# Non-Thermal UV-C Pasteurization: An Effective Method for Microbial Reduction in Liquid Foods

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**Abstract.** Thermal pasteurization, while effective, can compromise the nutritional quality and sensory attributes of food products but involves high energy consumption, nutritional degradation, and its appeal due to heat. As an alternative, Ultraviolet-C (UV-C) light pasteurization offers a non-thermal method for reducing microbial contamination in food, which addresses these drawbacks. This review examines the impact of UV-C radiation on food quality and safety, focusing on liquid foods. Studies show that UV-C light effectively reduces pathogenic microorganisms, including bacteria and viruses, in liquid foods such as fruit juice and liquid eggs. Despite its effectiveness, UV-C pasteurization has limitations with more viscous liquids, which may necessitate the combination with other pasteurization methods. Nevertheless, UV-C pasteurization represents a promising technology for enhancing food safety while preserving the sensory and nutritional qualities of food products.

## 1 Introduction

Pasteurization is a mild heat treatment applied to food, typically at temperatures below 100°C, aimed at destroying the vegetative cells of all pathogenic microorganisms as well as most non-pathogenic microorganisms [1]. Liquid food pasteurization is a process of heating food at a certain temperature for a certain period of time to kill pathogenic microorganisms and extend shelf life in both high-humidity and low-moisture foods [2]. This process was first introduced by Louis Pasteur in the 19th century and become an industry standard to ensure the safety and quality of liquid food products such as milk, juice, and other beverages [3]. Pasteurization plays a crucial role in the food industry, not only in ensuring that products are safe for consumption but also in maintaining the stability and quality of products during distribution and storage.

Thermal pasteurization in the food industry involves various methods used to ensure microbiological safety. The High-Temperature Short-Time (HTST) method is commonly used for liquid products such as milk, juice, soups, and sauces, effectively removing pathogenic bacteria like *Salmonella* and *Listeria* [4], [5]. HTST is also applied to egg products and baby food to reduce the risk of microbial infection [6], [7]. The Low Temperature Long Time (LTLT) method uses low temperatures (60-85°C) for an extended period to kill pathogenic microorganisms [8], [9]. Meanwhile, Ultra High Temperature (UHT) pasteurization involves heating products to very high temperatures for a short time, killing pathogenic microorganisms and extending the product's shelf life without requiring refrigeration [10].

Those traditional pasteurization methods are generally used heat to kill microorganisms [11]. These methods are effective in killing pathogenic bacteria such as *Salmonella, Listeria* and *Escherichia coli* [12]–[14]. However, heat pasteurization involves several challenges, one of which is the potential degradation of the nutritional quality and organoleptic characteristics of the product. The heating process used can result in damage to proteins, vitamins, and other important nutritional components [15]. In addition, changes in taste and color in products that are pasteurized with heat may also occur, potentially reducing their appeal to consumers.

In response to the challenges faced by traditional pasteurization methods, ultraviolet (UV) radiation has been introduced as a potential alternative. Ultraviolet radiation is a type of electromagnetic radiation that has a wavelength shorter than visible light but longer than X-rays [16]. Ultraviolet light has several spectral ranges, including UV-C (100 nm - 280 nm), UV-B (280 nm - 315 nm), and UV-A (315 nm - 400 nm) [17], [18]. Ultraviolet light has the ability to damage the DNA of microorganisms, resulting in cell death or the inability of microorganisms to reproduce [19]. This technology has been widely used in drinking water treatment and surface disinfection [20], and is now beginning to be adopted in the food industry for non-thermal pasteurization. In the ultraviolet spectrum, the UV-C range has high antimicrobial effectiveness so it is useful for ensuring microbial safety in food. The microbial genetic material, both DNA and RNA, shows strong absorption of UV photons at wavelengths of about 260-265 nm in the UV-C range corresponding to the peak point of maximum UV absorption [21]. Therefore, this

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review aims to provide an understanding of the effect of UV-C light on food quality and safety, especially on liquid food.

## 2 Methods

This article uses a literature review approach to investigate the use of non-thermal pasteurization in liquid foods. We conducted a systematic search using the keywords "pasteurization", "non-thermal", "liquid food", "ultraviolet", and "technology" in PubMed, Google Scholar, and ScienceDirect databases. The inclusion criteria included studies that discussed the application of non-thermal pasteurization techniques in English and published in peer-reviewed scientific journals. After the initial search, abstracts from each study were reviewed to verify their feasibility, and the relevant studies were then forwarded for full review. Evaluation of methodology, population samples, and study results was used to assess the quality and relevance of each selected study. Data extracted from the selected studies were then analyzed descriptively and qualitatively to identify the practical applications and challenges of non-thermal pasteurization techniques in the context of liquid food. The synthesis conclusions of the main findings were taken to present a comprehensive picture of the effectiveness and implications of this technology in the food industry.

## 3 Result and discussion

### 3.1 The microorganisms reduction capability

Ultraviolet (UV) pasteurization is a non-thermal food processing method that uses the electromagnetic spectrum of UV light, which is in the range between 100 to 400 nm [16], [18], [22]. Thus, some researchers have revealed the potential of UV-C rays in eliminating bacteria, viruses, and fungi because UV-C can penetrate and damage the DNA of microorganisms. This is in contrast to UV-A and UV-B, which are not capable of penetrating and damaging the DNA of microorganisms. Among these spectral ranges, UV-C light is the most effective light in non-thermal pasteurization with a range of 100nm-280nm.

United States Food and Drug Administration (USFDA) and United States Department of Agriculture (USDA) [23] have concluded that the use of UV-C light at a wavelength of 253.7 nm is safe to be used for food processing, and has approved its use as an alternative to reduce pathogens and other microorganisms. The USFDA has also stipulated in Code 21CFR179.41 that UV-C light can be used in the production, processing, and handling of food.

UV-C light exhibits broad antimicrobial activity, effective in inactivating a wide range of microorganisms including viruses, vegetative bacteria, bacterial spores, yeasts, conidia, and parasites [24], [25]. However, the impact of UV-C light on microorganisms can vary depending on factors such as the type of microorganism, strain, medium, population density of microorganisms, and the size of those microorganisms. The ability of UV-C to inhibit bacterial replication is associated with the process of thymine base dimerization in DNA [26].

The mechanism of ultraviolet radiation involves the direct absorption of UV light by nucleic acids, which then attack the DNA of microorganisms and trigger the formation of photochemical products. Cyclobutene-pyrimidine dimers (CPD) and 4–6 photoproducts (6–4 PP) are the primary outcomes of this process. CPD forms between adjacent pyrimidine molecules within the same DNA strand, which can disrupt the transcription or replication of DNA, particularly in thymine pairs [27]. Furthermore, exposure to these UV-C rays affects microorganisms at the DNA level causing damage to their reproductive system and ultimately inducing death [18].

This process interferes with the ability of microorganisms to replicate and cause their inactivation. Nonetheless, the effectiveness of UV-C light can be affected by factors such as product thickness, light intensity, exposure time, and product characteristics. Research shows that for liquid foods such as fruit juices, the penetration of UV-C light is limited to the first surface layer so that it can affect the efficiency of reducing microorganisms inside thicker products.

In fruit juice, approximately 90% of UV-C light is absorbed within the first 1 mm of the surface [28], [29]. Additionally, according to research by Koutchma et al. [30] and Murakami et al. [31], the rate of *E. coli* K12 inactivation is affected by the absorption capacity of the model solution. Furthermore, research has shown variations in juice quality due to differences in power levels, processing time, distance between the product and the UV-C light source, as well as the thickness of the product in achieving different levels of pathogen inactivation [32].

A study by Feng et al. [33] as shown in Fig 1 showed that the application of UV-C (2.7–37.5 J/mL) to watermelon juice was able to completely inactivate the coliform bacterial population and with a UV-C dose of 37.5 J/mL resulted in a 50% reduction in total aerobic bacteria and a 30% reduction in yeast and mold. Other studies such as those conducted by Keyser et al.[34] on apple juice showed that a UV-C dose of 230.0 J/L reduced aerobic plate count as well as yeast and mold by 3.5 logs and 3.0 logs, respectively. The use of UV-C in apple juice at a dose of 24.9 mJ/cm$^2$ was also able to reduce *E. coli K12* bacteria with a log reduction of less than 5 [30].

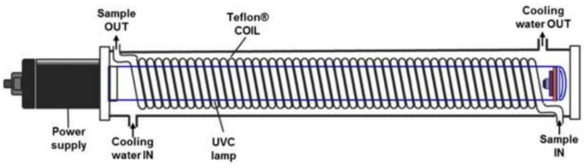

**Fig 1.** Teflon-coil® UV-C reactor used for watermelon juice treatment [33].

Another study involving apple juice showed that a UV-C dose of 1200 mJ/cm$^2$ reduced the yeast of

*Zygosaccharomyces rouxii* by 5.46 logs [29]. Shamsudin et al. [35] revealed that UV treatment of pineapple juice at a dose of 10.76 mJ/cm$^2$ could inactivate aerobic plate count as well as yeast and mold with a log reduction of 1.9 and 1.4, respectively. Inactivation of *S. typhimurium* has also been successfully carried out on pineapple juice with a UV dose of 0.000154 L/s which results in a log reduction of 3 [36]. Another study examining mango nectar showed that a UV-C dose of 45 J/cm$^2$ could reduce aerobic plate count by a log reduction of 2.7 [37].

De Souza et al. [38] used a UV-C reactor for eggs pasteurization (Fig 2) and showed that the use of UV-C light in the reactor was effective in inactivating *S. subterranea* DSM 16208, *Escherichia coli* DH5α, and *L. innocua* WS 2258 in liquid egg products. Log reductions of all inoculated microorganisms were achieved at doses of 8.0 kJ/L, 16.0 kJ/L, and 63.0 kJ/L, respectively. Moreover, Unluturk et al. [39] stated that exposure to UV-C light with an intensity of 1,314 mW/cm$^2$ for 20 minutes to liquid eggs inoculated with *Escherichia coli* K-12 (ATCC 25253), *Escherichia coli* O157:H7 (NCTC12900), and *Listeria innocua* (NRRL B33314) resulted in a decrease in the populations of *E. coli* K-12, *E. coli* O157:H7, and *L. innocua* by 0.896 CFU logs, 1.403 CFU logs, and 0.960 CFU logs, respectively.

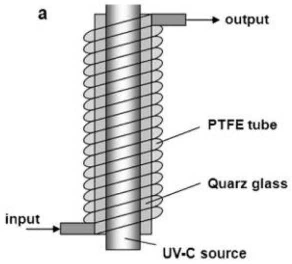

**Fig 2.** UV reactor for liquid egg product management [38].

Besides, the absorption coefficient of fruit juice and the length of certain paths can also affect the efficiency of UV-C light. The two key factors that have the potential to affect this parameter are the properties of liquid food such as turbidity, particle size, viscosity, total dissolved solids, suspended particles, and pH. These characteristics largely determine how much UV-C light can be absorbed by liquid food. Liquid foods have significant differences in optical, physical, and chemical properties compared to water [40]. The second factor is related to the design of the UV-C reactor used for juice photosensitization, which directly affects UV-C light transmission, radiation dose delivery, energy transfer, and microbial inactivation effectiveness [41].

In summary, the use of UV-C light is considered a promising alternative to heat treatment in the pasteurization of liquid foods [42]. UV light can enhance the safety of food and beverages by reducing microorganisms without the need of chemicals or generating waste [43]. The use of UV light in pasteurization can potentially offer superior organoleptic quality in food products with lower initial investment and operational costs [44].

## 3.2 The UV-C pasteurization drawbacks

UV pasteurization methods have been the focus of in-depth research in an effort to improve the microbiological safety of food products, compared to conventional methods such as hot pasteurization. On the other hand, heat pasteurization uses high temperatures to inactivate microorganisms, a method that has been shown to be effective in the food industry to ensure product safety, but often alters the physical, chemical, and nutritional properties of the product and can reduce sensory qualities [46].

The advantages of UV pasteurization include process speed and minimal impact on the nutritional and organoleptic properties of the product [45], as it does not require significant heating. However, this method has limitations in the penetration of UV-C light on products with a larger thickness, requiring special equipment, and higher operating costs. Furthermore, long term exposure for various techniques can harmful to human being as shown in Table 1.

**Table 1**. The advantages and disadvantages of some Pasteurization methods [47].

| Techniques | Benefits | Drawbacks |
|---|---|---|
| Irradiation | (1) Effective for several foods<br>(2) Many different sources available (Gamma rays, electron beam) | Limited public acceptance. The use of radiation dose up to 7 kilo Gray (KGY) has been sanctioned. |
| UV Radiation | (1) No chemical is used<br>(2) Non heat related method | Long term exposure can be harmful to the industry workers |
| High Hydrostatic Pressure (HPP) | Independent of the shape of food can be used for both solid and liquid sample | Changes in quality of food have been observed |
| Pulsed Electric Field (PEF) | Pulse applied for a short period so no generation of heat and less use of energy | Cannot be applied to foods which is not withstand high fields |
| Supercritical carbon dioxide | It can be used in a batch or continuous process | It's not more successful for solids food |

In addition, UV light has low penetration depth in liquid foods that have high UV absorbance and suspended particles, posing challenges in designing efficient UV reactors [42]. Hence, UV treatment is less effective for turbid and particulate-containing liquids, such as liquid eggs and some types of juice [43].

Despite the advantages of UV-C pasteurization, such as its speed and minimal impact on nutritional and organoleptic properties due to the absence of significant heating, it has notable limitations. The method suffers from limited UV-C light penetration in thicker products and in liquid foods with high UV absorbance and suspended particles, which complicates the design of efficient UV reactors. Additionally, UV-C pasteurization requires specialized equipment and incurs higher operational costs. Its effectiveness is also reduced for turbid and particulate-containing liquids, such as liquid eggs and certain types of juice.

### 3.3 The UV-C pasteurization in the future

Based on the results of this literature review, several future research recommendations can be identified. First, an in-depth study is needed on the impact of the use of UV-C radiation on the sensory quality and nutritional value of liquid food products. Research should include variations in processing parameters such as radiation dose, exposure time, and product characteristics to thoroughly understand the implications for the final product.

Second, further exploration is needed regarding the implementation of UV-C pasteurization technology on a large industrial scale, focusing on economic aspects, energy efficiency, and compliance with food regulations. Third, research on the environmental impact of the use of UV-C radiation in the pasteurization of liquid food should also be prioritized, including product life cycle evaluations and impacts on natural resources. This research field is important to optimize the use of UV-C radiation in the food industry and improve product safety and quality globally.

Various non-thermal processing technologies have been developed for food pasteurization, including PEF, UV exposure, membrane filtration [48], and HHP. Among them, PEF is one of the most promising non-thermal technologies and has been applied in industrial settings. PEF pasteurization involves the transmission of millisecond pulses with high electric field strength (5-55 kV/cm) to food [49]. PEF could be used to inactivate vegetative organisms such as *E. coli* and yeast. When PEF is applied, the accumulation of oppositely charged molecules around the membrane can increase the cell's transmembrane potential. As the result, the cell membrane becomes thinner as the transmembrane potential exceeds, leading to reversible or irreversible electroporation [50].

Using PEF in conjunction with UV-C exposure may have synergistic benefits because the microbial inactivation processes of PEF and UV-C radiation differ [49], [51], [52]. It has been found that PEF, followed by UV-C exposure, is most effective in maintaining the quality of mixed juices while reducing microorganisms [48].

In the context of combined pasteurization, integrating pasteurization techniques such as heating, cooling, or pressing can work together to ensure better food safety while preserving the desired product quality [53], [54]. Additionally, non-thermal pasteurization methods like radiation pasteurization, HPP, and PEF are often used for food processing [2], [55], [56].

For example, in the beverage industry, combined thermal and non-thermal pasteurization is used to process fruit juices and non-carbonated drinks. Some widely combined pasteurized fruit juices include orange, grape, and cherry [57]. By using these techniques, manufacturers can reduce the population of pathogenic and spoilage microorganisms while maintaining the natural taste and nutrition of the fruits. As a result, consumers can enjoy fresh and safe beverages [48], [54], [56], [58].

Additionally, the combination method is widely used in meat processing to kill pathogenic microorganisms while maintaining meat quality, especially in fast-food meat products [59]. In the dairy industry, combined pasteurization is used in processing products such as yogurt and cheese while preserving the nutritional content and organoleptic characteristics of these dairy products [60], [61]. For solid and semi-solid dairy products, combinations of technologies such as HPP, high-pressure homogenization, and others also hold promise as alternatives to conventional pasteurization or sterilization [62].

## 4 Conclusion

The review indicates that UV-C radiation is effective in reducing pathogenic microorganisms in liquid foods, including fruit juice and liquid eggs, while preserving sensory quality and nutritional value. UV-C pasteurization effectively inactivates bacteria and viruses, making it a viable alternative for maintaining food safety. The efficiency of UV-C technology is influenced by factors such as radiation dose, exposure time, and the physical characteristics of the liquid food, which must be carefully managed in industrial applications. In industrial settings, it is crucial to optimize UV-C parameters to ensure consistent effectiveness and guarantee the safety of the final product. Future studies should focus on further exploring UV-C pasteurization technology and other non-thermal methods to enhance food safety, particularly for liquid food products. In summary, UV-C pasteurization and other non-thermal methods represent promising solutions for ensuring food safety, offering advantages in maintaining the quality and nutritional value of liquid foods. Nevertheless, the usage of UV-C pasteurization have to consider the high cost investment, and its effectiveness for other liquid food.

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