



Pulsed Light in Food Processing: A Revolutionary Non-Thermal Technology

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In an era where consumers demand both safe and minimally processed foods, pulsed light (PL) technology has emerged as a groundbreaking non-thermal preservation method. Approved by the U.S. FDA in 1996, this technique uses intense, millisecond-long flashes of broad-spectrum light spanning ultraviolet to near-infrared wavelengths to instantly decontaminate food surfaces. The primary mechanism is photochemical: the UV-C portion of the light penetrates and damages the DNA and proteins of pathogenic microorganisms like *E. coli*, *Salmonella*, and *Listeria*, rendering them inactive without the need for heat or chemicals. Unlike conventional thermal pasteurization, which can degrade nutrients and alter sensory qualities, pulsed light is rapid, eco-friendly, and operates at room temperature. It has proven highly effective across diverse food categories, including fresh produce, meats, seafood, fruit juices, and spices. Moreover, it can even treat products inside transparent packaging, offering a versatile final-step safety hurdle. While its main limitation is low tissue penetration confining its efficacy largely to surface decontamination ongoing research continues to optimize its parameters and expand its applications, positioning pulsed light as a pivotal tool for delivering safer, fresher, and higher-quality foods to consumers.

What is pulsed light technology?

Pulsed light (PL) is an emerging non-thermal food processing technology that uses short, high-intensity pulses of broad-spectrum light to eliminate harmful microorganisms from food surfaces (Sruthi *et al.*, 2025). The technology generates high-power pulses of electromagnetic radiation spanning wavelengths from 200 to 1,100 nanometers covering the ultraviolet (UV), visible, and near-infrared regions of the spectrum (Sruthi *et al.*, 2025). These intense light flashes are produced by inert-gas flash lamps, typically xenon lamps, which release energy in pulses lasting only milliseconds (Armagan and Demirci, 2025).

How it works?

Pulsed light works like a super-intense camera flash. Special xenon lamps release bursts of broad-spectrum light in just 1–2 milliseconds.

The magic happens through three simultaneous actions:

- **Photochemical (Main Killer):** The UV-C portion of the light penetrates microbial cells and damages their DNA, creating "knots" (thymine dimers) that stop bacteria, molds, and viruses from reproducing. No replication = no infection.

- **Photothermal (Heat Shock):** The intense energy causes a microscopic, split-second temperature spike on the cell surface, denaturing (cooking) vital proteins and enzymes inside the pathogen.
- **Photophysical (Physical Rupture):** The sudden flash creates pressure waves that physically crack and burst the cell walls, causing immediate leakage of cell contents.



Fig. Application of pulsed light in food processing

Applications across food categories

- **Fresh produce**

One of the most promising applications of pulsed light is in the decontamination of fresh fruits and vegetables. These products are particularly challenging to sanitize because they are consumed raw and cannot withstand harsh thermal treatments.

- **Meat, poultry, and seafood products**

Pulsed light has shown considerable promise for decontaminating muscle foods, where surface contamination is a primary safety concern (Mayan *et al.*, 2025).

- **Fruit juices and beverages**

Pulsed light pasteurization is being actively explored as a substitute for conventional thermal pasteurization of juices, primarily because it offers better retention of nutrients and overall quality (Basak *et al.*, 2024).

- **Dairy and egg products**

Dairy items and egg products can also benefit significantly from pulsed light treatment, with reported microbial reductions ranging from approximately 1 to 7.8 Log (Gómez-López, 2024).

- **Spices and Herbs**

Pulsed light and UV treatments have emerged as effective, eco-friendly solutions for microbial decontamination and quality retention in spices. This application is especially valuable because spices are often consumed raw or with minimal processing and can harbor significant microbial loads (Cacace and Palmieri, 2014).

Key Advantages Over Conventional Methods

- **Superior Quality Retention**

Unlike thermal processing, which can cause undesirable changes in colour, texture, flavour, and nutritional value, pulsed light has only minimal effects on a product's taste, aroma, and appearance. This is because the treatment is applied at room temperature and for very short durations (Armagan and Demirci, 2025).

- **Environmentally Friendly and Cost-Effective**

Pulsed light is described as an economical, low-cost, sustainable technology that requires no heat and leaves no chemical residues. The process is dry, involves short processing times, and has lower energy requirements compared to many conventional techniques (Armagan and Demirci, 2025).

- **Rapid Processing**

The treatment occurs in milliseconds, making it highly suitable for integration into continuous production lines. This speed allows for high throughput without creating bottlenecks in manufacturing operations.

- **Potential for In-Package Treatment**

One particularly exciting advantage is that pulsed light can penetrate plastic packaging and kill pathogens living on the surface of produce even after packaging. This capability opens up new possibilities for ensuring food safety at the final stage of production.

- **Broad-Spectrum Efficacy**

Pulsed light has demonstrated effectiveness against a wide range of microorganisms, including both Gram-negative and Gram-positive bacteria, in both planktonic (free-floating) and biofilm states. Studies have shown that intense pulsed light can achieve over 99.9% sterilization efficacy for planktonic bacteria.

Limitations and Challenges

Despite its many advantages, pulsed light technology does have some limitations:

Low Penetration Depth: The primary limitation is that pulsed light is most effective as a surface decontamination technology. It has limited ability to penetrate into the tissue of foods, which means it is less effective for eliminating microorganisms that are embedded within the product. However, researchers are exploring various approaches to overcome this limitation, including the use of absorption-enhancing agents.

Shielding Effects: Food surfaces that are uneven, shadowed, or have complex geometries may not receive uniform light exposure, potentially leaving some areas untreated.

Quality Impacts at High Doses: While moderate treatment conditions preserve quality, higher fluence and more pulses can lead to color changes and lipid oxidation in some products. Careful optimization of treatment parameters is essential (Fracari *et al.*, 2024).

Future Outlook

Pulsed light technology has been under continuous study and testing by academic institutions since 1998, and the body of research continues to grow rapidly. Current research directions include:

- Optimizing parameters such as frequency, pulse rate, and exposure duration for different food products
- Combining pulsed light with other preservation technologies for synergistic effects
- Exploring applications in biodegradable food packaging
- Investigating effects on food allergen reduction

As the global population grows and the demand for safe, minimally processed, nutritious foods increases, pulsed light technology is positioned to play an increasingly important role in the food industry (Ouyang *et al.*, 2025). The challenge ahead lies in transitioning the substantial knowledge from academic research to widespread commercial implementation (Armagan and Demirci, 2025).

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