

Progress of pulsed light sterilization technology in the food field

Weijin Fang¹, Shengping Xue^{1,*}, Yitong Yue²

^{1,2}College of Bioscience and Engineering, Hebei University of Economics and Business, Shijiazhuang, 050061, Hebei, China

Abstract. In recent years, the rate of disease outbreaks caused by food-borne microorganisms is gradually increasing. The abuse of food preservatives has not only caused environmental problems, but also led to the gradual increase in the resistance of bacteria. As a non-thermal physical sterilization technology, pulsed light sterilization has attracted more and more attention in the field of food sterilization. Traditional heat sterilization will destroy the quality of food and cannot be used for preservation of fruits and vegetables. Chemical reagents will cause environmental problems. The pulsed light sterilization technology has the advantages of low cost, pollution-free, safe and efficient, and will not damage food quality. It can be perfectly applied in the field of food sterilization. Pulsed light can also be used in combination with other sterilization technologies. For example, the combined application of pectin coating and UV sterilization technology to treat food will achieve better results. The research on pulsed light sterilization at home and abroad is mainly based on the application in food sterilization. This article describes the mechanism of pulsed light sterilization, introduces the application examples of pulsed light sterilization in the food field, and discusses the impact on food quality.

1 INTRODUCTION

Food-borne diseases caused by eating food contaminated by microorganisms are still the main cause of morbidity worldwide^[1]. Therefore, adopting appropriate methods to reduce the hazards of food microorganisms is increasingly important for reducing the outbreak rate of foodborne diseases. Nowadays, there are a variety of methods for food preservation, such as heating, adding preservatives, freezing, and drying. These technologies can ensure the safety of food, but they all have certain limitations. For example, they are restricted by the objects to be processed. Heat sterilization cannot be used to preserve the freshness of fruits and vegetables. Preservatives cause environmental problems. Heating, drying and freezing cause changes in certain substances and affect food quality.^[2] In this context, physical non-thermal sterilization technology has been rapidly developed. This type of technology can maintain the nutritional value and sensory quality of food to the greatest extent while ensuring food safety. Among these emerging technologies, promising applications mainly include high-voltage processing, pulsed electric fields, and pulsed strong light sterilization technology^[3].

The well-known physical sterilization technology, continuous ultraviolet (UV) and visible light, has a very good killing effect on microbial cells. In recent years, a new method of using high power electricity to generate pulsed light (PL) to sterilize and preserve food has been

applied^[4]. PL has a good sterilization effect on the surface of the food and the environment in which the food is made. The earliest application areas of PL sterilization technology are mainly the sterilization of medical devices and transparent drugs. With the improvement of this technology, its application becomes more and more extensive, and it gradually transitions to food sterilization and preservation^[5]. Nowadays, research on PL sterilization is rapidly expanding, but there is still a gap between basic research and applied research on food sterilization.

This article mainly introduces the application of PL sterilization technology in the food field, discusses the combined application of PL sterilization technology and other sterilization technologies, and explores the sterilization mechanism, effectiveness and impact of PL on food quality.

2 PL sterilization mechanism

PL is a non-thermal physical food sterilization method that uses strong, short-time broad-spectrum pulses to kill microorganisms on the surface of food and packaging materials. The sterilization effect of PL depends on the intensity of light (J/cm^2) and the number of pulses^[6]. In some studies, irradiation is usually expressed in second, but there is no information about the number of pulses.

*Corresponding author: E-mail: xsp6210@163.com.

PL is produced by converting high-speed electronic pulses into short-time, high-peak energy pulses using engineering technology that is magnified several times. The system usually consists of three parts: a power supply, a pulse device and a lamp. The energy is stored in a high-power capacitor for a long period of time (a fraction of a second), and then released into a specially designed xenon lamp device in a shorter time (ns to ms). The high energy injected into the lamp produces intense light pulses, which are concentrated in the illuminated area, usually lasting several hundred milliseconds [7]. These lights include light with wavelengths in the UV to near-infrared spectrum. The wavelength range is 180-1100 nm, which is about 20,000 times the intensity of sunlight hitting the earth's surface [8].

The sterilization effect of PL increases with the increase of light intensity has been confirmed. The rich content of broad-spectrum UV light, short time, and high peak power in PL have a strong destructive effect on microorganisms [9]. The UV range contained in PL has a great influence on the sterilization effect. It has been confirmed that if the wavelength range below 320nm UV is removed, PL will not have a lethal effect on microorganisms [10]. PL mainly destroys nucleic acids, and UV light in PL mainly destroys DNA. The photochemical action causes pyrimidine bases to form dimers in the DNA of bacteria, viruses and other pathogens, blocking DNA replication, and if there is not enough repair mechanism, it will lead to the death of microorganisms [11].

Enzymatic repair of DNA does not occur after PL treatment, because the damage caused by PL is too severe for the repair mechanism to work [12].

3 Technical advantages

3.1 Comparison between PL sterilization and traditional thermal sterilization

For traditional heat sterilization technology, because it can accurately kill various microorganisms, and the degree of sterilization can be accurately controlled, as an effective sterilization method, it is widely used in the food sterilization. However, heat sterilization requires high temperature conditions. It will inevitably affect the sensory, color, quality and nutrients of the food [13]. As a new type of non-thermal sterilization technology, PL sterilization technology not only has the advantages of energy saving, high efficiency and safety, but also can effectively kill microorganisms while maintaining the color, quality and taste of food to the maximum extent, effectively making up for the defects of traditional heat sterilization technology.

3.2 Comparison between PL sterilization and UV sterilization

The principle of UV sterilization is that UV rays can destroy the molecular structure of DNA or RNA in microbial cells and cause the death of bacteria, achieving the effect of disinfection and sterilization. Photochemical action is the main mechanism of traditional UV

sterilization. For molds and spore microorganisms, it is difficult for UV to penetrate the dense cell wall structure, causing DNA (RNA) to be unable to absorb UV rays. PL sterilization not only relies on photochemical action, photothermal action and photophysical action also exert effects at the same time. When microorganisms receive PL at close range, they absorb a large amount of light energy in a short time, and the surface temperature of microorganisms will rise sharply. The structure will be completely destroyed and died [14]. Since the entire sterilization process lasts for a very short time, the irradiated object will not heat up, nor will it affect nutrients.

4 PL sterilization effect on different microorganisms

Table 1 Sterilization effect of different microorganisms by PL

Strain	Processing energy	Effect
<i>Botrytis cinera</i>	15 Hz, 30 μ s	3~4logs
<i>L. Innocua</i>	12J/cm ²	1.11logs
<i>Salmonella enterica</i>	11.9J/cm ²	1.8logs
<i>L. Monocytogenes</i>	1.75J/cm ²	2.2logs
<i>E. coli O157:H7</i>	28.2J/cm ²	>5.7logs
<i>Penicillium expansum</i>	32J/cm ²	3.76logs
<i>Pseudomonas aeruginosa</i>	0.97J/cm ²	7logs
<i>Cryptosporidium parvum</i>	6.29 μ J/cm ²	4logs
<i>Murine orovirus</i>	14.02J/cm ²	4.79logs

It can be seen from Table 1 that different microorganisms have different sensitivity to PL. Most food-borne microorganisms have been reduced by more than 3logs after PL treatment. It can also be seen from Table 1 that Gram-negative bacteria are less sensitive to PL than Gram-positive bacteria.

5 Application fields

5.1 Application in liquid food

The penetrating power of PL becomes weaker as the transparency of liquid food gradually decreases. For example, it has higher penetrating power to water, but it has weak penetrating power to liquid foods with higher turbidity such as milk products. In an aqueous solution, the lower the penetration of light, the worse the sterilization effect of PL. Smith [15] used PL with a wavelength of 248nm to process four sets of pre-set bulk milk at an intensity of 25J/cm², and then observed them at 4°C and room temperature (22°C) for 21 days. During this period of the two temperature conditions milk does not breed any bacteria. Fine [16] et al. set up 1-25 pulse experiments to explore the PL intensity required to completely kill beer yeast, and found that the PL intensity corresponding to 24 pulses was 58.51 J/cm², which completely inactivated the microorganisms. By adjusting the distance between the light source and the experimental

object to adjust the PL intensity, it is found that the microorganisms can be completely killed when the energy reaches 58~117 J/cm². Elmnesser [17] and others explored whether the amino acid composition and UV absorbance of milk were changed after PL was used to treat milk. Experimental results confirmed that only a small amount of disulfide bond aggregation occurred after PL was used to treat milk. The structure of amino acids has not changed, and oxidation of fat has not occurred.

5.2 Application in fresh keeping of fruits and vegetables

PL keeps fruits and vegetables fresh through the following two aspects: (1) Extend the shelf life of fruits and vegetables. (2) Inhibit the browning of fruits and vegetables. When the amount of yeast in fruits and vegetables reaches 10⁵ CFUg⁻¹, decay and deterioration can be detected. The large water content, high sugar content, and low pH of fresh fruits and vegetables can easily cause the reproduction of microorganisms, leading to rot and economic losses. Many experiments have confirmed that PL has a significant effect in killing microorganisms on fruits and vegetables and extending their shelf life. Ripe blueberries have a short shelf life and are easily rotted by various pathogens. Cao [18] explored the effect of PL on blueberry, such as the inactivation of *Salmonella* and the shelf life, quality attributes and beneficial compounds of blueberries. Set PL (untreated) (6 J/cm²) and water-assisted PL (the sample is stirred in water during PL treatment; 9J/cm²), dry control (untreated) and water-assisted control (washed without PL), respectively. Subsequently, the blueberries were stored at room temperature (3 days) or 5°C (7 days). The experimental results confirmed that water-assisted PL treatment of blueberries can effectively remove *Salmonella* from blueberries, extend the shelf life of blueberries, and have almost no effect on the quality attributes and beneficial compounds of blueberries.

5.3 Application in the field of meat preservation

Many scholars have studied the impact of PL sterilization technology on meat quality and found that fresh chicken, fish and other meat products have a certain degree of adaptability to PL. Haughton et al. [19] used high-intensity PL technology (3hz, 505J/pulse, 360μs) to sterilize raw chicken and its related packaging materials. After 5s of processing, *Campylobacter jejuni*, *E. coli* and *Salmonella* enteritidis the reductions were 1.22, 1.69 and 1.27 logs on the material surface and contact surface respectively; the corresponding microbial reductions in skinless chicken breasts were 0.96, 1.13 and 1.35 logs. This experiment shows that PL is an effective decontamination method for meat surface and its packaging materials

6 Combined application of PL sterilization technology and other technologies

6.1 PL and pectin coating technology to treat freshly cut fruits

Moreira et al. [20] soaked fresh-cut apples in an ascorbic acid/calcium chloride solution and then coated them with pectin, and then treated them with PL, which effectively reduce the softening and surface browning of apples. The pectin coating has no effect on the sensory and physical and chemical properties of apples. Pectin-coated PL-treated apples showed higher antioxidant activity value than PL-treated apples. At the end of storage, the combination of these two treatment methods resulted in a reduction of the number of microorganisms by nearly 2 logs. It is concluded that pectin-coated fresh-cut apples subjected to PL treatment can effectively maintain the quality of the fruit and extend its shelf life.

6.2 Synergistic sterilization effect between PL and thermal effect

B. cinerea spores and *M. fructigena* spores are important reasons of economic loss during storage and transportation of strawberries and sweet cherries. David et al. [21] first used a single PL to treat the two conidia, and applied 30μs pulse light treatment at a frequency of 15hz. The time ranged from 1-250 s, and the maximum inactivation was 3 and 4logs. Conidia inactivation increased with the increase of PL intensity, but did not reach complete inactivation. Two kinds of conidia were treated with heat-light pulse combination, and the spore inactivation effect was significantly increased. After 40 s PL treatment at 41 °C for 15 min, or at 41 °C under 80 s light treatment for 10 min, it completely died.

6.3 Synergistic sterilization effect between PL and UV

Combining PL and UV-C (λ=254nm) to sterilize strawberries inoculated with *B. cinerea* spores, it was found that this method did not significantly increase the sterilization effect on *B. cinerea* spores [21]. The reason may be that the sterilization mechanism of these two methods is similar, so the combined use may only increase their strength. And there is a DNA repair mechanism in the microorganism, which is triggered by UV irradiation. According to the current experimental research, the main object of PL sterilization is bacteria [9], and the resistance of fungi to PL is higher than that of bacteria. Therefore, the use of PL technology to control fungal diseases of fruits and vegetables requires more experimental research.

7 Conclusion and Prospect

As a new type of cold sterilization technology, PL has the characteristics of high efficiency, environmental protection, and the ability to maximize the quality of food under certain conditions. PL has a very high level of killing microorganisms. For some opaque and irregular foods, although some microorganisms can be concealed, PL can still reduce the total number of microorganisms by 1~3 logs. At the same time, the cost of using this

technology to process food is not high, and it will not affect the quality of food, so the application prospect is very broad. In February 1994, the FDA accepted the application of PL to sterilize food. The application of PL in foreign countries mainly focuses on the sterilization of food and food packaging materials. However, there are few researches on PL sterilization technology in China, and it is in the initial stage, so more experiments are needed to further explore.

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