Canrea Journal: Food Technology, Nutritions, and Culinary, 2025; 8 (1): 120-132 OPEN ACCESS

e-ISSN : 2621-9468

Type of the Paper (Article)

Development and efficacy assessment of an intense pulsed light sterilization device for pickled fruits and vegetables

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Abstract

This study presents the development and efficacy assessment of an intense pulsed light (IPL) sterilization device tailored for the pickled fruit and vegetable industry. The project aimed to (1) design and construct a compact IPL unit for industrial use, (2) validate its microbial reduction performance through laboratory and field testing, and (3) promote technology transfer via operational trials. The prototype integrates a xenon lamp, pulse generation circuit, conveyor belt, and control interface, allowing precise adjustment of exposure parameters. Experimental results showed over 90% microbial reduction within 120 seconds at an average light intensity of 1.7 mW/cm² and a frequency of one pulse per second. The findings demonstrate the device's potential for improving food safety without compromising product quality. Furthermore, the study evaluates its industrial applicability, highlighting opportunities for broader adoption and scalability across production settings.

Article History
Received December 13, 2024
Accepted June 28, 2025
Published June 30, 2025

Keywords
Intense Pulsed Light, Food Sterilization, Industrial Pasteurization, Microbial Reduction.

1. Introduction

The global food industry is continually adopting innovative technologies aimed at enhancing food safety, prolonging shelf life, and preserving the nutritional and sensory properties of food products. Among various emerging non-thermal sterilization methods, Intense Pulsed Light (IPL) has emerged as a promising technique due to its ability to rapidly inactivate a wide range of microorganisms through high-intensity, short-duration light pulses (1). IPL operates primarily via photochemical and photothermal mechanisms, leading to structural damage in microbial DNA and cell membranes while maintaining the integrity and quality of food matrices (2). This makes IPL a compelling alternative to conventional methods such as thermal pasteurization and chemical disinfection, which often compromise food texture, flavor, or nutrient content (3).

Despite the recognized potential of IPL technology, its practical application in industrial settings remains underexplored, particularly for sensitive, microbially active products such as pickled fruits and vegetables (4,5). Fermented and acidified foods are especially susceptible to microbial contamination during processing, packaging, and storage, compromising both safety and quality (4). While conventional sterilization methods such as heat treatment, chemical preservatives, and pasteurization are widely used, they often alter sensory properties (taste, color, texture) and degrade heat-sensitive nutrients such as vitamin C or

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ISSN 2621-9468 online, DOI 10.20956/canrea.v8i1.1721

polyphenols (6). The growing consumer demand for minimally processed, additive-free products reinforces the need for alternative non-thermal technologies like IPL.

This research aims to develop and implement a custom-designed, multipurpose IPL device specifically engineered for the pickled fruit and vegetable industry. The study assesses the device's effectiveness in reducing microbial load particularly yeasts, molds, and lactic acid bacteria without compromising key quality attributes such as texture, color, or pH stability (2,3). Additionally, the research evaluates the feasibility of integrating this technology into existing industrial production lines, with special emphasis on energy efficiency, maintenance requirements, and operator usability (1,4). The significance of this study lies in its potential to deliver a novel, non-thermal, and environmentally friendly sterilization solution for high-risk fermented products. By aligning with global trends toward sustainable production and clean label food processing, this technology offers a competitive advantage in international markets. This is especially relevant for Thailand, a major exporter of pickled fruits and vegetables, where technological innovation in food safety can enhance export value and consumer trust (4).

2. Materials and Methods

2.1. Factors Affecting the Efficacy of Sterilization of Pickled Fruit and Vegetable Products

This research systematically evaluated factors influencing the sterilization efficacy of pickled fruits and vegetables. The study analyzed 13 samples of packaged fermented food products obtained from R&D Food Products Co., Ltd., including shredded and sliced sweet turnips, various types of bamboo shoots, Japanese wasabi-flavored pickled radish, yuzu-scented turnip, and multiple varieties of pickled cabbages. Assessments involved measuring physical quality (color values using a Colorimeter Spectrophotometer), chemical quality (water activity with a Water Activity Meter and pH using a pH meter), and microbiological quality (Total Plate Count, yeast and mold, coliforms, *E. coli*, and *Salmonella spp.*) (7–9). These products were selected based on their popularity in the local market, varied packaging materials, and diversity in texture, pH, and fermentation profiles factors that influence sterilization outcomes and thus offer a comprehensive assessment of IPL efficacy.

2.2. Parameters Required for Designing the Prototype Machine

To evaluate IPL sterilization, cultures were grown on media plates and exposed to varying parameters, including distance from the light source, number of pulses, light intensity, energy per area, and electricity consumption. These parameters were systematically controlled during experiments to optimize sterilization efficacy. The microbial load was monitored before and after treatment in collaboration with microbiology experts and accredited laboratories. Adjustments to parameters such as pulse duration and wavelength were made based on initial results to further enhance the efficiency of the sterilization process, ensuring that all experimental conditions were tailored to maximize microbial inactivation while preserving the integrity of the samples (10).

2.3. Energy Consumption Per Sterilization Control

The pulse frequency of the IPL system illustrates the power supply's capacity to recharge the capacitor after each flash, critical for maintaining consistent energy delivery throughout the sterilization process. The minimal energy level required by the system is determined by multiplying the pulse frequency with the energy output per pulse. The operational parameters of the IPL system are quantified in terms of the electrical power applied per area, measured in watts per square meter (W/m²), and the energy imparted per unit area, gauged in joules per square meter (J/m²). Time intervals are crucial, measured in seconds, with the pulse repetition rate (PRR) defining the number of pulses emitted per second, either in Hertz (Hz) or pulses per second (PPS). The maximum power output, quantified in watts (W), is calculated as the energy per pulse divided by the pulse duration. This precise quantification of energy parameters ensures optimal microbial inactivation while minimizing energy consumption, vital for the scalability of food sterilization technologies. Energy calculations are further supported by Equation (1) and Equation (2), which systematically address the storage and discharge cycles of energy within the system.

This is an example of an equation:

$$E = \frac{1}{2}CV^2 , \quad (1)$$

$$W_{avg} = Ef , \quad (2)$$

Where

E is the energy stored in the capacitor,
W_{avg} is the average electrical power (11,12),
C is the capacitance used in the system,
V is the voltage (volts),
f is the frequency of energy discharge.

2.4. Inspection of Characteristics of Fermented Food Products in Sealed Packaging

From Table 1, the physical characteristics were consistent across samples of the same vegetable type, showing only minor variations attributable to processing conditions. Both shredded and diced turnips displayed similar brightness (L*) and color balance (a*, b*) values, evidencing the minimal impact of pulsed light treatment on maintaining the aesthetic and sensory qualities of the vegetables. This consistency is crucial in ensuring that the pulsed light technology not only sterilizes but also preserves the visual appeal and marketability of the products (4,6). However, this study did not include direct assessments of sensory attributes such as taste, aroma, or texture, nor nutrient analysis such as vitamin C retention. These aspects are acknowledged as limitations and are recommended for inclusion in future research to comprehensively evaluate the consumer acceptance and nutritional preservation of IPL-treated products.

From Table 1, the physical quality of 13 fermented food samples from R&D Food Products Co., Ltd. was analysed prior to IPL sterilization to serve as a baseline for post-treatment comparison. The analysis includes L* (brightness), a* (green to red), and b* (blue to yellow) color parameters, where higher L* indicates greater brightness, positive a* reflects redness, and positive b* indicates yellowness. The results showed that vegetables of the same type, such as shredded and diced sweet chayote, exhibited similar L*, a*, and b* values. Likewise, various bamboo shoot products (white, yellow, sliced, and those in yangna water) showed comparable brightness, although those in yangna water had reduced L* and exhibited a more greenish hue, possibly due to pigmentation from the soaking medium. The white cabbage kimchi presented moderate brightness with red to yellow hues. Similarly, yuzu- and wasabi-flavoured pickled radishes showed similar brightness and green-to-yellow tones. The three variants of pickled cabbage (regular, sour, and three-flavoured) also had comparable L* values, with color variations across green-yellow to red-yellow spectrums. In terms of food safety, all products complied with regulatory requirements, with water activity (aw) levels exceeding 0.85 and pH values below 4.5, as mandated by health standards to inhibit microbial growth (5,6).

Table 1. Physical and chemical quality analysis of products before testing.

Product Sample	L*	a*	b*	aw	pH
Shredded Sweet Pickle	45.98±0.33	8.23±0.26	24.92±0.35	0.86±0.00	3.98±0.02
White Bamboo Shoot Strips	33.97±0.80	8.71±0.51	17.97±1.12	0.81±0.00	3.89±0.02
Yellow Bamboo Shoot Strips	76.13±1.79	0.00±0.34	18.79±0.64	0.99±0.00	3.75±0.02
White Bamboo Shoot Sheets	73.27±0.36	-1.71±0.57	40.31±0.24	0.99±0.01	4.52±0.01
Yellow Bamboo Shoot Sheets	73.81±1.72	-0.75±0.13	40.70±0.63	0.99±0.00	4.22±0.01
Bamboo Shoot Logs	72.97±3.40	0.77±0.13	16.89±2.84	0.99±0.00	2.54±0.02
Bamboo Shoots in Pandan Water	75.43±0.93	-2.49±0.90	46.91±0.17	0.99±0.00	4.70±0.01
Kimchi White Cabbage	59.27±0.84	-0.21±0.42	33.25±0.30	0.98±0.00	4.94±0.01
Japanese Wasabi Flavored Turnip	48.58±6.20	23.51±1.77	43.85±3.42	0.97±0.00	4.07±0.02
Yuzu Scented Turnip	68.41±2.46	-4.42±0.24	19.50±0.76	0.98±0.00	3.70±0.00
Salted Cabbage	79.99±0.58	-1.87±0.02	11.27±0.63	0.98±0.00	3.67±0.01
Sour Salted Cabbage	67.54±2.75	-4.93±0.86	54.68±2.26	0.97±0.00	3.43±0.02
Three-flavored Pickled Cabbage	28.60±8.11	1.63±0.40	25.65±9.76	0.98±0.00	2.96±0.02

Note: All sample analyses were replicated three times.

In addition to physical characteristics, the microbiological quality of these fermented products prior to IPL treatment was assessed, as shown in Table 2. Most samples exhibited satisfactory microbial safety profiles, with non-detectable levels of total coliforms, fecal coliforms, and *E. coli.* However, the shredded sweet pickle and Japanese wasabi-flavored turnip showed detectable total plate counts (5.1×10^3 CFU/g and 3.4×10^6 CFU/g, respectively), indicating varying initial microbial loads among different products. These findings emphasize the importance of applying effective sterilization technologies like IPL to reduce microbial contamination while preserving product quality (13,14). However, this study did not include direct assessments of sensory attributes such as taste, aroma, or texture, nor nutrient analysis such as vitamin C retention. These aspects are acknowledged as limitations and are recommended for inclusion in future research to comprehensively evaluate the consumer acceptance and nutritional preservation of IPL-treated products.

Table 2. Pre-test microbial quality analysis of fermented food products in sealed packaging

Product Sample	Total Plate Count (CFU/g)	Yeast and Mold (CFU/g)	Total Coliform (MPN/g)	Fecal Coliform (MPN/g)	*E. coli*
Shredded Sweet Pickle	5.1×10^3	Not detected	<3.0	<3.0	Negative
White Bamboo Shoot Strips	7.3×10^2	Not detected	<3.0	<3.0	Negative
Yellow Bamboo Shoot Strips	Not detected	Not detected	<3.0	<3.0	Negative
White Bamboo Shoot Sheets	Not detected	Not detected	<3.0	<3.0	Negative
Yellow Bamboo Shoot Sheets	Not detected	Not detected	<3.0	<3.0	Negative

Product Sample	Total Plate Count (CFU/g)	Yeast and Mold (CFU/g)	Total Coliform (MPN/g)	Fecal Coliform (MPN/g)	*E. coli*
Bamboo Shoot Logs	Not detected	Not detected	<3.0	<3.0	Negative
Bamboo Shoots in Pandan Water	Not detected	Not detected	<3.0	<3.0	Negative
Kimchi White Cabbage	Not detected	Not detected	<3.0	<3.0	Negative
Japanese Wasabi Flavored Turnip	$3.4x10^6$	Not detected	<3.0	<3.0	Negative
Yuzu Scented Turnip	$1.5x10^2$	Not detected	<3.0	<3.0	Negative
Salted Cabbage	Not detected	Not detected	<3.0	<3.0	Negative
Sour Salted Cabbage	Not detected	Not detected	<3.0	<3.0	Negative
Three-flavored Pickled Cabbage	Not detected	Not detected	<3.0	<3.0	Negative

2.5. Design of a Multipurpose Sterilization Device Using Intense Pulsed Light Technology

The integration of the Intense Pulsed Light (IPL) sterilization device into the pickled fruit and vegetable production line was carefully engineered to ensure operational efficiency, as illustrated in Figure 1. The system employs a xenon lamp that emits high-intensity light pulses across a broad wavelength spectrum, effectively inactivating microorganisms while preserving the physicochemical qualities of the products. The design was informed by empirical studies that determined optimal pulse durations and light intensities required for maximum microbial reduction without compromising product quality. This alignment with food safety standards supports enhanced shelf life and consistent product integrity. Moreover, the system's adaptability to existing infrastructure underscores its value as a scalable and regulatory-compliant solution for modern food processing (15,16).

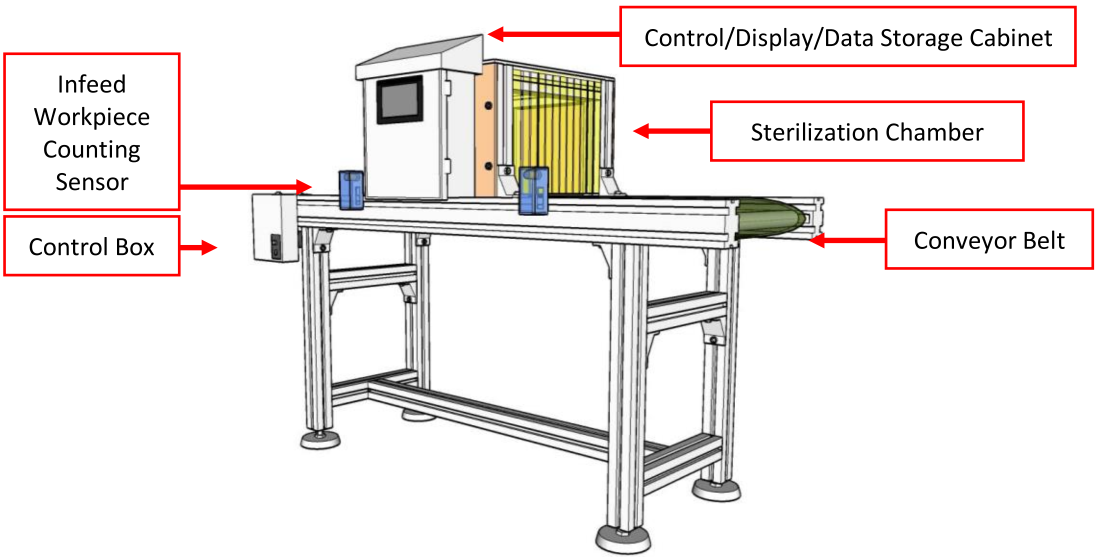


Figure 1. Design of a multipurpose sterilization machine using intense pulsed light technology.

Figure 2 provides a detailed illustration of the physical configuration of the IPL sterilization system, highlighting key components including the control box, infeed workpiece counting sensor, and sterilization chamber. The diagram also presents the electrical and control architecture, showing the integration of the xenon lamp, sensors, and conveyor motor in a layout optimized for sterilization efficiency. This schematic serves as a technical reference that facilitates understanding of the coordinated operation between components, supporting both effective microbial inactivation and system reliability. Additionally, the inclusion of such schematics aids in maintenance and troubleshooting, underscoring the system's robust engineering tailored to meet industrial sterilization standards without compromising safety or throughput.

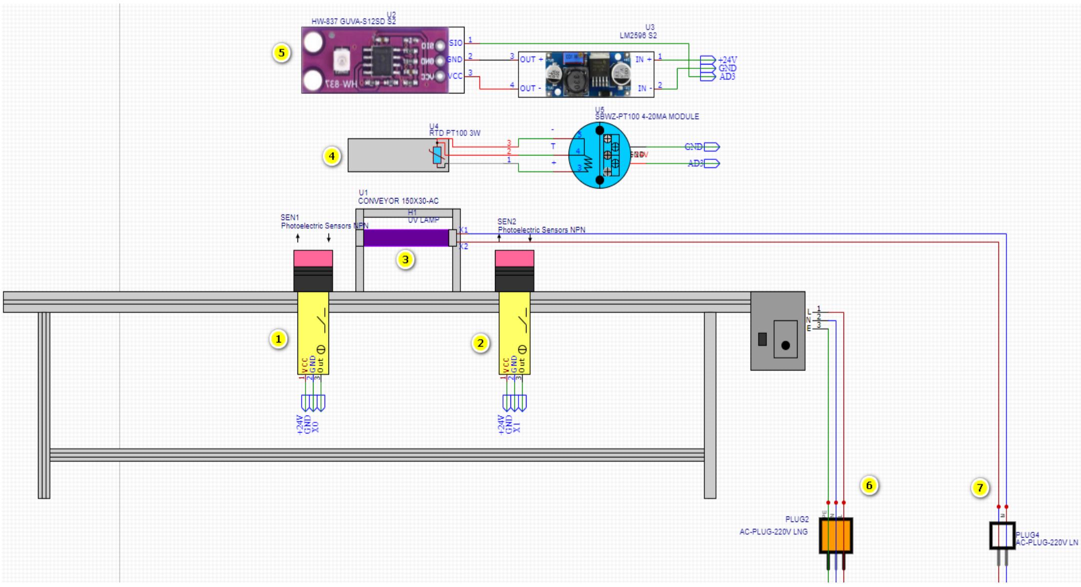


Figure 2. Electrical and control layout of the IPL sterilization machine.

Figure 3 illustrates the advanced interface of the IPL device's control system, which enables operators to monitor and adjust key parameters such as UV exposure time and intensity with high precision. This real-time control enhances the flexibility and consistency of the sterilization process, allowing fine-tuning for optimal microbial inactivation. The interface also provides immediate feedback on system performance, contributing to more reliable and standardized outcomes. Such control functionality is essential for compliance with stringent food safety standards and supports the device's adaptability across diverse industrial applications. Overall, the control system represents a critical component that enhances operational efficiency, safety, and user accessibility in modern food processing environments.

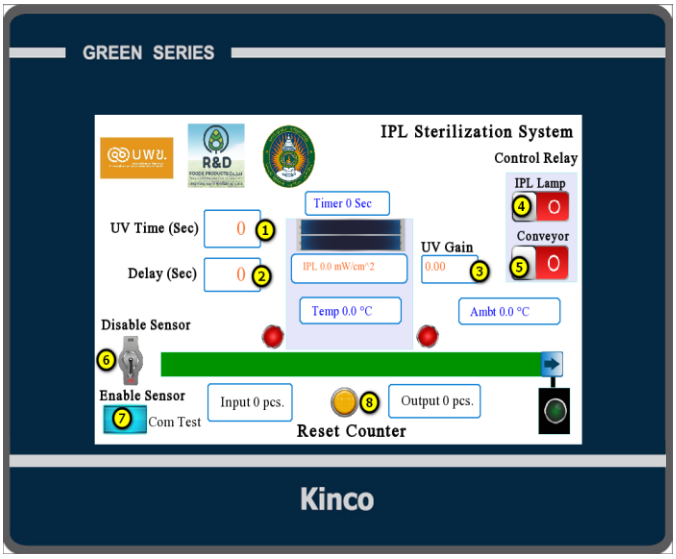


Figure 3. Display screen showing the operation of a multipurpose sterilization machine using intense pulsed light technology.

3. Results and Discussion

3.1. Efficiency of the Multipurpose Sterilization Device Using Intense Pulsed Light Technology

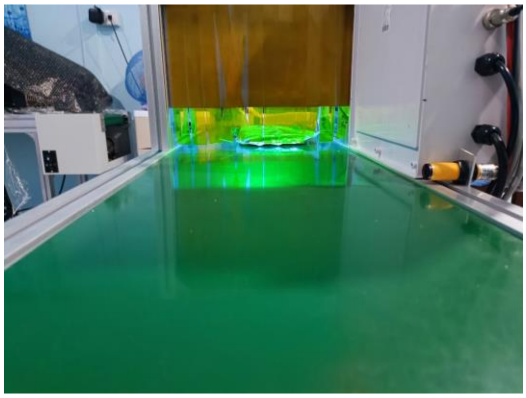
To evaluate the field efficacy of the developed IPL-based sterilization prototype, a comprehensive sampling protocol was implemented to ensure representative coverage of the entire production process. For each production batch, samples were randomly collected from the beginning, middle, and end, with three subsamples from each segment to assess microbial loads both prior to and following IPL treatment. After undergoing sterilization with the prototype device, the samples were subjected to standardized microbial enumeration procedures. The results were statistically analysed to calculate microbial reduction percentages, with outcomes summarized in Table 3 and visualized in Figures 4. The findings clearly demonstrate the device's robust performance in reducing microbial contamination across various product types. These empirical results are consistent with existing studies that support the effectiveness of IPL technology in enhancing food safety, thereby reinforcing its applicability in real-world food processing environments (5,17)

Table 3. Microbial counts before and after sterilization by high-intensity pulsed light.

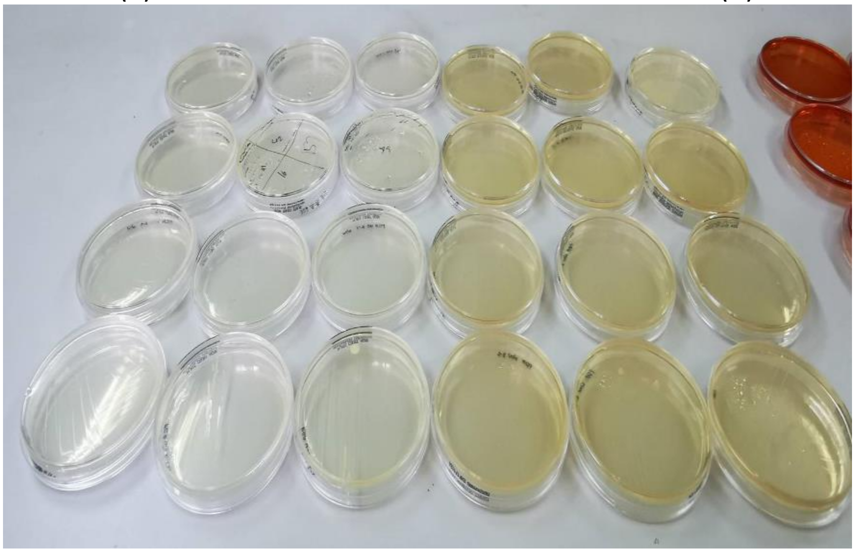
Product Sample	Before sterilization			After sterilization		
	Total Plate Count (CFU/g)	Yeast and Mold (CFU/g)	Salmonella spp.	Total Plate Count (CFU/g)	Yeast and Mold (CFU/g)	Salmonella spp.
Shredded Sweet Pickle	N/A	N/A	N/A	N/A	N/A	N/A
Chopped Sweet Radish	N/A	N/A	N/A	N/A	N/A	N/A
Kimchi White Cabbage	$178x10^2$	N/A	N/A	$118\ x10^2$	N/A	N/A
Pickled Radish with Wasabi Flavor	N/A	N/A	N/A	N/A	N/A	N/A

Note: All samples were tested in triplicate. N/A indicates that no microbial growth (Total plate count) was detected.

(a)



(b)



(c)

Figure 4. Visualization of the intense pulsed light (IPL) sterilization process and its microbial reduction efficacy on sample products. (a) The operational interface of the IPL device showcasing the control settings. (b) The device in action, illustrating the emission of intense pulsed light in a controlled environment. (c) Comparative microbial analysis before and after IPL treatment, displaying total microbial count (Total plate count) and yeast and mold levels on agar plates, demonstrating the device's effectiveness in reducing microbial presence.

Experimental assessments of selected products—including shredded sweet turnip, sliced sweet turnip, and Japanese wasabi-flavoured pickled turnip (as illustrated in Figure 4c)—revealed an absence of microbial growth both prior to and following treatment with the multipurpose IPL sterilization device. These findings suggest that the upstream production process is inherently effective in microbial control and that the sterilization device reinforces this safety assurance. During operational evaluation (Figure 4b), the device demonstrated consistent performance under standard industrial conditions. For the white cabbage kimchi samples, although total microbial counts were present, no yeast or mold were detected before or after sterilization, indicating a substantial reduction in spoilage organisms. The complete absence of *Salmonella* spp. and the notable reduction in overall microbial counts relative to baseline levels further support the efficacy of IPL treatment. As presented in Figure

4c, a comparative analysis clearly shows that non-sterilized samples exhibit higher microbial loads than their IPL-treated counterparts, validating the device's effectiveness in microbial load reduction. These outcomes are consistent with prior studies that affirm the potential of pulsed-light sterilization technology to enhance microbial safety while preserving the physicochemical quality of food products (18,19).

3.2. Discussion

The efficacy of IPL technology demonstrated in this study is consistent with previous research highlighting its effectiveness in microbial reduction while preserving the sensory and nutritional integrity of food products (20). IPL's non-thermal mechanism enables its application in sterilizing heat-sensitive foods such as pickled vegetables without compromising taste, texture, or nutrient content. Additionally, the technology is gaining recognition for its contribution to modern food safety protocols due to its minimal chemical usage and energy-efficient nature (21).

This study confirms the feasibility of integrating IPL systems into existing industrial production lines with minimal modifications, making it suitable for large-scale deployment. However, limitations such as the relatively small sample size and absence of long-term quality evaluations were identified. Future research should incorporate sensory analysis, nutrient retention (e.g., vitamin C), and texture assessments to comprehensively evaluate consumer acceptance.

Moreover, discussion of scalability is expanded by considering practical parameters such as throughput capacity i.e., the ability of the IPL system to process multiple tons per hour and packaging compatibility. Preliminary observations suggest that the device is effective for products in transparent packaging; however, further studies are necessary for opaque or multi-layered materials. Regulatory considerations also need to be addressed, including compliance with food safety regulations in Thailand, the European Union, and the United States. Addressing these aspects will be crucial for successful commercialization and cross-border deployment of IPL technology in the food industry.

3.3. Integration with Existing Research

Recent comparative studies, such as those by Liang and Chen, have explored the potential of advanced oxidation processes (AOPs) in enhancing microbial inactivation when integrated with Intense Pulsed Light (IPL) systems (4). These studies suggest that IPL, when combined with complementary non-thermal technologies such as cold plasma, ultraviolet-C (UV-C) radiation, or ozone treatment can significantly improve sterilization efficacy while reducing energy inputs and preserving product integrity. This synergistic approach offers promising avenues for optimizing microbial control strategies, particularly for heat-sensitive and fermented products.

Furthermore, Hwang et al. emphasized the transformative potential of emerging food safety technologies in elevating industrial sterilization standards, noting the increasing demand for scalable, environmentally friendly alternatives to conventional heat or chemical-based methods (22). In alignment with this perspective, the work of Wasuri and Chainok on low-heat sterilization systems illustrates how combining controlled energy delivery with modular system designs can lead to superior sterilization outcomes without compromising food quality (23). These integrated approaches demonstrate feasibility for large-scale implementation, addressing industry concerns such as processing speed (throughput), packaging compatibility, and regulatory compliance.

Future research should focus on validating these hybrid systems in diverse food sectors, particularly through pilot-scale trials that evaluate not only microbial reduction but also consumer-oriented parameters like sensory acceptability and nutritional retention. Such efforts are essential to ensure regulatory approval and foster cross-industry adoption of IPL-based solutions.

3.4. Future Directions

Future research on IPL technology should delve deeply into its long-term effects on the nutritional content of food products, as this remains a significant concern for consumers and regulators. While the immediate benefits of microbial reduction are well-documented, understanding how IPL influences the stability of essential nutrients, vitamins, and antioxidants over extended storage periods is critical. Additionally, research could explore the potential for synergistic effects when IPL is combined with other preservation techniques, such as high-pressure processing or advanced oxidation processes. These combinations may optimize microbial inactivation while preserving the sensory and nutritional qualities of the food. Investigating these multi-modal approaches could also uncover new opportunities for customizing sterilization protocols based on specific food types, thereby broadening the applicability of IPL across diverse food industries. Moreover, it would be valuable to conduct cross-disciplinary studies involving material science to assess how IPL interacts with modern packaging materials, as these interactions could further enhance the overall safety and shelf life of food products.

3.5. Economic Considerations

The economic feasibility of adopting IPL technology in large-scale industrial settings has been rigorously assessed, revealing several advantages that could justify its implementation. Key findings highlight that IPL systems, despite their initial capital investment, offer significant cost savings in the long term by reducing energy consumption compared to traditional heat-based sterilization methods. Moreover, the absence of chemical additives in IPL treatment not only minimizes operational costs but also aligns with consumer demand for cleaner, more natural food processing methods. Maintenance requirements for IPL devices are generally lower due to their reliance on fewer mechanical components, further contributing to operational savings. From a business perspective, the adoption of IPL technology can also enhance market competitiveness by meeting stricter regulatory standards for food safety and quality, thereby opening opportunities for export markets with stringent compliance requirements. Economic models indicate that scaling IPL technology across production lines could significantly enhance efficiency and profitability, making it an attractive option for forward-thinking food manufacturers.

Preliminary cost modelling suggests that a medium-sized facility operating at a throughput of 1 ton/hour could recover its investment within 2–3 years, depending on local energy prices and equipment lifespan.

4. Conclusions

This study successfully designed, developed, and validated a multipurpose intense pulsed light (IPL) sterilization device tailored for industrial-scale application in the pickled fruit and vegetable sector. Laboratory and field experiments confirmed that the IPL system significantly reduced microbial contamination, achieving over 90% reduction within 120 seconds, without compromising the sensory or physical qualities of the products. These outcomes demonstrate IPL's potential as a viable non-thermal sterilization alternative to conventional chemical or heat-based methods.

The integration of this technology into real production environments showed promising results in terms of operational compatibility, energy efficiency, and ease of adoption, reinforcing IPL’s industrial relevance. Furthermore, the study aligns with sustainability goals by eliminating the need for chemical additives and minimizing energy consumption, thereby promoting safer and cleaner food processing.

Future research should investigate long-term nutritional stability post-IPL treatment, explore synergistic use with other preservation techniques, and analyse device scalability across various product types. Incorporating comprehensive economic models will also be critical to guide industrial decision-making regarding technology adoption.

In summary, the developed IPL device represents an innovative and scalable solution for enhancing food safety in fermented and pickled products. It contributes significantly to the evolving field of clean food technology, supporting Thailand's role as a global exporter and offering a roadmap for broader industry application.

Acknowledgements

The authors express heartfelt gratitude to the Faculty of Science and Technology, Nakhon Pathom Rajabhat University, for their essential facilities and unwavering support. Special thanks go to the Industrial Education Department for expertise in mechanical design and development and the Intelligent Control Innovation Department for system integration and control contributions. This research was generously funded by the Science, Research, and Innovation Promotion Fund in collaboration with the Competitive Fund Management Unit for Country Competitiveness Enhancement. We also deeply appreciate the reviewers' constructive feedback, which greatly enhanced the manuscript's quality, and acknowledge our colleagues and collaborators for their invaluable assistance and expertise throughout the project.

Author Contributions

B.W. conceived and designed the experiments; P.N. performed the experiments and analyzed the data; B.C. interpreted the data and wrote the paper; P.C. reviewed and provided critical feedback.

Funding

This research was funded by Science, Research, and Innovation Promotion Fund and The Competitiveness Enhancement Fund Management Unit (CEF) number C02F660015, Fiscal Year 2023 under Boonthong Wasuri.

Institutional Review Board Statement

The research involving human participants was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of Nakhon Pathom Rajabhat University.

Data Availability Statement

Invalid.

Conflicts of Interest

No conflicts interest.

References

1. Elmnasser N, Guillou S, Leroi F, Orange N, Bakhrouf A, Federighi M. Pulsed-light system as a novel food decontamination technology: a review. Can J Microbiol. 2007;53(7):813–21.
2. Mandal R, Mohammadi X, Wiktor A, Singh A, Pratap Singh A. Applications of pulsed light decontamination technology in food processing: An overview. Appl Sci. 2020;10(10):3606.
3. Oms-Oliu G, Martín-Belloso O, Soliva-Fortuny R. Pulsed light treatments for food preservation. A review. Food Bioprocess Technol. 2010;3:13–23.
4. Salehi F. Application of pulsed light technology for fruits and vegetables disinfection: A review. J Appl Microbiol. 2022;132(4):2521–30.
5. Nastasijevic I, Milanov D, Velebit B, Djordjevic V, Swift C, Painset A, et al. Tracking of Listeria monocytogenes in meat establishment using Whole Genome Sequencing as a food safety management tool: A proof of concept. Int J Food Microbiol. 2017;257:157–64.
6. Cao X, Huang R, Chen H. Evaluation of pulsed light treatments on inactivation of Salmonella on blueberries and its impact on shelf-life and quality attributes. Int J Food Microbiol. 2017;260:17–26.
7. Cozzolino D, McCarthy J, Bartowsky E. Comparison of near infrared and mid infrared spectroscopy to discriminate between wines produced by different Oenococcus Oeni strains after malolactic fermentation: A feasibility study. Food Control. 2012;26(1):81–7.
8. Wang W, You Y, Gunasekaran S. LSPR-based colorimetric biosensing for food quality and safety. Compr Rev Food Sci Food Saf. 2021;20(6):5829–55.
9. Mihafu FD, Issa JY, Kamiyango MW. Implication of sensory evaluation and quality assessment in food product development: A review. Curr Res Nutr Food Sci J. 2020;8(3):690–702.
10. Lu H, Zheng H, Hu Y, Lou H, Kong X. Bruise detection on red bayberry (Myrica rubra Sieb. & Zucc.) using fractal analysis and support vector machine. J Food Eng. 2011;104(1):149–53.
11. Oms-Oliu G, Aguiló-Aguayo I, Martín-Belloso O, Soliva-Fortuny R. Effects of pulsed light treatments on quality and antioxidant properties of fresh-cut mushrooms (Agaricus bisporus). Postharvest Biol Technol. 2010;56(3):216–22.
12. Figueroa CR, Pimentel P, Dotto MC, Civello PM, Martínez GA, Herrera R, et al. Expression of five expansin genes during softening of Fragaria chiloensis fruit: Effect of auxin

treatment. Postharvest Biol Technol. 2009;53(1–2):51–7.
13. Babilas P, Schreml S, Szeimies R, Landthaler M. Intense pulsed light (IPL): a review. Lasers Surg Med Off J Am Soc Laser Med Surg. 2010;42(2):93–104.
14. Liang J, Huang TY, Li X, Gao Y. Germicidal effect of intense pulsed light on Pseudomonas aeruginosa in food processing. Front Microbiol. 2023;14:1247364.
15. Huang R, Chen H. Comparison of water-assisted decontamination systems of pulsed light and ultraviolet for Salmonella inactivation on blueberry, tomato, and lettuce. J Food Sci. 2019;84(5):1145–50.
16. Ma Y, Xu Y, Chen Y, Meng A, Liu P, Ye K, et al. Effect of different sterilization methods on the microbial and physicochemical changes in Prunus mume juice during storage. Molecules. 2022;27(4):1197.
17. Bansal V, Mishra SK. Reduced-sodium cheeses: Implications of reducing sodium chloride on cheese quality and safety. Compr Rev food Sci food Saf. 2020;19(2):733–58.
18. Huang Y, Ikenaga T, Liu Q, Wu S. rate distortion optimized multi stage rate control algorithm for h 264 avc video coding. Regul Toxicol Pharmacol. 2009;98:115–28.
19. Gasparrini M, Forbes-Hernandez TY, Cianciosi D, Quiles JL, Mezzetti B, Xiao J, et al. The efficacy of berries against lipopolysaccharide-induced inflammation: A review. Trends Food Sci Technol. 2021;117:74–91.
20. Zhao X, Xu X, Zhou G. Covalent chemical modification of myofibrillar proteins to improve their gelation properties: A systematic review. Compr Rev Food Sci Food Saf. 2021;20(1):924–59.
21. Guo J, Huang K, Wang X, Lyu C, Yang N, Li Y, et al. Inactivation of yeast on grapes by plasma-activated water and its effects on quality attributes. J Food Prot. 2017;80(2):225–30.
22. Hwang HJ, Kim JW, Choi JB, Chung MS. Effects of the Specific Wavelength and Intensity of Intense Pulsed Light (IPL) on Microbial Inactivation. Food Bioprocess Technol. 2025;18(2):1719–29.
23. Chainok B, Wasuri B. Low-heat sterilization system on fruit and vegetable pickling line production with pulsed lighting. Suranaree J Sci Technol. 2023 Nov 10;30:010254(1-9).