Innovative Food Science and Emerging Technologies 39 (2017) 1–6

Contents lists available at ScienceDirect

Innovative Food Science and Emerging Technologies

journal homepage: www.elsevier.com/locate/ifset

Construction of a pilot-scale continuous-flow intense pulsed light system and its efficacy in sterilizing sesame seeds

Hee-Jeong Hwang [a], Chan-Ick Cheigh [b], Myong-Soo Chung [a,*]

[a] Department of Food Science and Engineering, Ewha Womans University, Seoul 120-750, South Korea
[b] Department of Food and Food Service Industry, Kyungpook National University, Sangju 742-711, South Korea

A R T I C L E I N F O

Article history:
Received 8 July 2016
Received in revised form 17 October 2016
Accepted 22 October 2016
Available online 24 October 2016

Keywords:
Intense pulsed light (IPL)
Pilot-scale
Cyclone
Sesame seed
Decontamination efficiency

A B S T R A C T

The purpose of this study was to identify the decontamination level of a laboratory-scale intense pulsed light (IPL) system and compared with that of newly constructed pilot-scale system in our laboratory. Sesame seeds, in which the initial microbial load was 10^4–10^5 CFU/g, were treated by laboratory-scale IPL treatment at a total fluence of 39.85 J/cm^2. 0.86 log microbial reduction was achieved and adding a mixing step increased this to a 1.02 log reduction. We concluded that combining a mixing process and powerful IPL is essential to decontaminate sesame seeds satisfactorily, and so a pilot-scale IPL device in which the sample is placed in a cyclonic flow was designed and constructed in our laboratory. The xenon lamp and power supply were also upgraded. This modified device achieved a 1.46 log reduction at a total fluence of 44.46 J/cm^2. Changing the material of the treatment chamber from acrylic to stainless steel induced light reflections that resulted in improvement of the decontamination efficiency. Although this study showed a potential of a pilot-scale IPL device for treating larger amount of sample at once, further studies of technical improvement are essential to achieve higher decontamination level.

1. Introduction

Intense pulsed light (IPL) is a nonthermal method of food preservation that involves the use of intense, short-duration pulses of broad-spectrum (Oms-Oliu, Martín-Belloso, & Soliva-Fortuny, 2010). The wavelength distribution of IPL ranges from 200 to 1100 nm, and it is 20,000 times more intense than sunlight at the earth's surface (Dunn, Ott, & Clark, 1995). The inactivation effect of IPL is generally attributed to inhibition of the formation of new DNA chains in the process of cell replication by forming pyrimidine dimers (Devi & Guttes, 1972; Esbelin, Malléa, Clair, & Carlin, 2016). Increased concentrations of eluted protein and structural changes also have been observed in yeast cells after exposure to IPL, and the photoreactivation rate of microorganisms is lower than UV treatment (Gómez-López, Devlieghere, Bonduelle, & Debevere, 2005; Otaki et al., 2003; Takeshita et al., 2003).

IPL exhibits high efficacy in disinfecting transparent liquid foods because it can penetrate them easily, which means that the efficacy of IPL in disinfecting liquids varies widely according to their optical properties such as the transmittance and absorbance (Koutchma, 2009; Unluturk, Arastoopour, & Koutchma, 2004). This highlights the importance of the design of a treatment chamber for sterilizing translucent and opaque liquids providing a high level of microbial reduction. Some studies have investigated the bactericidal effects of IPL on liquid foodstuffs in continuous-flow IPL devices (Artíguez, Lasagabaster, & Martínez de Marañón, 2011; Krishnamurthy, Demirci, & Irudayaraj, 2007; Pataro et al., 2011). In all of these studies, the treatment chamber was constructed so that pulsed light was effective at penetrating the liquid foodstuffs. We previously studied the inactivation of microorganisms in transparent liquids using a pilot-scale IPL device with a chamber volume of 66 L, and achieved a 4.79 log reduction of *Escherichia coli* C600 in untreated groundwater when using an energy dose of 14.02 J/cm^2 (Yi, Lee, & Chung, 2016).

However, there have been few published studies of microbial inactivation in powdery foods using newly designed or pilot-scale IPL devices. Some studies have investigated powdery foods using laboratory-scale IPL devices (Choi, Cheigh, Jeong, Shin, & Chung, 2010; Fine & Gervais, 2004; Sharma & Demirci, 2003). One problem encountered in the IPL treatment of powdery foods is a shadow effect, and solving this requires not only higher IPL energy levels but also the development of novel treatment chambers that can minimize the shadow effect. A pilot-scale IPL device for treating bulk amounts of powdery foodstuffs is required before applying IPL technology in the food industry.

Sesame seeds (*Sesamum indicum* L.) are one of the most-used food ingredients in Korea. During cultivation processes, sesame seeds are exposed to several pollutants, such as soil, fertilizer, wild birds and animals. So, sesame seeds are commonly distributed to consumers after a mild thermal process has been applied to inactivate microorganisms.

* Corresponding author.
E-mail address: mschung@ewha.ac.kr (M.-S. Chung).

http://dx.doi.org/10.1016/j.ifset.2016.10.017
1466-8564/

However, thermal treatment can cause some damage to sesame seeds such as to their color or nutrients, thereby decreasing the final product quality. Thus, an alternative decontamination process that provides both safety and high quality would be beneficial.

The aim of this study was to determine the microbial reduction when using a laboratory-scale IPL device and to develop a pilot-scale continuous-flow IPL system for the decontamination of sesame seeds. In addition, the microbial reductions achieved by applying this IPL device to sesame seeds by varying the total fluences were evaluated to assess the feasibility for commercial application.

2. Materials and methods

2.1. Sample preparation

Most of the sesame seeds used in Korea are imported based on considerations of their cultivation and price. This study used sesame seeds from China that were purchased from a local market and then stored at below 25 °C and under 80% of relative humidity in a sunless place for 15 days. The initial microbial load of the sesame seeds was maintained at 10^4–10^5 CFU/g (80–90% of bacteria and 10–20% of molds and yeasts).

2.2. Preliminary investigation of a laboratory-scale IPL device

Before constructing a pilot-scale IPL device, a preliminary investigation using a laboratory-scale IPL device was performed. The laboratory-scale IPL device was designed and constructed in our laboratory, and it consists of a power supply, treatment chamber, and lamp (Hwang, Cheigh, & Chung, 2015). When the power supply is turned on, generated electrical energy is stored until it reaches a specific value that can be controlled by the voltage, frequency, and treatment time. This electrical energy is then delivered to a xenon lamp (type NL4006, XAP series, Heraeus Noblelight, Cambridge, UK). This cylindrical lamp is made from quartz material, filled with xenon gas, and can emit irradiation over a spectral range from 200 to 1100 nm when the electrical energy is delivered to it. To maintain a constant temperature during IPL treatment, an air fan was installed as a cooling system in the upper part of the chamber. We found that the temperature of the samples increased by <10 °C during the experiments performed in this study.

Sesame seeds (10 g) were placed on a 150-mm-diameter Petri dish that was placed vertically beneath the lamp. The distance between the lamp and the bottom of the Petri dish was determined as 3.5 cm without significant temperature rise (below 5 °C) through preliminary experiments. The sesame seeds were irradiated with different energies by variation of the voltage (800–1800 V) which resulted in fluencies of 6.87–37.85 mJ/cm^2 and treatment times (60–240 s) at a frequency of 5 Hz.

The aim of this study was to develop an IPL device for sterilizing sesame seeds in bulk. Since it is important to irradiate all sides of the seeds, the addition of a mixing step during the treatment was considered. To identify the effect of a mixing step on the microbial reduction, two groups of seeds were equally irradiated by IPL with the voltage of 1600 V, which resulted in a total fluence of 39.85 J/cm^2 and treatment time of 240 s at a frequency of 5 Hz. One group was constantly irradiated by IPL for 240 s. In case of another group, on the other hand, break time was added after every 60 s of IPL treatment. During break time, seeds were mixed using a sterilized spreader (90050, SPL, Gyeonggido, Korea) within 10 s. All of these experiments were conducted in triplicate for each condition.

2.3. Constructing a pilot-scale IPL device and the treatment condition

The pilot-scale IPL device was also designed and constructed in our laboratory (Fig. 1). The xenon lamp and power supply were upgraded. Upgrading the light output of the xenon lamp was essential for bulk decontamination, and so the lamp was changed from type NL4006 to type NL9553 (Heraeus Noblelight). The type NL9553 xenon lamp is 271 mm long and 11 mm in diameter, while the type NL4006 lamp is 145 mm long and 7.14 mm in diameter. The electrical energy delivered by the power supply was increased. The absolute irradiances of IPL are compared between the type NL4006 and type NL9553 lamps in Fig. 2. In spite of the treatment condition being same, with a voltage of 1800 V and a frequency of 2 Hz, the total fluence and the shape of the spectral distribution measured by the spectroradiometer differed with the lamp type. The absolute irradiance increased, and the fluence of each pulse was enhanced from 37.85 to 88.66 mJ/cm^2.

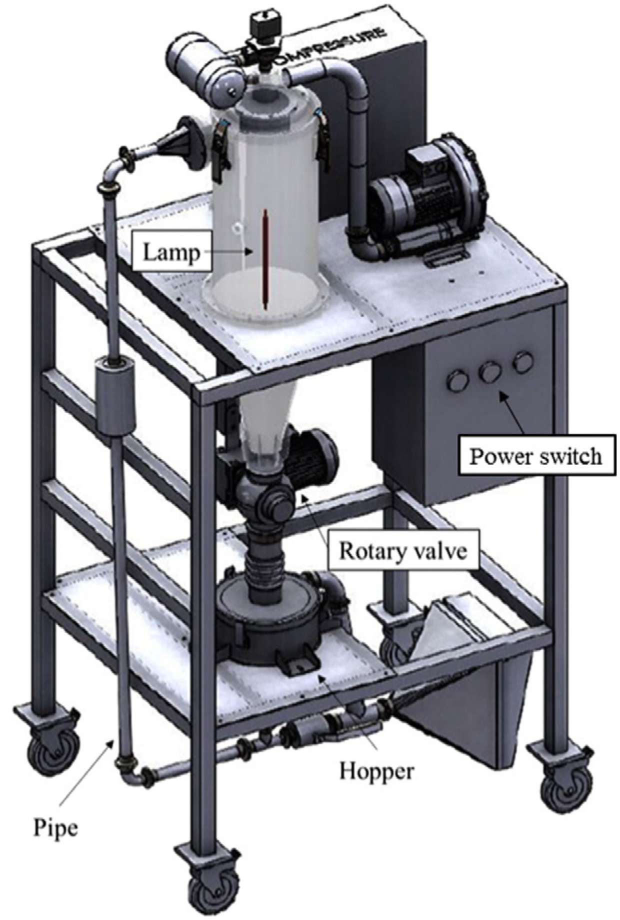

Fig. 1. Schematic diagram of the pilot-scale intense pulsed light (IPL) treatment system.

The power supply was upgraded to cope with the increases in lamp size and light output. First, the values of some control factors that could be adjusted were increased. The maximum voltage and frequency were increased from 1800 to 2400 V and from 10 to 15 Hz, respectively. The biggest difference between the original and upgraded power supplies was that the pulse duration of IPL could be controlled. The pulse duration of IPL, which is the time interval during which energy is delivered to a treated sample (Gómez-López, Ragaert, Debevere, & Devlieghere, 2007), was fixed at 0.1 ms for the original power supply, while with the upgraded power supply this could be adjusted from 0.5 to 3.0 ms. Fig. 3A shows the fluence for one pulse according to the pulse duration and voltage. The IPL fluence tended to increase in a similar way with the voltage at a specific pulse duration (0.5, 2.1, and 3.0 ms). This result implied that the sesame seeds could be treated with IPL for a shorter time using the upgraded lamp and power supply.

Besides the xenon lamp and power supply, the treatment chamber was also newly designed. A maximum of 3 kg of seeds can be added to the intake hopper. When the power switch is turned on, the inner part of the chamber is kept in a vacuum state by the compressor. This causes the seeds to travel up the pipe, and the raised seeds then fall