

## Review

# UV Light Application as a Mean for Disinfection Applied in the Dairy Industry

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**Featured Application:** The practical aspects of the use of UV technology in dairy processing are discussed in this paper. The possible area of applications and limitations of UV treatment is presented. A direct comparison of the influence of UV light and pasteurization on milk components and characteristics of milk and dairy products was made.

**Abstract:** Thermal treatment is the most popular decontamination technique used in the dairy industry to ensure food protection and prolong shelf life. But it also causes nutrient and aroma degradation, non-enzymatic browning, and organoleptic changes of dairy products. Non-thermal solutions, on the other hand, have been extensively explored in a response to rising market demand for more sustainable and safe goods. For a long time, the use of ultraviolet (UV) light in the food industry has held great promise. Irradiation with shortwave UV light has excellent germicidal properties, which can destroy a variety of microbial pathogens (for example bacteria, fungi, molds, yeasts, and viruses), at low maintenance and installation costs with minimal use of energy to preserve food without undesirable effects of heat treatment. The purpose of this review is to update the studies made on the possibilities of UV-C radiation while also addressing the essential processing factors involved in the disinfection. It also sheds light on the promise of UV light-emitting diodes (UV-LEDs) as a microbial inactivation alternative to conventional UV lamps.

**Keywords:** UV light; dairy industry; disinfection; UV applications; UV-C fluence



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## 1. Introduction

Foodborne illnesses induced by the ingestion of etiological agents make food safety a critical problem for the food industry and food services. According to the World Health Organization, 600 million people—almost one out of every ten people on the planet—become sick after consuming contaminated food each year, with 420,000 of them dying [1].

Pasteurization and ultra-high temperature (UHT) treatments are two thermal processes commonly used in dairy production. Heat treatments may have a detrimental impact on food by altering sensory properties including color, texture, and taste. Furthermore, the consequence may be a reduction in nutritive value, for instance, the loss of certain bioactive compounds, enzymatic breakdown, vitamin loss, lipid rancidity, and denaturation of proteins, which may result in low food quality. For instance, as the temperature rises, the level of the milk serum component changes. The levels of calcium and phosphate in milk serum drop from the initial level 9 to 3 mmol L<sup>-1</sup> and 12 to 8 mmol L<sup>-1</sup>, respectively, as the temperature rises from 4 to 90 °C; heat-induced reductions in serum magnesium and citrate are also found, but to a lesser extent [2]. There is no change in the level of potassium and sodium in the milk serum caused by heat treatment [3]. The pH of milk decreases as it is heated, and at temperatures above 80 °C, the pH decreases linearly with increasing temperature [4,5]. However, the heat treatment of milk which occurs at temperatures above 70 °C will change the properties of milk fat globule membrane (MFGM) proteins, leading

to the exposure of reactive groups. Additionally, more extreme heat treatments (above 90 °C) can cause permanent changes in mineral balance in milk [6]. Another drawback is that thermal processing consumes a lot of energy, which can lower the final product value and reduce industry profitability [1].

At a compound annual growth rate (CAGR) of 6.9%, the global market of dairy product is projected to rise from \$675.78 billion in 2020 to \$722.14 billion in 2021 and at a CAGR of 7%, the market is forecast to hit \$956.26 billion in 2025 [7]. As a result, new manufacturing methods must be developed to satisfy global demand. In European Union, a food product should be considered a novel food when it is produced with a process not used within the Union before 15 May 1997, and which results in significant changes in the composition or structure of food affecting its nutritional value, metabolism or level of undesirable substances [8].

Non-thermal technologies, i.e., microfiltration, UV light processing, pulsed light, high hydrostatic pressure, high-pressure homogenization, pulsed electric fields, ohmic and microwave heating, and carbon dioxide processing, have recently been implemented as an alternative to thermal treatment and have piqued public interest as a means of avoiding nutrient damage that would otherwise occur during food heat processing [9].

The Sun is the primary source of Ultraviolet light, which radiates light at several different wavelengths [10]. The alternative UV radiations can be emitted from tanning beds, mercury vapor lamps, selected halogens, fluorescents, incandescent lights, and some types of lasers [11]. Ultraviolet radiation is a non-ionizing source of invisible light that exists between visible light and X-rays in the electromagnetic spectrum (EM). UVA (315–400 nm), UVB (280–315 nm), UVC (200–280 nm), and vacuum-UV (100–200 nm) are the four major forms of UV rays produced by ultraviolet light with wavelengths between 100 and 400 nm as shown in Figure 1 [1,12]. UV has the best germicidal effect when the wavelength is about 254 nm, which mercury vapor lamps emit [13]. The microbial deactivation can become more efficient through greater penetration of UV light which is possible with the correct UV source [10].

In most UV-based disinfection systems, mercury lamps have been the source of radiation which is primarily of two types: medium pressure mercury (MPM) and low-pressure mercury (LPM) UV lamps that are reliable disinfection sources with high efficiency and low cost [10].

UV-C rays, which act as germicides, have the greatest effect on various microorganisms which include bacteria, viruses, protozoa, fungi, algae [14], and bacterial spores [1,12,15–17]. UVC germicidal lamps are used to sterilize air, disinfect surfaces, deter microorganisms from accumulating on food surfaces, and are a convenient and effective method to clean water without the usage of toxic chemicals [18].

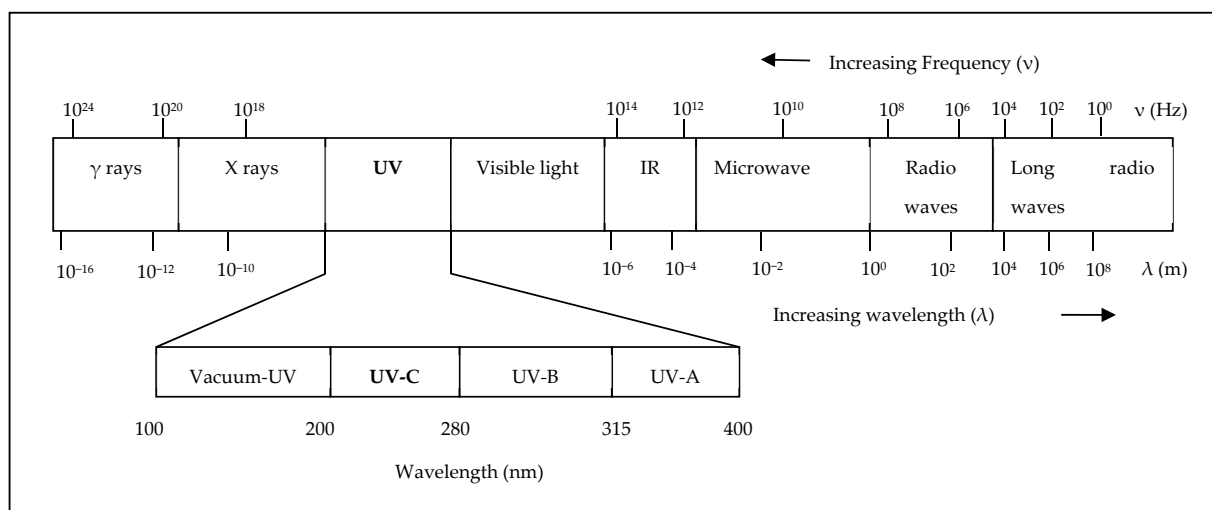


Figure 1. UV radiation and wavelengths [19–21].

In a survey study, UV radiation was identified as one of the main novel technologies currently applied or with the potential to be commercialized in 5–10 years. The respondents (food professionals from industry, academia, and government) from North America and Europe classified UV as the third and fourth cutting-edge food processing technology, respectively. The results of the survey demonstrated that the main drivers for the commercialization of novel technologies, i.e., UV treatment, were higher quality products (94%), product safety (92%), and shelf life (91%) [22].

In January 2016 [23], the EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) delivered an opinion on UV-treated milk as a novel food submitted pursuant to Regulation (EC) No 258/97. The European Food Safety Authority (EFSA) stated that “the novel food is cow’s milk (whole, semi-skimmed or skimmed) to which treatment with ultraviolet (UV) radiation is applied after pasteurization in order to extend the shelf life of the milk and increase the vitamin D3 concentrations by conversion of 7-dehydrocholesterol to vitamin D3. The EFSA panel concluded that the novel food, UV-treated milk, is safe under the intended conditions of use as specified by the applicant.”

With an increasing number of studies related to the application of UV radiation in the food industry, especially milk and dairy products, this review aimed to systemize the information by describing the fundamentals of this technology, with emphasis on inactivation dose and influence on physicochemical and sensory characteristics as compared with conventional heat treatment.

## 2. The UV Process

UV treatment kills bacteria by introducing energy to the surface of the food or into the liquid medium [9], which is capable of affecting microorganism DNA, altering metabolism and replication, and ultimately causing cell death [1]. When UV energy is incorporated into liquid media its germicidal energy is capable of penetrating liquids, however, the strength of UV light decreases as a result of attenuation and dissipation [9].

The photochemical reactions of microorganism biomolecules primarily have a germicidal effect, inhibiting microbial growth or inactivating the cell. An anti-microbial impact of Ultraviolet radiation is caused by the cross-linkage in just the same target DNA seen between the foundation of neighboring dimer pyrimidine. All this leads to replication and transcription of nucleic acids, which is referred to as clonogenic death. In certain cases, depending on the species of the microorganism, the metabolic rate can cure DNA damage by photoreactivation or darkreactivation. However, due to broader damage, the healing becomes impossible at significant UV dosages [10].

UV dose, which refers to UV or UV intensity stream and is characterized by the intensity and exposure duration. It is primarily responsible for the germicidal effects of UV radiation and is defined by the following equation:

$$D = I \times t \quad (1)$$

where;

$D$  ( $J/m^2$ ) = UV ‘dose’ or the sum of UV energy applied to a particular surface during a unit of time,  $I$  ( $W/m^2$ ) = UV intensity measured at the surface, and  $t$  (s) = exposure time [1]

The distance between the UV light and the packaging affects the strength of the radiation. For example, in the case of yogurt filling, the studies have shown that 150-mm-depth cups can be disinfected during 4 s and sealed foils in 2 s under the same pressure. For this reason, the UV disinfection would be better in the packaging of acidic fresh milk products like yogurt and kefir that are held in the cool chain to extend their shelf life. This ensures the dairy industry would receive far fewer spoiled product complaints, saving time, efforts, and money in the process [24].

UVC radiations can be used after disinfection with low-percentage hydrogen peroxide (1–3%) to effectively inactivate even the most UVC-resistant mold fungi. This process includes two mechanisms: UVC radiation inactivates bacteria that are resistant to hydrogen peroxide, such as *Bacillus subtilis* spores, while hydrogen peroxide kills microorganisms

that need a high UVC dose, such as *Aspergillus niger* spores. This results in broad and effective germicidal effect and the necessary microorganism reduction rate of 4 log, “Ultra-clean,” [25]. The germ load reduction was reported at the level up to 99.99% [25].

Another study conducted in the cheese processing industry showed that UV treatment resulted in a 5 log (99.999%) reduction of bacteriophages and a 3 log (99.9%) reduction of thermophilic bacteria [26].

### 3. Inactivation Dose

The key processing factors in designing a UV-C treatment system are UV dosage, exposure time, Reynold’s number, i.e., turbulence and UV transmittance of the liquid food [12].

Disinfection, not sterilization, is a process of removing bacteria from packaging materials [24] either by killing or inactivating microorganisms by damaging nucleic acids and disrupting their DNA, making them incapable of performing essential cellular functions. The systems of surface disinfection are used to eliminate microbial counts on yogurt, milk, butter, and other dairy goods packaging, such as tubs, bottles, containers, lids, and foils. Spoilage microorganisms are removed by UV irradiation of the surfaces prior to filling, such treatment increases the shelf life of the product and lowers the risk of contamination [26].

Ultraviolet radiation with wavelengths of 254 nm has higher energy content than the sun’s terrestrial UV light. The DNA of the microorganisms is destroyed by UV light, which transmits a particularly short wavelength. The inactivation time of viruses is about a few seconds and bacteria, yeasts, and fungi are killed in an environmentally friendly way without the use of chemicals. The lethal dose of UV radiation, which can be defined as the dose at which the cells can no longer sustain their metabolism or multiply, is already defined for a wide range of microorganisms. The lethal dose for various foodborne pathogens is distinctly high due to the cell wall structure. As a result, bacteria with a relatively thin cell wall that can only marginally block UV radiation, such as *Salmonella* and *E. coli*, are highly susceptible and are easily killed. Mold spores, on the other hand, have a thick cell wall that can also be pigmented to shield them from UV radiation and in that case, a UV dose 10 to 100 times higher is used to destroy them [24].

The influence of UV-C (254 nm) on the survival of distinct vegetative bacteria and selected spores is shown in Table 1.

**Table 1.** UV-C lethal fluence (F) for varying levels of bacterial survival [14].

Microorganism	F <sub>-1 log</sub> (J/m <sup>2</sup> )	F <sub>-4 log</sub> (J/m <sup>2</sup> )	Reference
Bacilli			
Vegetative: <i>B. anthracis</i>	12–45	26–110	[27,28]
<i>B. megaterium</i>	56	-	[29]
<i>B. paratyphosus</i>	32	-	[27]
<i>B. subtilis</i>	40–60	-	[30,31]
Spores: <i>B. anthracis</i>	275	620	[32]
<i>B. megaterium</i>	290	600	[29]
<i>B. subtilis</i>	260	600	[32–34]
Other vegetative microorganisms			
<i>Burkholderia cepacia</i>	31	92	[35]
<i>Burkholderia pseudomallei</i>	44	130	[36]
<i>Campylobacter jejuni</i>	11	21	[37]
<i>Citrobacter freundii</i>	-	80	[38]
<i>Corynebacterium diptheriae</i>	34	-	[27]
<i>Eberthella typosa</i>	21	-	[27]
<i>Enterobacter cloacae</i>	-	100	[38]
<i>Enterocolitica faecium</i>	-	170	[38]
<i>Escherichia coli</i>	20–40	50–110	[27,37]

Table 1. Cont.

Microorganism	F <sub>-1 log</sub> (J/m <sup>2</sup> )	F <sub>-4 log</sub> (J/m <sup>2</sup> )	Reference
<i>Klebsiella pneumonia</i>	-	110	[38]
<i>Listeria monocytogenes</i>	50	96	[39]
<i>Micrococcus cadidus</i>	61	-	[27]
<i>M. piltonensis</i>	81	-	[27]
<i>M. sphaeroides</i>	-	100	[38]
<i>M. smegatis</i>	-	200	[38]
<i>Neisseria catarrhalis</i>	44	-	[27]
<i>Phytomonas tumefaciens</i>	44	-	[27]
<i>Proteus vulgaris</i>	26	-	[27]
<i>Pseudomonas aeruginosa</i>	55	110	[27,38]
<i>P. fluorescens</i>	35	-	[27]
<i>Salmonella typhimurium</i>	80	130	[27,38]
<i>S. typhi</i>	51	90–140	[27,40]
<i>Serratia marcescens</i>	23	130	[27,38]
<i>Shigella paradysenteriae</i>	17	-	[27]
<i>Shigella sonnei</i>	40	75	[41]
<i>Spirillum rubrum</i>	44	-	[27]
<i>Staphylococcus albus</i>	21	-	[27]
<i>S. aureus</i>	22–49	-	[27,38]
<i>Streptococcus hemolyticus</i>	22	-	[27]
<i>L. lactis</i>	62	-	[27]
<i>S. viridians</i>	20	-	[27]
<i>Vibrio cholera</i>	11	25–50	[38,42,43]
<i>Yersinia enterocolitica</i>	13	36–110	[37,38]
“Dysentery” bacilli	22	-	[27]

Most bacteria’s sensitivity reports are within a factor of two between various investigations, except for *Y. enterocolitica*, for which variability by a factor of three was observed. The survival of vegetative bacteria had sensitivity ranging from 11 to 80 J/m<sup>2</sup> for a 1 log and 25–200 J/m<sup>2</sup> for a 4 log inactivation respectively [14]. Furthermore, bacterial inactivation by UV treatment is based on the organism’s species, age, initial bacterial load, and spore presence. Bacteria that are Gram-negative, such as *Pseudomonas* and *Escherichia*, are more vulnerable to UV radiation than Gram-positive bacteria (*Bacillus* and *Staphylococcus*). The optimal time of UV treatment for inactivation of vegetative bacterial cells is during the early lag period, as the bacteria are more resistant to UV light before successful cell division. Bacterial sensitivity to UV radiation is also boosted by the absence of oxygen in the food medium [9].

#### 4. Effects of UV on Food Components and Quality

UV light catalyzes other steps of the oxidation process and initiates free radical oxidation. It produces superoxide radicals (SOR), lipid radicals, and H<sub>2</sub>O<sub>2</sub>. Superoxide radicals may also cause protein fragmentation, protein crosslinking, carbohydrate crosslinking, unsaturated fatty acid peroxidation, and the lack of membrane permeability. UV radiation can cause denaturation of components such as proteins, amino acids (especially amino acids with aromatic compounds), and enzymes in milk, resulting in textural changes. Water absorbs UV photons and creates OH<sup>-</sup> and H<sup>+</sup> radicals, which may induce changes in other food components. High doses UV light treatment results in variations of the chemical properties of food products and deteriorations of product content. As a result, it is critical to properly refine the disinfection process to preserve the consistency of the food items while also guaranteeing their safety [44].

The review of different studies on the application of UV technology in the food industry is shown in Table 2.

**Table 2.** Impact of ultraviolet radiation technology on the microbial inactivation of dairy products.

Dairy Product	Microorganism(s) Affected	UV Processing Parameters	Results	Reference
Bovine skim milk	<i>B. subtilis</i> spores	<ul style="list-style-type: none"> <li>UV pretreatment (D Act <math>2.37 \pm 0.126</math> J/mL) combined with thermal treatment at 110 °C for 30 s</li> </ul>	<ul style="list-style-type: none"> <li>Reduction of approximately 6 log CFU/mL</li> </ul>	[12]
Whole bovine milk			<ul style="list-style-type: none"> <li>Reduction of 2.90 log CFU/mL</li> </ul>	
Ovine milk			<ul style="list-style-type: none"> <li>Reduction of 1.1 log CFU/mL</li> </ul>	
Raw milk	<i>Staphylococcus aureus</i>	<ul style="list-style-type: none"> <li>Pulsed ultraviolet light</li> <li>Number of passes (min.-max.): 1–3</li> <li>Distance from a UV-light strobe: 5-, 8-, or 11-cm distance, which corresponds to the energy 1.07, 0.98, and 0.80 W/cm<sup>2</sup>, respectively.</li> <li>Flow rate: 20, 30, or 40 mL/min</li> </ul>	<ul style="list-style-type: none"> <li>Log<sub>10</sub> reductions varied from 0.55- to 7.26-log<sub>10</sub> CFU/mL</li> <li>Complete inactivation of <i>S. aureus</i> was obtained and was affected by the sample distance from quartz window, number of pass and flow rate combinations.</li> </ul>	[45]
	<i>Listeria monocytogenes</i>	<ul style="list-style-type: none"> <li>Dose—21.3 mJ/cm<sup>2</sup></li> <li>Time—60 min at 25 °C</li> </ul>	<ul style="list-style-type: none"> <li>1~6 log<sub>10</sub> reduction (in 60 min)</li> </ul>	[46]
UHT whole and skim milk	<i>Bacillus subtilis</i> spores	<ul style="list-style-type: none"> <li>LPM UVC lamps</li> <li>254 nm (UVC)</li> <li>Dose ranging from 10 to 160 J/mL</li> </ul>	<ul style="list-style-type: none"> <li>Initial concentration about 6 log CFU/mL</li> <li>Doses from 100 J/mL with several passes produced the best lethality results (above 4 Log CFU/mL)</li> <li>Effective distance from the UVC source: 0.02 mm for whole milk and 0.06 mm for skim milk</li> </ul>	[47]
Raw soymilk	<i>Escherichia coli</i> W1485 and <i>Bacillus cereus</i> spores	<ul style="list-style-type: none"> <li>Coiled tube UV reactors at a constant residence time of 11.3 s with UV-C dose of 11.187 mJ/cm<sup>2</sup></li> </ul>	<ul style="list-style-type: none"> <li>Maximum reductions of 5.6 log<sub>10</sub> CFU/mL of <i>E. coli</i> and 3.29 log<sub>10</sub> CFU/mL of <i>B. cereus</i> spores.</li> </ul>	[17]

Table 2. Cont.

Dairy Product	Microorganism(s) Affected	UV Processing Parameters	Results	Reference
Goat milk	<i>Escherichia coli</i>	<ul style="list-style-type: none"> <li>Pulsed UV light</li> <li>Generated using an exciplex laser unit</li> <li>Doses of 5000 and 10,000 mJ/cm<sup>2</sup></li> </ul>	<ul style="list-style-type: none"> <li>6-log reduction achieved using 10,000 mJ/cm<sup>2</sup> of pulsed UV.</li> </ul>	[48]
	<i>Listeria monocytogenes</i> (L-2289)	<ul style="list-style-type: none"> <li>UV light using the CiderSure 3500 apparatus</li> <li>Dose between 0 and 20 mJ/cm<sup>2</sup></li> </ul>	<ul style="list-style-type: none"> <li>More than 5-log reduction when exposed to a dose of <math>15.8 \pm 1.6</math> mJ/cm<sup>2</sup>.</li> <li>For 1-log reduction, a UV dose of approximately 15, 7.3, 3.9 mJ/cm<sup>2</sup> is required when operating at 20, 50, and 75% running capacity respectively.</li> </ul>	[49]
Donkey milk	<i>L. innocua</i> , <i>S. aureus</i> , <i>B. cereus</i> , <i>Cronobacter sakazakii</i> , <i>E. coli</i> , and <i>Salmonella enteritidis</i>	<ul style="list-style-type: none"> <li>Low-power UV unit</li> <li>UV doses: 0, 91.8, 275.4, 459, 642.6, 826.2, 1000.8, 1100, 1200, and 1300 J/L</li> <li>Intensity 17.7 mW/cm<sup>2</sup></li> <li>Flow rate 4000 L/h</li> </ul>	<ul style="list-style-type: none"> <li><i>L. innocua</i> was the most UV-C-resistant, complete inactivation at 1100 J/L, while the rest of the bacteria tested was destroyed by the range of 200–600 J/L</li> </ul>	[50]
Kashar cheese	mold count and quality analysis	<ul style="list-style-type: none"> <li>UV-C lamp</li> <li>4 cm from the surface of the samples</li> <li>Intensity 32.1 W/m<sup>2</sup></li> <li>Treated for 10, 30, 60 and 300 s corresponding to doses of 0.32, 0.96, 1.93 and 9.63 kJ/m<sup>2</sup>, respectively</li> </ul>	<ul style="list-style-type: none"> <li>2–3 log reduction in the mold population when treated with doses above 1.93 kJ/m<sup>2</sup>.</li> </ul>	[51]
Fresh Kashar cheese	<i>Staphylococcus aureus</i> and <i>Escherichia coli</i> O157:H7	<ul style="list-style-type: none"> <li>Pulsed ultraviolet light</li> <li>Different times (5, 15, 30, 45, 60 s)</li> <li>Distance from the quartz window: 5, 8, and 13 cm</li> </ul>	<ul style="list-style-type: none"> <li>The most efficient treatment: 45 s–13 cm treatment (<math>\sim 44</math> J/cm<sup>2</sup>) yielded about 1.62 and 3.02 log<sub>10</sub> reductions (cfu/cm<sup>2</sup>) for <i>S. aureus</i> and <i>E. coli</i> O157:H7, respectively</li> </ul>	[52]
Fiordilatte cheese	<i>Pseudomonas</i> spp. and <i>Enterobacteriaceae</i> , and microbial growth	<ul style="list-style-type: none"> <li>UV light of intensity 20 W/m<sup>2</sup></li> <li>5, 30, 60, 150, 300, 450 and 750 s</li> <li>0.1, 0.6, 1.2 and 3.0, 6.0, 9.0 and 15.0 kJ/m<sup>2</sup> fluence</li> <li>2 cm from the surface of the samples</li> </ul>	<ul style="list-style-type: none"> <li>Reduction of about 1–2 log cycles</li> </ul>	[53]



Table 2. Cont.

Dairy Product	Microorganism(s) Affected	UV Processing Parameters	Results	Reference
Fresh cheese	<i>Enterobacteriaceae</i> , <i>Pseudomonas</i> spp. and pH	<ul style="list-style-type: none"> <li>Fluences from 0.39 to 28.0 J/cm<sup>2</sup></li> </ul>	<ul style="list-style-type: none"> <li>Reduction of about 1 log cycle</li> </ul>	[54]
White American cheeses	<i>Penicillium roqueforti</i> and <i>Listeria monocytogenes</i>	<ul style="list-style-type: none"> <li>Pulsed UV light for 40 s at 5 cm</li> </ul>	<ul style="list-style-type: none"> <li>The maximum reduction for <i>P. roqueforti</i> was 1.32 log CFU/cm<sup>2</sup> on unpackaged cheese and 1.24 log CFU/cm<sup>2</sup> on packaged cheese.</li> <li>Reductions of about 2.9 and 2.8 log CFU/cm<sup>2</sup> of <i>L. monocytogenes</i> on packaged and unpackaged cheeses, respectively.</li> </ul>	[55]
Ricotta cheese	<i>Pseudomonas fluorescens</i>	<ul style="list-style-type: none"> <li>Distance 6 cm from the LED light source for 400 s</li> <li>dose of 6.54 J/cm<sup>2</sup></li> </ul>	<ul style="list-style-type: none"> <li>At inoculation levels of 3 and 4 log CFU/mL a decrease in the microbial population was below the detection limits (&lt;100 CFU/g)</li> <li>When 5 log CFU/mL inoculum was applied, the inactivation level was <math>-1.03 \pm 0.02</math> CFU/g after treatment</li> </ul>	[56]
Sliced cheese packed with 0.07 mm films of polyethylene terephthalate (PET), polyvinylchloride (PVC), polypropylene (PP), and polyethylene (PE)	<i>Escherichia coli</i> O157:H7, <i>Salmonella typhimurium</i> , and <i>Listeria monocytogenes</i>	<ul style="list-style-type: none"> <li>Set of 5 germicidal emitting lamps</li> <li>The distance between lamps and tray was 10 cm</li> <li>Treatment time 1 min.</li> <li>The light intensity at the sample location was 3.04 mW/cm<sup>2</sup></li> </ul>	<ul style="list-style-type: none"> <li>After 1 min exposure of PP and PE packaged cheese slices, the reduction in <i>E. coli</i> O157:H7 cell numbers was 3.36 and 3.12 log, respectively.</li> <li>Significant reductions were not observed in PET and PVC packaged cheese slices.</li> <li>The inactivation of <i>S. typhimurium</i>, and <i>L. monocytogenes</i> was similar to the results of <i>E. coli</i> O157:H7.</li> <li>Adjusted PP or PE film packaging in combination with UV-C radiation can be applied to control foodborne pathogens in the dairy industry</li> </ul>	[57]
White Cheddar and processed cheeses	<i>Pseudomonas fluorescens</i> , <i>Escherichia coli</i> ATCC 25922 and <i>Listeria innocua</i>	<ul style="list-style-type: none"> <li>Xenon flash lamp</li> <li>3 pulses/s</li> <li>Lamp-Product distance 5.8 cm</li> <li>Fluence levels of 1.02, 3.07, 6.14, 9.22, and 12.29 J/cm<sup>2</sup></li> </ul>	<ul style="list-style-type: none"> <li>Maximum inactivation levels of 3.37, 3.74, and 5.41 log, for <i>Listeria innocua</i>, <i>P. fluorescens</i>, and <i>Escherichia coli</i>, respectively</li> </ul>	[58]



The application of ultraviolet light for the disinfection of milk and dairy products was a subject of much research (Table 2). The material used in these studies was milk of different species [12,16,45,46,48–50], Kashar cheese [51], Fresh Kashar [52], Fiordilatte [53], fresh cheese [54], Hard cheeses [55], white American cheese [55], Ricotta [56] and Cheddar cheese [57,58]. A significant reduction in the number of various microorganisms in milk and dairy products was reported. The conditions of the UV treatment, i.e., dose, distance from the light, affect to a great extent the effectiveness of this technology in the reduction of bacteria count. The major drawback of UV radiation is limited penetration capacity and as a result this technology can be used merely for the surface decontamination of solid foods such as cheeses.

Few studies have examined the potential negative effects of UV light on the physico-chemical and sensory features of dairy products, necessitating additional research in this area. It has been discovered that using UV radiation in foods does not have a significant negative impact on milk and dairy products, particularly when used in small doses [45]. Higher UV doses, on the other hand, have been reported to cause nutritional depletion, consistency degradation, and the development of undesirable compounds [1,59].

The potential effect of UV-C and pasteurization on the properties of milk and dairy products are shown in Table 3.

**Table 3.** An overview of the effects of UV-C radiation and pasteurization on the components, physicochemical parameters, and sensory attributes of milk and dairy products.

Quality Parameter	Pasteurization	UV-C
Protein denaturation	Increases with temperature [60]	Little [61] or no [51] effect
Protein oxidation	No difference [62]	Little effect when treated with less than 4.2 J/cm <sup>2</sup> fluences [63]
Protein precipitation	No effect	Observed [59]
Fatty acid profiles	HTST treatment: almost no effect, UHT treatment: Considerable changes [64] especially decrease in PUFA content and increase in saturated FA, including low molecular FA	Almost no change [65,66]
Lipid oxidation	Little [62] or significant changes [67]; temperature-dependent	No changes [52]
Level of vitamin D3	No impact [68]	Increases [65]
Level of vitamin B12	Reduces [62]	No impact [62]
Thiobarbituric acid reactive substances	No significant difference [62]	Significant [66] or no [62] change
Level of aldehydes and hydrocarbons	Increases [69]	Increases [61]
pH	Decreases [62]	Mild or no impact [1,59,61]
Sensory characteristics	Decrease as temperature increases [70]	Dose-dependent [61,66]
Color	Changes more likely at a higher intensity (95 °C and 45 s) [64]	Unchanged [56,59] or significant changes [52]

In general, UV light treatment of food has been shown to have no negative consequences, particularly when applied in moderate quantities [71]. However, for certain foods, alteration and optimization of the UV radiation can be needed for the effective application of the procedure [44].

In the case of the FFA profile, some studies [62] showed a significant increase in %FFA after combined use of HTST pasteurization and UV light treatment. However, it was concluded that it may result from the possible damage to MFGM, which enhanced oxidative rancidity, due to excessive pumping of the milk.

In consideration of UV impact on sensory characteristics, which are very important factors determining consumer acceptance of food products, it must be stated that different findings were reported. In general, the dose of UV radiation to a great extent influences the degree of changes in sensory properties. For instance, Fernández et al. [61] reported differences in odor and flavor in Gouda and Manchego cheeses immediately after treatment with doses of  $\geq 4.2 \text{ J/cm}^2$  as a result of sulfur notes increase. They have also demonstrated that the level of sulfur volatile compounds and the corresponding sensory notes disappeared during cold storage. The study of Matak et al. [66] showed that ultraviolet irradiation at the wavelength 254 nm and a dose of  $15.8 \pm 1.6 \text{ mJ/cm}^2$  resulted in changes in the chemical and sensory properties of fluid goat milk. Whereas, Kharitonov et al. [65] showed no effect on fatty acid profile during UV treatment of milk either raw or pasteurized for 5–25 min which corresponded to the surface bactericidal irradiation dose 5.1–102 mJ/cm<sup>2</sup>.

The sensory defects that were reported after UV treatment was described as follows: tallowy flavor [62], manure, stinky, barnyard, and goaty aroma [66], burnt, off, strong and stale [72], burnt feather [51], and burned flavor [53].

## 5. Application Areas

When compared to fruit juices, milk and dairy products contain a considerably higher number of bacteria and spoilage microorganisms, making UV treatment more difficult. In brine, sweet, and acid whey, cumulative bacterial count reductions of 7 log CFU/mL were achieved, demonstrating the possible use of UV light technology in whey and brine in dairy production [9]. Some of the major applications of UVC are described below.

### 5.1. Air Disinfection

For the food processing sector, clean and fresh air is needed. In the fields of processing, packing, cooling, transportation, and ripening, UV technology may be used to prevent the dissemination by successfully inactivating the airborne pathogenic microorganisms [10]. A disinfection system to control the multiplication of fungus on objects inside manufacturing industries which has relatively high moisture, for instance, filters of recirculating air conditioners, was commercially launched. As molds generate spores and mycotoxins which can be distributed with the aid of an air conditioner throughout the entire manufacturing space and ultimately resulting in significant health concerns for both employees and products. This system is effective as it does not produce ozone. Moreover, UV-C light treatment can be applied to inactivate bacteriophages that are widespread in the dairy industry [73]. The low-pressure mercury vapor lamps are efficiently used as the source of UV light. This method's effectiveness relies upon region volume and UV light power [10].

### 5.2. Water Disinfection

UV-C radiation has been utilized over many years in the disinfection of water and was effective in killing various kinds of micro-organisms. This is a suitable technology in comparison to chlorine treatment [10]. Effluent from dairy processing plants may be processed without the use of toxic substances that are harmful to the environment [26]. UV technology can be used to sterilize drinking, processing, effluent, and saltwater [10]. As process water can be filtered and recycled using UV, the volume of wastewater released is significantly reduced which results, all discharges comply with municipal environmental laws [26].

### 5.3. Disinfection of Liquid Products (Milk, Syrup)

UV lamps could be used to disinfect the headspace of liquid holding tanks. If condensation occurs on the inside of liquid storage tanks and drips into the viscous product, molds or yeasts may grow in pools of diluted sweeteners. The low water content in full-strength syrup usually inhibits the development of contaminating microbes. The risk of contamination can be reduced when UV lamps shine on the syrup surface. A blanket of sterile air may also be used as an alternative [13].

Since the use of nonpasteurized milk is an important food safety issue in the cheese industry, the ability of UV rays to decontaminate without using heat will be a huge benefit [9].

Moreover, the impact of UV treatment on the degradation of aflatoxins in milk should be mentioned. The degradation ratio of AFM1, with the initial contamination level of  $0.1 \mu\text{g L}^{-1}$ , reached 96% when UV treatment was applied at the following conditions: 365 nm,  $0.05 \mu\text{Wm}^{-2}$ , 1 min, 1 mm thickness [74]. However, the thickness of the sample is a crucial parameter as the degradation efficiency of AFM1 in milk declines with increasing thickness of the milk sample.

#### 5.4. Disinfection of Packaging Materials

Microbiologically responsive bulk items, such as food, require packaging materials with low microorganism counts in particular. These materials surfaces can be treated in a variety of ways. UV light radiation treatment is a more successful and cost-effective approach than chemical and thermal treatments [24]. UV sterilizes the products and packaging materials used in food industries [75]. By using the necessary UV light doses to packaging materials such as packets, foils, cartons, films, cans, wrappings, bottles, seals, caps, and lids, the number of germs on the surfaces may be significantly decreased. Until filling or closing the lid, the containers can be exposed to UV light, or the prepared food can be subjected to UV-C light [10]. This could extend the shelf-life of the products, therefore, minimize production wastage and cost savings [73].

The transmission of UV-C light through polyethylene terephthalate (PET) and polyvinyl chloride (PVC) is minimal whereas polypropylene (PP) and polyethylene (PE) permitted ample transmission of UV-C light. PP and PE transmitted 80.4% and 59.6% of UV-C light, respectively, at a wavelength of 254 nm. It was also found that thicker films are unsuccessful in lowering pathogen numbers in both the PP and PE film tests. The UV-C reduction in population of *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes* was significantly higher when inoculated cheese slices were packed in 0.10 or 0.13 mm thick PP or PE films compared to non-packaged treated samples or those packaged with 0.07 mm films [57]. Also, commercially packaged sliced cheese brands usually have a film thickness of less than 0.04 mm. Therefore, the discussed film type and thickness (less than 0.07 mm) can be used to create decontaminating interventions that shield not only sliced cheese products but also a variety of processed foodstuffs from microbial contamination after manufacturing.

#### 5.5. Disinfection of Food Contact Surfaces

In dairy technology, cross-contamination of micro-organisms between machines and products is a major concern [10]. The growth of bacteria, fungi, and yeasts is easily obtainable in every area [76]. Surfaces of conveyors as well as other devices being used during preparing, processing, and storage regions may cause contamination and it can be disinfected with UV light [10]. UV light is a dry and biologically inert process that decreases the microorganism count by around 99.9% with minimum heating of the packing material [25]. Between the UV lamp and the area to be disinfected, there should be no obstruction. Since dirt absorbs radiation and thereby protects bacteria, the effectiveness of this application is therefore dependent on the sanitation of the material surfaces. As a result, it is possible to conclude that UV light should be used during the washing of dairy appliances [10].

### 6. Advantages, Disadvantages, and Limitations

While ultraviolet light has proven beneficial in food production, but still has a few drawbacks. Table 4 describes the key benefits, drawbacks, and shortcomings of Ultraviolet light treatment for food protection [1].

**Table 4.** UV radiation handling of dairy products: Advantages, disadvantages, and limitations [3,4].

Advantages	Disadvantages and Limitations
Low costs of repair, installation, and service	Poor productivity in foods with a high suspended solids content
Maintains the physicochemical features and nutritious value of the food without causing unpleasant sensory changes	Limited transmission of UV through opaque liquids
There are no negative consequences for the environment (no chemical residue, toxins, wastes)	Humans may be harmed by prolonged contact (eyes, burns, and skin cancer)
There is no heat generation (economical aspects)	Low penetration capacity into solid foods (limited use solely for the surface decontamination)
Possibility of combining with other non-thermal manufacturing methods	The rate of UV disinfection on food surfaces is difficult to estimate.
Possibility to operate in a continuous manner	The tendency of spores to get repaired after UV treatment
Low energy consumption	
Suitable for commercial processing	
Inactivation of pathogenic and spoilage microorganisms	

In contrast to chemical disinfectants, UV does not introduce toxins or contaminants into product water and therefore does not modify the disinfected fluid's chemical constituent, flavor, scent, or pH. It is particularly essential in the milk sector, where chemicals can produce off-flavors and modify the basic characteristics of the product by dosing the entering treated water. Since UV light does not have a residual impact, the ideal place for the treatment plant would be right before the usage. This assures the deactivation of incoming microbial pollutants and a very low likelihood of contamination after treatments. Other than this, it can also disinfect water that has direct contact with the product, thus allowing process water to be reused, cuts costs and improves efficiency without compromising quality standards [2].

There is another mode of UV light than continuous mode and it is termed as pulsed UV light mode. In this mode, the Ultraviolet light is held in a capacitor and discharged in the form of small pulses which enhances the immediate intensity of energy. As a result, pulsed UV light tends to generate more immediate energy in comparison to continuous UV light for the very same power provided. The inactivation of microorganisms by pulsed UV light irradiation is perhaps faster and better than continual UV-light, as the energy multiplies by many multiple sets. Furthermore, the continuous and pulsed UV sources create wavelength spectrums between 100–400 nm and 100–1100 nm respectively [45].

## 7. Future Technology: UV-LEDs

UV-LED lamps (UV-LEDs) are much smaller than traditional lamps, allowing them to be readily integrated into a variety of device designs [77]. UV-LEDs are being looked at as a possible competition and replacement for UV lamps. They have long been known to outperform traditional lamps, such as low pressure (LP) and medium mercury (MP) lamps, in terms of environmental friendliness and mercury-free operation [78]. UV-LEDs also emit high-intensity light immediately after being turned on; there is no warm-up time [77]. Some experiments comparing the effectiveness of UV-LED emission at various wavelengths with traditional lamps have been performed in terms of germicidal effectiveness [78].

Li et al. [79] used two UVC-LEDs emitting at 265 and 280 nm with an LP lamp (254 nm) to equate disinfection capacity and repair repression of *E. coli*. In comparison to 280 nm UVC-LED and LP lamps, the findings revealed that 265 nm UVC-LED showed the highest inactivation efficacy against *E. coli* [80].

Green et al. [81] also found that UVC-LEDs had the same degree of inactivation or higher than LP lamps (253.7 nm) for *E. coli*, *Listeria*, and *Salmonella* at an equal dosage of 7 mJ/cm<sup>2</sup> for 259, 268, and 275 nm wavelength. The UVC-LED wavelength of 268 nm was

found to be the most powerful in the sample. As a result, it was reported that the closer the LED wavelength to 280 nm, the better the UV-LED results [80].

Furthermore, another study revealed that UV-LEDs do not contain mercury and produce steady irradiation yield irrespective of temperature, which makes them useful even at refrigerated conditions [82].

UVC generated by LEDs is a new technology that may be used to compensate for the limitations of mercury lamps. One of UV-LED technology's main advantages is that it can be programmed to produce a certain wavelength. Whereas, UV lamps can only create a peak wavelength of 254 nm, as their inactivation ability has only been tested at that wavelength [77].

## 8. Conclusions

The application of UV technology can have many advantages in the dairy industry, including increased shelf life and microbial protection of dairy products, as well as energy savings due to the non-thermal technology. Nowadays, consumers look for goods that are manufactured in an environmentally friendly manner, so sustainability and environmental issues are becoming highly relevant. Ultraviolet processing can provide more desirable food items with fresh-like qualities. Many microorganisms are killed by short-wave UV-C radiation, which can be used to make food items safe. Despite the fact that UV light radiation can inactivate a broad variety of microorganisms, some elements of its usage in food should be examined. Currently, this technology is not commonly used in the dairy industry, although it may be in the future and, in order to maximize its impact on foodborne pathogens and spoilage microflora, the appropriate form of the lamp should be considered in each method. It would be of great importance to investigate the impact of this treatment on foods in terms of nutritive value as well bioavailability of nutrients.

The research showed that the MPM UV lamp is an economical and practical alternative especially for those companies that want to increase the quality of the final product. Some of the technologies are already well-established across the globe like disinfection of drinking water with UV light which is used for brewing and drug treatment. The studies in this review demonstrated the advantages of ultraviolet light, but there are some drawbacks to use it in dairy products, such as limited penetration potential, and contamination. To overcome contamination, UV Light Emitting Diodes could be of great potential instead of mercury or amalgam lamps, as these are more food plant-friendly.

Moreover, the application of UV technology in combination with other techniques, such as pasteurization, ultra-high pressure homogenization (UHPH) was reported. However, there is a need for further research in this area, in order to determine the optimal conditions for manufacturing safe products at a minimal shift in sensory and nutritive properties.

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