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Post-packaging application of pulsed light for microbial decontamination of solid foods: A review

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ABSTRACT

Non-thermal processes have become increasingly popular over the last decades. As one of the emerging non-thermal technologies, pulsed light (PL) represents a fast, tailored and residue-free technology that — via high frequency, high intensity pulses of broad-spectrum light rich in the UV fraction — is capable of inactivating microbial cells and spores.

This review provides some updated information on PL and its suitability for surface decontamination of solid matrices such as food and food-contact materials. The focus is on post-packaging application, which allows treatment of the packaged food thus avoiding undesirable recontamination. Furthermore, prerequisites for in-package application, the efficacy of the treatment compared with the non-packaged pendant and the alteration of both the product and packaging material accomplished by PL are discussed. In the case of packaging material, not only physical stability and mechanical stability but also chemical migration and possibly arising safety concerns are highlighted.

Industrial relevance: This review offers a comprehensive survey of the use of pulsed light for the decontamination of unpackaged as well as packaged solid foods and associated food contact materials. Based on this background, food scientists as well as research and development can develop suited packaging concepts and optimize the treatment with regard to decontamination efficiency, product quality and safety.

Contents

1. Introduction

Non-thermal technologies have gained an increasing interest over the last decades in the food producing sector (Knorr et al., 2011). This trend derives from the fact that consumer expectations and preferences have changed according to the societal and demographic developments. Foods nowadays are expected to be nutritious, organoleptically satisfactory, minimally processed and safe in terms of physical, chemical and

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microbial hazards (Aymerich, Picouet, & Monfort, 2008; Havelaar et al., 2010; Sofos, 2008; Weiss, Gibis, Schuh, & Salminen, 2010). With the marketer's goal to design fresh-like yet shelf-stable functional products comes the technologist's need to develop highly sophisticated systems.

Non-thermal processes such as hydrostatic pressure, pulsed electric fields, osmotic dehydration, radio frequency electromagnetic field and pulsed light (PL) represent a mild but tailored alternative to conventional food processes like heat treatment, which are likely to adversely affect the organoleptic and nutritive properties of the treated products (Butz & Tauscher, 2002; Ortega-Rivas, 2012, chap. 12; Palmieri & Cacace, 2005; Sofos, 2005).

Common to non-thermally processed foods is that they often require a change in packaging design or material. This can be attributable to the process itself or the consequential unique quality parameters of the respective product. Therefore the development of a suitable packaging can be seen as one of the key factors in successful commercialization of these systems (Han, 2005, 2007).

Aiming to maintain the quality and to facilitate handling of processed goods, a food packaging system has to fulfill the basic functions of storage, preservation and protection. Additionally, secondary functions like information about the product, convenience, presentation, brand communication, promotion, economy and environmental responsibility, which have become increasingly important in the past, are covered by the packaging system (Coles, 2003; Han, 2007).

In packaging design and development processes it is therefore of elementary importance to consider all tasks in a package's life cycle from production over distribution to consumption as well as waste management. In detail, six points, namely (i) product needs, (ii) distribution needs and wants, (iii) packaging materials, machinery and production process, (iv) consumer needs and wants, (v) market needs and wants and (vi) environmental performance have been identified by Coles (2003), based on the work of Paine (1987).

Intensive research is necessary to understand the actual requirements in the context of developing new or adapting existing packaging materials to newly developed non-thermal processes (Guillard, Mauricio-Iglesias, & Gontard, 2010; Han, 2007). Only then, the often-existing gaps among the developments in the various food production sectors can be closed and subsequent successful commercialization of the product is possible (Han, 2007).

One characteristic of classical food stabilization processes is that, in many cases and with the exception of canned food sterilization, packaging is only possible after the food has been processed. In this case, the packaging material is separately pre-disinfected or sterilized. Currently, some of the emerging food processing technologies such as hydrostatic pressure or pulsed light treatment have the benefit to treat foods inside the packaging. Clear advantage of these “in-package food processing technologies” is the avoidance of undesirable post-treatment contact of the food with the environment and in particular with microorganisms or oxygen (Guillard et al., 2010). Examples like the successful commercialization of high pressure processing of food applied as an in-package treatment show that the prerequisite for a sophisticated process development is a simultaneous development and perfection of the packaging concept. Here, volume and temperature changes due to compression and decompression during high pressure in-package processing represent major challenges that may affect oxygen and vapor barrier properties of flexible laminate films and may lead to partial delamination (Bull, Steele, Kelly, Olivier, & Chapman, 2010). However, by taking into account aspects such as head-space volumes, laminate adhesives as well as compressibility and resilience of individual layers of a multilayer structure, these issues could be overcome and polymeric multilayer films have been shown to meet the requirements (Caner, Hernandez, & Harte, 2004a). Similarly, respective process–product–packaging interactions need to be taken into account for the development of successful PL in-package treatment concepts.

2. Pulsed light

2.1. Fundamentals of pulsed light application

PL is an emerging non-thermal decontamination technology, which is capable of inactivating microorganisms on various surfaces, including food and food-contact materials (Dunn, Ott, & Clark, 1995). In its basics, the PL technology comprises the generation of high-power electrical pulses that are subsequently transformed to short-duration, high-power pulses of broad-spectrum (180–1100 nm) electromagnetic radiation (light) via an inert-gas (mainly xenon) flash lamp. In this context, the applicable rule is that the shorter the pulse duration, the higher the delivered energy and consequently the antimicrobial action (Dunn et al., 1989). A schematic layout of a PL device is provided by Heinrich, Zunabovic, Varzakas, Bergmair, and Kneifel (2015).

In general, three main factors, namely the treated matrix (e.g., food), the degree and nature of microbial contamination and the process parameters affect the efficiency of a pulsed light treatment. The matrix influences the efficiency with regard to transparency or opacity, surface characteristics and composition. Optimal results are achieved when the matrix has a low reflection-, high absorption- and transmission coefficient. Meaning that, aside from transparent liquids, effect of the PL technology is limited to the surface or uppermost layer of a semi-solid according to its capability to absorb and transfer light (Dunn et al., 1989; Gómez-López, Ragaert, Debevere, & Devlieghere, 2007; Palmieri & Cacace, 2005). Further, the target surface should be as smooth as possible, since vast irregularities and light-absorbing matter constitute a shelter for microbial contaminants and an obstacle for the incident light (Dunn et al., 1995; Gómez-López, Devlieghere, Bonduelle, & Debevere, 2005a; Gómez-López et al., 2007; Lagunas-Solar & Gómez-López, 2006; Palmieri & Cacace, 2005; Sommers, Cooke, Fan, & Sites, 2009). Ultimately, the matrix should contain only low quantities of substances able to competitively absorb light such as fat and protein. Carbohydrates, however, do not show this pronounced light-absorbing effect (Gómez-López et al., 2005a; Rajkovic et al., 2010).

Microbial contamination influences the efficacy of a PL treatment in respect of the microorganism, its physiological constitution, population density and the growth parameters (growth rate and lag time) (Augustin et al., 2011; Cudemos, Izquier, Medina-Martínez, & Gómez-López, 2013; Dunn et al., 1989). Some distinctions regarding the susceptibility of microorganisms to PL can be observed. For example Gram-positive bacteria seem to be more resistant than Gram-negative because of their cell structure. Also, mucoid- and pigment-forming bacteria can have a lower susceptibility to PL. Furthermore, fungi seem to be more resistant than bacteria, bacterial spores are more resistant than their corresponding vegetative cells and smaller bacteria are more than larger ones, due to the faster dissipation of heat from the surface (Anderson, Rowan, MacGregor, Fouracre, & Farish, 2000; Farrell, Garvey, Cormican, Laffey, & Rowan, 2010; Rowan et al., 1999). Since high population density and stationary growth phase can impair the decontamination efficiency, it is recommended to start the PL treatment as soon as possible after the contamination takes place (Anderson et al., 2000; Farrell et al., 2010; Gómez-López, Devlieghere, Bonduelle, & Debevere, 2005b; Hiramoto, 1984; Rajkovic, Tomasevic, et al., 2010).

The effect of PL on the microbial inactivation has been explained by photophysical (structural cell damage), chemical (cell death due to DNA lesions) and thermal (cell death due to disruption and structural changes) mechanisms (Cheigh, Park, Chung, Shin, & Park, 2012; Dunn et al., 1989; Farrell et al., 2010; Takeshita et al., 2003; Wekhof, 2000; Wekhof & Trompeter, 2001). Acting in parallel or in sequence these effects make PL treatments more effective than the conventional used UV systems (Dunn et al., 1989).

Repetitively, authors have demonstrated that the inactivation curve of PL treatment is non-linear and that, in consequence, the commonly used linear models cannot accurately describe the observed inactivation pattern (Farrell et al., 2010; Keklik, Demirci, Puri, & Heinemann, 2012;