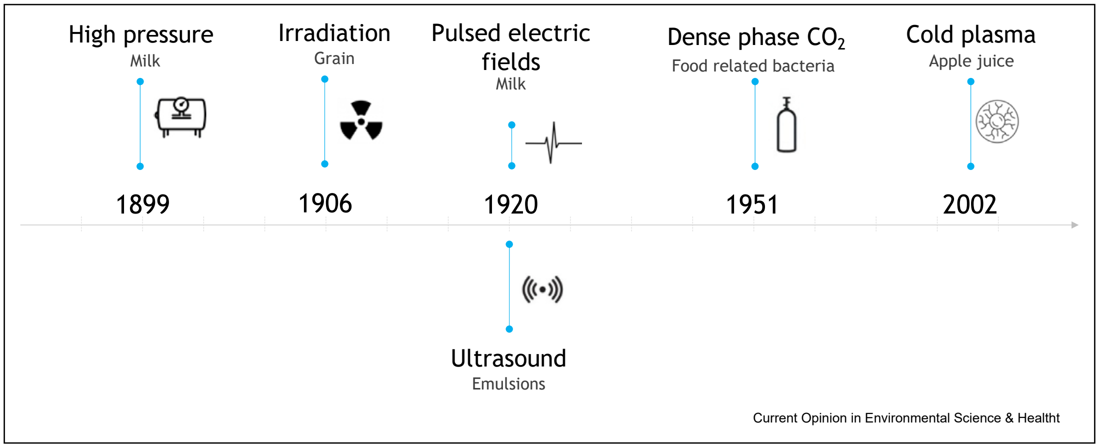
Technology	Applications for food processing	Opportunities to progress toward a more resilient food system	Reference
High pressure	Microbial inactivation, modification of enzymatic activity, enhancement of extractability of compounds from food processing side streams, allergen control.	Significantly improve safety and quality of food, enables side streams utilization.	[14–18]
Pulsed electric fields	Enhancement of extractability of compounds from food processing side streams, acceleration of mass transfer (drying, brining), reduction of food contaminants, reduction of initial microbial load.	Enables side streams utilization, improve functionality, extractability and recovery of valuable compounds, improves process efficiency and sustainability.	[14,19,20]
Cold plasma	Surface disinfection of foods and food packaging materials, degradation of toxins, allergen control.	Significantly improve safety and quality of food.	[14,21]
Pulsed light	Surface treatment of foods and food packaging materials, treatment of wastewater for reprocessing.	Significantly improve safety and quality of food, enables water recycling and wastewater utilization.	[22]
Ultrasound	Accelerate processes (filtration, freezing/thawing, mass transfer, sterilization/pasteurization), enhancement of extractability of compounds from food processing side streams	Enables side streams utilization, improves process efficiency and sustainability.	[14–16]
Irradiation	Food surface treatment, reduction of initial microbial load	Significantly improve safety and quality of food	[14,23]
3D food printing	Customized food design and production	Allow for personalized, precise, and reproducible nutrition containing personalized, appropriate amounts of nutrients.	[12]
ICT-Internet of Things	Online monitoring of food quality and safety in the processing plant	Radically transform and disrupt safety and quality, waste remediation and recycling, security, and authenticity and traceability.	[12]

Figure 1



Historical timeline of thermal food processing.

Figure 2

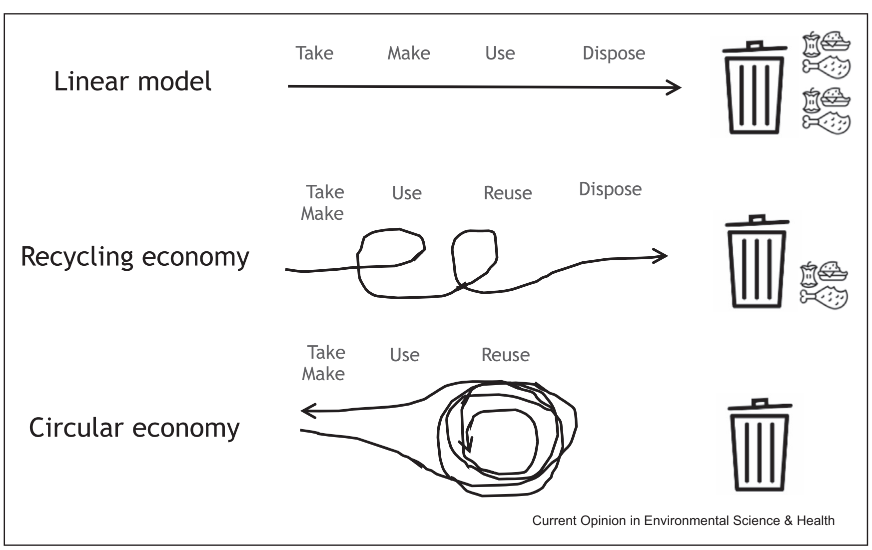


Historical timeline of nonthermal food processing.

set the recommendation of food sustainability. New operations should be provided with the aim to reduce the use of chemical food preservatives and unsustainable packaging systems [8].

Nonthermal processing technologies, such as high hydrostatic pressure, pulsed electric fields, ultrasound and cold plasma, have been applied to exemplify scalable and flexible food production processes [20]. Significant basic research has been conducted to adequately define and understand the fundamental principles underlining the main nonthermal processing technologies (Figure 2). The demand for safe and high-quality foods has introduced high pressure as the most developed emerging food processing technology for mild preservation of food and the possibility to achieve and scale-up significant extension of shelf life of a wide range of food products without the use of chemical and preservatives. The inactivation of spoilage and pathogenic microorganisms is the most wide industrial application of high pressure worldwide [26]. The first high pressure treatment has been reported in the late 1890s, regarding the microbial inactivation in dairy products (milk) [27]. During the past two decades, the number of the industrial high pressure systems shows a steady increase at several countries in Europe, USA, and Asia. Nonthermal

Figure 3



Illustrative definition of linear model, recycling economy, and circular economy approach.

processing, such as high pressure, has been recently be used to enhance the bioavailability of food constituents, modify the activity of enzymes correlated to maturation processes, proteins and food biopolymers structure, enhancing specific food properties [17,18,28,29]. It may also accelerate the extraction of bioactive compounds from food waste and potentially increase their bioavailability [15,16].

Food processing waste valorization: from linear model to circular economy

Based on the Farm to Fork strategy, a circular economy should also be achieved. It has been estimated that it might take a generation, *i.e.*, 25 years, to transform an industry sector and all the related value chain, based on a targeted action plan [30]. Between 1970 and 2017, the annual extraction of materials was triplicated worldwide, based on the linear economy model, and a steady increase has been reported, representing a major risk (Figure 3). The transition to the circular model offers a great potential for more environmentally friendly technologies resulting in lower emissions, sustainable production, and services and job creation at all stages of the food chain [8]. However, this transition is time-consuming and with significant variations between different food processing applications and host countries [31]. In addition, it is necessary to consider the simultaneous environmental and socio-economic impact of food waste and food loss reduction. With the announcement of Sustainable Development Goals by the EU, the implementation of scientific studies focusing on the adoption of circular economy models and tools in the EU practices has been encouraged [32].

Approaches such as the 'biorefinery' concept provide major aspirations toward the development of increasingly integrated technologies. Several waste biorefinery prototypes have been recently developed towards sustainable circular bioeconomy in the food production sector [33]. Aguieiras et al. [34] produced a fungal crude lipase by solid state fermentation using babassu cake as substrate. Fermented solids were applied for the biocatalysis of was ester synthesis. An integrated biorefinery has been developed by Tsouko et al. [35] by the use of orange peel waste obtained from catering services.

Conclusions

Facing shifts at a historically unprecedented pace in a rapidly growing world population, research and advances in the field of food engineering will make a major contribution to ensuring adequate quantities of high-quality food. Food process optimization integrates cost, water and raw material savings and waste and environmental burden prevention to deliver food products of high quality with enhanced economic and environmental sustainability.

Using state-of-the-art science and engineering expertise and modern tools, such as numerical process simulation, advanced measuring equipment, online process analysis, microstructuring and nanostructuring technologies, enables targeted product, process and package design to be focused on a deeper understanding of food component structures and properties. Promising innovative processes have become internationally marketable applications based on research conducted over the last decades.

Food engineering and processing advances, however, are mainly enhancements and the incorporation of new knowledge and concepts into existing processes. The ultimate challenge is to define the niche applications for each breakthrough that will optimally fulfill the objective of highest quality food products with full environmental and economic sustainability.

Credit author statement

Conceptualization: T.T. and N.G.S.; Investigation: T.T., A.K., I.M., and N.G.S.; Writing-Original Draft: T.T.; Writing-Review & Editing: T.T., A.K., I.M., and N.G.S.; Visualization: T.T. and N.G.S.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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** of outstanding interest

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