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Challenges and perspectives of advanced technologies in processing, distribution and storage for improving food safety

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Processing, distribution and storage compile the main parts of the food chain. Processing eliminates and/or prevents the microbes to proliferate and consequently spoil the food or cause a disease. It also affects other quality indices aiming at enhancing the shelf life of the product. The more mild the processes, the less their effect on the nutritional value of the products. A series of advanced physical technologies (e.g., plasma, pulsed electric field) have been proposed the past years but their further up-scaling and industrial application requires a better understanding of their antimicrobial mechanisms of action and their efficacy in controlling food safety. Radio frequency identification and time-temperature integrator devices can be used to monitor and log the temperature of foods during distribution and storage. Their combination with predictive microbiology tools can also lead to effective management systems improving food safety and quality. Their further implementation will require more awareness of their critical benefits and the better communication of their applicability.

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Introduction

Consumers are cognizant of the health benefits and risks associated with consumption of food. Therefore, the food industry devotes expertise and resources to the production of wholesome and safe products. It also focuses on increasing productivity in order to meet the demands of a growing population, but also making the market more financially sustainable and attractive. The latter is also achieved by reducing the costs due to water and energy, aiming at higher product quality, longer shelf-life, and reducing to minimal any lost sales.

Numerous alternative or complementary processing and distribution technologies to classical processing were developed the past years but some of them are not yet commercialized or their optimization is still based on empirical approaches. On the one hand, the goal of the processing technologies is to be mild for food especially with respect to its nutritional value while diminishing any pathogenic and spoilage risk or any quality deterioration [1]. Many of these technologies also aim at energy saving and being environmentally friendly. On the other hand, distribution technologies aim at accurately monitoring, recording and controlling critical parameters during the product's life cycle.

These are the major incentives for the food science and technology in order to develop alternatives technologies for improving the food safety. It is therefore evident that innovation in the food industry is a societal challenge with high potential for sustainable competiveness, innovation and growth. The main objective of this article is to review recent developments in the area of food processing, distribution, and storage, describing recent trends and highlighting the challenges that will need to be addressed during the coming years.

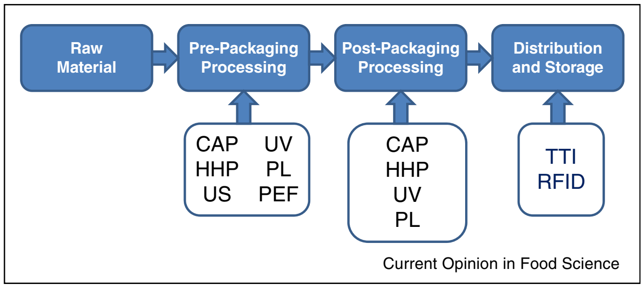
Food processing technologies

There are a series of different technologies that are used in the food processing, and preservation. The most evident approach to classify them is the following:

- Chemical (e.g., chlorine, organic acids, ozone)
- Biological (e.g., plant extracts, bacteriocins)
- Physical (e.g., high pressure, pulsed electric field, ultrasound, pulsed light)

Chemical technologies have been studied extensively the past years and their application got a lot of attention especially in the area of fresh produce decontamination [2]. Biological technologies have been promoted as alternatives for a more sustainable treatment of food products aiming at improved preservation strategies while they have been applied in combination with some other physical technologies. The focus of this article is on the main

Figure 1



Overview of the application of advanced technologies in processing, distribution and storage for improving food safety.

advanced physical technologies which are not based on heat generation (e.g., ohmic heating, radiofrequency, microwave, infrared heating) and have been proposed as alternatives to food pasteurization/sterilization/decontamination for pre-packaging or post-packaging applications. An overview of these processing advanced technologies is shown in Figure 1. Considering that these technologies can be applied before and after a product is packaged, they are also classified based on this characteristic.

Cold Atmospheric Plasma (CAP)

Plasma is an emerging technology generated by applying energy to a gas. This results in the production of ionized gas which contains free electrons, ions, and neutral particles. The produced so called plasma represents a dynamically environment, which consists of electrons and ions, free radicals, reactive (oxygen/nitrogen) species, electric and electromagnetic fields, visible, and UV emission [3•]. As a result a non-equilibrium chemical environment is created which has an impact to the living organisms and properties of products exposed to it.

There are different plasma based technologies reported in the literature, such as thermal, vacuum, low and atmospheric pressure plasmas. As reported by Schluter *et al.* [4•] atmospheric pressure plasma (by the use of plasma jet, dielectric barrier discharges) is more preferable for applications in the food sector because they allow continuous process control and do not accelerate undesirable phase transitions. It has been successfully applied at a research level in fruits, vegetables, cereals, nuts, fish, meat, eggs for different target microorganisms, including Gram + (e.g., *Listeria monocytogenes*, *Bacillus*), Gram – (e.g., *Escherichia coli*, *Salmonella*) and fungi (*Candida*, *Aspergillus*) (refer for examples to [5]). Nevertheless, it is still not industrially applied in the food industry.

The main challenges of this technology are the proper use of diagnostics in order to assess the impact of the processing parameters to any microbial or quality responses. For example the use of Optical Emission Spectroscopy is the most commonly used method to investigate species intensity [5], while a series of other diagnostics have been reported [6]. Considering that plasma generation results to a non-equilibrium chemical environment its reproducibility and proper reporting of the effect of processing parameters on the microbial responses (i.e., pathogens and spoilers) is of utmost importance. Further work on assessing induced microbial resistance following plasma treatments will be required. Similar approaches were implemented in High Hydrostatic Pressure and mild bactericidal treatments [7,8]. Although the main antimicrobial mechanisms of plasma treatments have been reported, i.e., DNA modifications and consequently erroneous cell replication, membrane rupture, oxidation of cell membranes [9•,10] further characterization of these mechanisms will be needed. On this aspect studies with knockout mutants of different susceptibility to different stresses (e.g., thermal, oxidative) will permit the identification of specific regulons which may play a key role in microbial stress responses generated during plasma treatments (e.g., [11•,12]). Additionally, differential gene expression studies following exposure to plasma could be considered [13]. These studies will permit a further understanding of the antimicrobial mechanism of action of plasma and the future application of this technology in food processing environments for packed and un-packed liquid and solid food products.

Ultrasound

Ultrasound generates sonic waves of specific intensity and amplitude. These are dependent on the frequency of operation. It is considered a non-water based or reduced water usage technology. Low-power ultrasound (from 100 kHz and above) and high-power ultrasound (from 20 to 100 kHz) are the main types of ultrasound used for food applications. It is the high power ultrasound that has a direct effect on the inactivation of microbes during decontamination and processing treatments, while the phenomena of acoustic cavitation and acoustic streaming contribute to the antimicrobial mechanism of action of this technology [2].

High-power ultrasound (HPU) technology could be used for the pasteurization of fruit juices. The main advantages of its application in food processing and preservation include the reduced energy consumption, the increase in homogeneity, the minimal flavour loss in liquid foods (e.g. juices), and the breakdown of agglomerates of bacteria [2]. It could also replace the heating steps of fruit juice or the microbial filtration step of concentrated juices. The minimal effects of ultrasound treatment on other quality parameters of ultrasound on fruit juices have been extensively reviewed by Millan-Sango *et al.* [2]. The majority of the current industrial applications of ultrasound are on controlling quality issues of beverages (e.g., de-foaming) than decontamination of liquids foods.