Chem Rep, 2019, 1(2): 108-111
DOI: 10.25082/CR.2019.02.007

RESEARCH ARTICLE

Pulsed light treatment in food

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Abstract: Currently, there is a necessity for new technologies that are less harmful to the environment. Consumers have become increasingly demanding towards the quality of the processed products they consume as well as their environmental impact. Pulsed light (PL) technology is a green technology capable of maintaining food quality and safety without impairing nutritional value. PL has been used in the treatment of different food and its constituents. This mini-review aims to describe the basic principle of PL functioning as well as provide examples of the newest applications in the food industry.

Keywords: pulsed light, food preservation, microbial inactivation

1 Introduction

New technologies for food preservation that have minimal impact on food quality are desired. Many technologies based on light's ability to interact with food and microorganisms have been explored[1] . Pulsed light (PL) is an emerging[2] , green, and non-thermal technology used to decontaminate surfaces applying short time pulses (0.2-0.4 ms) of high-energy broad-spectrum lights (200-1100 nm) that include ultraviolet (UV) light, visible light, and infrared radiation.[3–5] PL can replace the use of chemicals; its effects are fast, and the technology can be easily incorporated to processing lines without change them[5] .

PL processing can be described as a sterilization or decontamination method used primarily in food surfaces,[6,7] packaging material,[8] and surface equipment.[9] This technology applies concentrated light energy exposing the sample to intense pulses of light. Usually, for food processing, about one to twenty flashes per second are used.[10] The antimicrobial effect of PL is damage to the cell wall and microbial membranes, however, DNA damage (UV-C region, 200-280 nm) is the main cause of microbial death using PL.[11]

Some advantages of PL are rapid disinfection, without residual effects and without the use of chemicals that could be harmful to the environment and humans. However, its main disadvantage is that the sample can be heated; another problem is that some microorganisms can absorb the rays of light causing shadowing.[1]

The objective of this mini-review is to explain the principles of PL functioning and provide recent examples of PL application in the food area.

2 Basic principle

The PL system involves the generation of pulsed light that gradually increases releasing large concentration of energy that ensures the microbial decontamination of surfaces.[10] PL has a large range of lights or wavelengths from 200 to 1100 nm and can combine visible, UV light, and infrared radiation.[1,5,12,13] The UV light can be divided in vacuum UV (100-200 nm), UV-C (200-280 nm), UV-B (280-315 nm), and UV-A (315-400 nm).[5] UV-C is the most important part of UV light related to microbial inactivation.[1]

The radiation effect is evaluated using the fluence parameter which is the energy supplied by the lamp to the sample per unit area, J/cm^2.[10,13] When light radiation reaches an opaque surface, light reflection can occur at the same angle as the beam incident (specular reflection) or in all directions (diffuse reflection). In the case of a perfectly transparent surface, the incident light can penetrate below the surface.[14] When light is applied to a surface of a food, which is neither perfectly opaque nor transparent, part of its energy is: reflected by the surface; absorbed by the layers of the sample where it penetrated; and transmitted to the inner layers. The degree to which any of these phenomena occur depends on type of light used and the composition and structure of the sample.[13] In addition, impurities or large particles contained in food can reflect and scatter light energy, reduc-

Received: April 30, 2019 **Accepted:** June 1, 2019 **Published:** June 4, 2019

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Citation: Aguilar JGDS. Pulsed light treatment in food. *Chem Rep*, 2019, **1**(2): 108-111.

ing the quantity of energy available for destroying microorganisms, which also can hide under these particles not being able to receive PL.[15]

The light can be applied continuously or intermittently (pulses). The delivery of energy in form of pulses is independent of the number and duration of them; the power supplied by the pulses is greater than that provided by light radiation. Considering the same total energy of the system, the shorter the duration of each pulse, the greater the pulse power. Therefore, pulsed light has a greater penetration capacity than continuous irradiation.[16]

A PL system for processing food consists of an electrical unit that provides the high-powered electrical pulses, a lamp that transforms the electrical pulses into high-powered pulses of light, a treatment chamber, and some auxiliary equipment such as an acquisition system data, control, and cooling system.[13] The efficiency of PL treatment depends on number of flashes, voltage, lamps, range of lights, time, sample, and microorganism target.[17] Figure 1 shows a functional layout of a basic PL system.

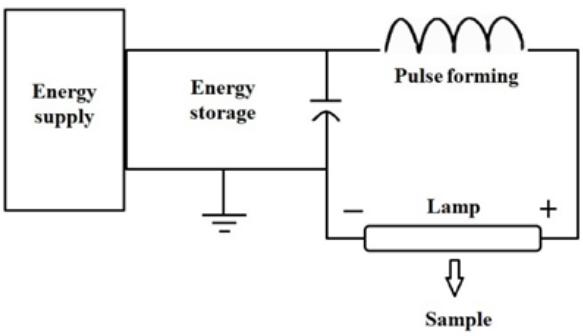

Figure 1. PL system diagram. Adapted from Cacace and Palmieri[13]

3 Pulsed light treatments in food

PL technology has been studied in the treatment of food, being effective in the sterilization of solid's and liquid's transparent surfaces using batch or continuous processing.[13] It is also useful for inactivating bacteria, fungi, spores, and viruses in various food materials. Since 2002, the Food and Drug Administration (FDA) approved the use of PL for food treatment.[15]

The effect of PL application on the decontamination of salmon was evaluated by Pedrós-Garrido, *et al.*[10] After optimization of the treatment conditions (9 s at 3.5 cm and dose of 152.6 mJ/cm^2) a bacterial reduction of 1.3 log CFU/g was observed. Koch, *et al.*[18] evaluated the effect of PL on pork skin. The best treatment parameters were defined as: fluence of 9.11 J/cm^2 for 30 s and distance, between the lamp and sample, of 8.3 cm. PL treatment reduced the *Salmonella typhimurium* and *Yersinia enterocolitica* counting by observing the reduction of 2.97 and 4.19 log CFU/cm^2, respectively. Table 1 provides more examples of microbial reduction in food using PL treatment.

PL combined with a stabilizing dip improved the quality of fresh cut strawberries. Aside from this, the fungal contamination was delayed and the color of the strawberries was preserved. Total phenolics and antioxidant activity were not modified with treatment and vitamin C and anthocyanins were reduced by 20-30%. Doses of 4 and 8 J/cm^2 were the most efficient in maintaining fruit qualities[27] . The same treatment (PL plus stabilizing dip) was applied to fresh-cut 'Golden delicious' apples. Reduction in the natural microbiota of the apples was observed. PL did not cause darkening or oxidation of fruits. The contents of phenolic compounds and vitamin C were maintained. The most effective treatments were doses of 8 and 16 J/cm^2[28] .

Duarte-Molina, *et al.*[29] evaluated strawberry fruit treated by PL (doses of 2.4-47.8 J/cm^2). The incidence of mold contamination was reduced by 16-42% after treatment. Parameters that evaluate firmness were not reached by the treatment. Kramer et al.[21] demonstrated that PL was more efficient than the use of sanitizers, electrolyzed water (40 ppm free chlorine) and chlorine dioxide (15 ppm), in mung bean sprouts and endive salad wash process. PL was able to reduce 2.5 log of the microbial count against 1.5 log reduction achieved by the sanitizers. The results demonstrated that PL is a promising technique for increasing the shelf life of strawberries. Sousa, *et al.*[30] evaluated the effect of PL on Cantaloupe melons. The authors observed that PL combined with 1-MCP application promoted an additional 12 days of shelf life for fruits. PL promoted increased activity of phenylalanine ammonium lyase (67%) responsible for the synthesis of phenolic compounds (55%). The treatment with a dose of 9 J/cm^2 stimulated the melons post-harvest defense mechanisms. Carotene slices treated with PL demonstrated higher concentrations of β-carotene (under treatment of 2.26 and 4.52 J/cm^2) and other bioactive compounds[31] .

Enzyme inactivation using PL is related to the emission of UV-light that can be absorbed by proteins and amino acids like tryptophan, tyrosine, phenylalanine, and cystine, responsible for the photochemical inactivation of proteins[32] . Pellicer, *et al.*[32] evaluated the effect of PL on the activity of polygalacturonase; an enzyme related to food firmness. The results showed 90% of activ-

Table 1. Microbial reduction in food after PL treatment

Food	Microorganism	Fluence (J/cm^2)	Log reduction (log)	Reference
Apple juice	*Penicillium expansum*	32.00	3.76	[19]
Avocado	Aerobic mesophilic	14.00	1.20	[20]
Endive salad	*Listeria innocua*	0.32	2.50	[21]
Goat milk	*Escherichia coli*	10.00	6.00	[22]
Orange juice	*Escherichia coli*	5.10	2.42	[23]
Sesame seeds	Total viable count	44.46	1.46	[24]
Raspberry	*Salmonella*	28.20	4.50	[25]
Turnip juice	*Candida inconspícua*	19.71	2.80	[26]

ity reduction after applying 128 J/cm^2. The authors suggested that the PL treatment caused inactivation of polygalacturonase due to the disruption of disulfide bridges which caused enzyme unfolding. Another important enzyme in the food industry, lipase, was studied after treatment with PL. Intense PL was used in *Chromobacterium viscosum* lipase. The activity of the enzyme decreased as pulse fluence and treatment time increased. The authors concluded that the enzyme was inactivated due to fragmentation caused by the treatment, which caused the loss of the tertiary structure[33] . Valdivia-Njar, *et al*.[34] studied the impact of PL on the physical quality of fresh-cut tomatoes. The microbial count had a 2 log reduction in relation to the untreated samples. The fruits showed small losses in firmness as well as little modification on the enzymatic activity of pectinmethyl esterase and polygalacturonase.

4 Conclusion

PL is an emerging, non-thermal, fast, and ecofriendly technology efficiently used in microbial reduction and inactivation of foods and surfaces. Due to its simple application and versatility, PL can be incorporated into existing processing lines, having the potential to be used in the food industry for safety purposes, and not changing the original structure of the treated foods.

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