Provisional chapter

Ultraviolet Light Applications in Dairy Processing

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Additional information is available at the end of the chapter

Abstract

The main objective of this chapter is to discuss the potential of ultraviolet (UV) light applications in dairy industry. The principles, inactivation mechanisms, sources and devices of UV light are reviewed as well as its advantages and disadvantages. The factors affecting the efficacy of UV light are also discussed. The potential and present applications of UV light on disinfection of air, water, food contact surfaces and packaging materials are introduced. The efficacy and quality effects of UV light treatment for liquid dairy products are presented. In addition, as a promising application to prevent post-contamination after heat treatment, surface processing by UV light is emphasized. Besides its use for microbial inactivation by UV light, its possible uses such as creating novel dairy products are also introduced. The legal aspects on UV light for production, processing and handling of food briefly are given. Benefits, limitations and challenges of UV light for the future adaption in dairy industry are discussed.

Keywords: UV light, dairy products, processing, microbial inactivation, quality changes

1. Introduction

Dairy products create good growth conditions for a variety of microorganisms because they are rich in many kinds of nutrients including carbohydrates (especially lactose), lipids, proteins, essential amino acids, enzymes, vitamins and minerals. Therefore, producing safe dairy products are more challenging compared to producing many other foods.

Thermal processing is the most common decontamination method to ensure food safety and to prolong shelf life by eliminating the spoilage and pathogenic microorganisms and enzymes. In recent years, use of non-thermal technologies is increasing as an alternative to the thermal processing in food industry. Ultraviolet (UV) light, which is a non-thermal technology, has recently attracted a lot attention to improvement of food safety. Compared to thermal processing, this promising technology can provide consumers with minimally processed, microbiologically safe and fresh-like products with minor effects on the nutritional and sensory properties of the product. On the other hand, this technology must not replace hygiene, good manufacturing or agricultural practice.

UV light application can also be introduced as an alternative to the use of chemicals in food industry. Besides, the use of UV light does not generate chemical residues. Additionally, it offers some technological advantages especially in developing countries in a small-scale production due to its low maintenance cost, low installation cost and low operational cost with minimal energy use. The operation and cleaning of the treatment is quite easy. In spite of its many advantages, its low penetration power restricts the area of use in food industry. Furthermore, its inactivation efficiency may be reduced or prevented because of physical features of food. At high doses, it can create negative effects on quality and some vitamins. In order to obtain effective results, applications should be made considering these situations.

UV irradiation of milk was first used in the mid-1900s for the purpose of vitamin D enrichment [1]. Efficacy of UV light treatment has been studied in recent years and more and more research has also been carried out to evaluate the potential applications of UV light as a non-thermal alternative to thermal processing of milk. On the other hand, due to the confirmed success and convenience of thermal processing, potential processing alternatives for milk are still limited. The use of UV light must not only be considered for microbial inactivation but also for the development of novel dairy products. The UV-treated pasteurized cow's milk was authorized as a novel food in market by European Commission. It is reported that the treatment of the pasteurized milk with UV radiation results in an increase in the vitamin D3 (cholecalciferol) concentrations by conversion of 7-dehydrocholesterol to vitamin D3 [2].

Contamination of dairy products with microorganisms may occur at several stages of production, originating from a variety of sources during production. Although heat treatment is applied for inactivation of foodborne pathogens, dairy products especially cheese can be contaminated with undesirable microorganisms. After pasteurization process, handling of the curd, equipment, processing lines, packaging or storage rooms can result in cross-contamination with a variety of microorganisms. Even if good manufacturing practices are applied, surface applications of antimicrobial agents before packaging are commonly used to prevent spoilage and extend storage life for some dairy products. Instead of chemical preservatives, additional solution is needed to control the growth of microorganisms just before or after packaging of dairy products. Surface application of UV light after production can offer an attractive alternative method to eliminate or control the growth of post-processing contamination. Other promising uses of UV light are the disinfection of air and water used in dairy plant, and surface decontamination of food contact surfaces and packaging materials.

A lot of research is mainly focused on the application of UV light to reduce microorganisms in milk, and relatively little research focuses on the decontamination of the surfaces of solid dairy products. There is lack of information about the relation of quality and safety of dairy products. Thus, the application of UV light for various dairy products needs to be investigated in terms of both quality and safety in order to increase the use and reliability of UV light in industry. There is also need for research on various applications of UV light on dairy plant.

In this chapter, UV technology is explained in terms of its principles, inactivation mechanisms, and available UV light sources and reactors are reviewed. Then, the effects of UV light on the inactivation of microorganisms and changes in the chemical and nutritional aspects of various dairy products are discussed.

2. UV light technology

2.1. Principles of UV light technology

UV light includes the wavelengths from 100 to 400 nm on the electromagnetic spectrum. UV light can be subdivided into four regions according to their wavelength: UV-A (315–400 nm), UV-B (280–315 nm), UV-C (200–280 nm) and vacuum UV (100–200 nm). UV-C light has the most effective germicidal effect on microorganisms, such as bacteria, viruses, protozoa, fungi and algae [3, 4]. UV-C radiation in the range of 250–260 nm has the highest germicidal effect and ultraviolet energy at a wavelength of 253.7 nm shows the maximum effect, at which the absorption of DNA is stronger [3].

In principle, the photochemical reactions of biomolecules of microorganism primarily result in germicidal effect leading to inhibition of microbial growth or to inactivation of the cell. Germicidal effect of UV light on microorganisms occurs because of cross-linking between the bases of adjacent pyrimidine dimers in the same DNA strand [5]. This situation leads to inhibition of transcription and replication of nucleic acids, which is called clonogenic death [6, 7]. In some conditions, the metabolism can repair the DNA damage by photoreactivation or darkreactivation depending on the microorganism. Nevertheless, at high UV doses, the repair cannot be possible because of the wider damage [8].

2.2. Factor affecting the efficacy of UV light in food industry

The UV light efficacy depends on several factors related to UV equipment, UV sources, operating and measuring conditions, target microorganisms and material or food to be exposed in food industry, which are summarized as:

- UV light source and UV dose
- UV sensitivity of microorganisms
- The composition of target
- Physical properties of target (turbidity, opaque, color, etc.)
- Surface properties of target (roughness, dirt, etc.)

The germicidal effects of UV radiation primarily depend on the UV dose (J/m^2) which refers to the UV irradiance or UV intensity flux and is defined as the function of the intensity and time of exposure. The UV intensity (W/m^2) is the total radiation from the specified area. In most cases, as the exposure time and intensity of UV light increase and the distance from light source to target decreases, inhibition rate of cells increases. In addition, whether the sample is located directly under lamp or not affects the inhibition ratio of microorganisms for a group of samples.

The UV light sensitivity of the target microorganism is an important parameter for the selection of the UV light dose. Microorganisms have different structures due to their many characteristics. The necessary energy can vary for a certain species of microorganism according to strain, growth medium and stage of the culture. Therefore, different doses are needed for inactivation of various microorganisms. UV doses as D values required for reducing populations of various microbial groups are reported by Koutchma [9] in **Table 1**. Besides the sensitivity of microorganism its contamination level also affects the decontamination degree. In fact, in our research on decontamination of mold on the yoghurt surface, the population of mold affected the decontamination level of mold. This can be attributed to overlapping of microorganisms which prevents UV light from reaching the population at the lower layer.

In dairy industry, one of the most important problems for dairy industry is biofilm formation which occurs with colonization of microorganisms on the surface. These biofilms block the light transmission, act as a protective barrier for microorganisms against the light and reduce the efficacy of UV treatment [10, 11].

Physical, compositional and surface properties such as thickness, viscosity, density, optical properties, color differences, dirtiness, roughness etc. can change the process efficiency. UV light has a restricted penetrability. Transparent fluids such as water are effectively disinfected by UV light, whereas opaque fluids such as milk are affected less due to poor penetration depth of light, and microorganisms cannot be affected directly [11, 12]. The composition of target is also important for the efficacy of UV light. Dissolved solids, suspended particles, organic solutes, macromolecules especially proteins and fat globules in food have shadowing effect on target microorganisms and limit the penetration and efficacy of light [11–13] Treatment efficacy also depends on the characteristics of surface exposed to light and application to

Microbial group	***D* Value (mJ/cm^2)***
Enteral bacteria	2–8
Cocci and micrococci	1.5–20
Spore formers	4–30
Enteric viruses	5–30
Yeast	2.3–8
Fungi	30–300
Protozoa	60–120
Algae	300–600

*The D value is a measure of the resistance of a microorganism. It is given as the dose needed for an exponential decay of the target microorganism.

Table 1. UV inactivation doses measured at 253.7 nm for various microbial groups [9].

smooth surfaces is more effective than rough surfaces. The dirtiness and roughness can cause to form shadows and prevents direct access of light to the microorganism. Viscosity and density determine the effectiveness of the transfer and flow model of the liquid in the system, while optical properties affect the UV light transmittance [9]. Light transmission of food and packaging material in UV application to the surface of unpacked and packaged food is a critical factor for decontamination. Higher absorbsion of light is obtained in dark foods, causing decrease of available energy for microbial inactivation [11].

2.3. UV light sources

Choosing the right UV source can increase the efficiency of microbial inactivation by increasing UV light penetration. The first and natural source of UV light is the Sun. The Sun emits radiation across a wide range of wavelengths. Other UV light sources are lamps. Many alternative UV light sources have been developed, such as low pressure mercury (LPM), medium pressure mercury (MPM), low pressure high output mercury lamp-amalgam type, mercury free amalgam lamps, pulsed-light (PL) and excimer lamps. LPM lamps are commonly used in food applications [14].

Mercury lamps have been the sources of radiation in most UV-based disinfection systems. The low and medium pressure mercury UV lamp sources are reliable sources for disinfection applications which are beneficial for their performance, and low cost. They are based on the vapor pressure of mercury while the lamps are operating. LPM lamps are designed to deliver a continuous monochromatic light at 254 nm. MPM lamps emit germicidal polychromatic light between 200 and 300 nm [9]. A breakthrough for economic UVC generation is the discovery of low pressure amalgam lamps [15]. This technology has recently been developed and incorporated into disinfection applications. The mercury emissions from lamps to the environment have encouraged the investigation of mercury-free lamps [9]. Xenon lamps are used in the Pulsed light UV technology. These lamps emit flashes in a short period of time. They have a broad spectrum of radiation between 180 and 1100 nm. Another UV light source is excimer lamps, which can emit pulsed light at 248 nm. It is possible to emit light in desired wavelength by using various gases such as He, Ne, Ar, Kr, Xe in the excimer lamps. The excimer lamps can be operated even at very low surface temperatures [7].

2.4. UV light devices

UV light applications are carried out with different equipment for solids or liquids: UV reactor designs for liquids according to flow types and UV cabinet designs for solids. It is necessary to increase the absorbed energy to the maximum level by developing the design of UV light device with appropriate lamp and size in order to achieve the desired effect.

2.4.1. Reactors

Reactors are devices used for UV light application to liquids. UV reactor contains UV lamps inside. Each UV lamp is in a separate protective quartz tube to prevent the direct contact with liquid. The liquid flowing through the UV reactor is exposed to UV rays emitted from lamps.

Thus, the microorganisms in the liquid become ineffective. In the selection of UV reactors, the physical, chemical and microbiological properties of the liquid to be disinfected and the amount of the liquid passing through are the most important parameters. In this context, the UV light dose should be determined according to the nature of the fluid and the target microorganism. In addition, to increase the efficiency of disinfection, parameters such as sediment and turbidity in liquid should be removed with sensitive filters.

The flow pattern of liquid in the UV reactor has also significant effect on total UV dose due to the differences in the position and residence times of the microorganisms in certain regions of the irradiated field [9]. The inactivation of microorganisms increases using turbulent flow in continuous flow UV reactors [16, 17].

The first reactor design is a thin film UV reactor. Thin-film reactors are characterized by laminar flow with a parabolic velocity profile [16]. Another reactor having laminar flow is laminar Taylor-Couette UV reactor. In both reactors, the two cylinders in the system are intertwined. While the system is running, the gap between the cylinders is filled with liquid product. In the thin film reactor, the UV lamps are placed in the inner cylinder, whereas in laminar Taylor-Couette UV reactor the lamps are placed on the outer cylinder and the inner cylinder turns around by creating whirlpools [18, 19]. The second design approach is turbulent flow reactors. They increase the turbulence within the reactor in order to make the liquid close to UV light source. In another approach, the UV reactor called Dean flow reactor includes a coiled Teflon tube with UV lamps and reflectors placed both inside and outside the tube, which are used to promote additional turbulence and to create a secondary swirling flow, also known as "Dean effect" [9].

2.4.2. UV cabinets and tunnels

UV cabinets are devices developed for UV light applications on the surface of solids. The number and position of lamps in the UV cabinet are the most critical factors for the disinfection of entire food surfaces. The UV processing units for solid food was well schematized by Manzocco and Nicoli [11]. If one side of the solid food is exposed to UV light, the food is placed on a support. For the exposure to the top and bottom sides, the food can be placed on a film or turned upside down during treatment. If all the surfaces of the solid food are exposed to the UV light at the same time, it is needed to increase the number of lamps and place the food on a film. For example, in dairy industry, only upper surface of the yoghurt in package is enough to be treated by UV light while all surfaces are exposed for many cheeses. If there is no food support, the product flows near the lamps coated with waterproof quartz tubes in a vessel containing water.

It is also possible to design a tunnel with a dynamic system moving with the food. In this type of cabinet system or tunnel, the food material is conveyed through UV tunnel and taken from the other end. The width and height of the tunnel are designed according to expectations of user. UV application time is adjusted by conveyor speed. Such tunnels provide convenience for industrial use. They are added to the desired point of production line and their use in the system is practical.

2.4.3. Pulsed UV light

Pulsed UV light is a modified and improved version of the UV-C light. Pulsed UV light is an application using devices containing ultraviolet lamps that emit ultraviolet light at high power at regular intervals. It is applied in a very short time (1 μs–0.1 s) in the range of 200–1100 nm [7]. In this technology, combined effect of photochemical, photothermal and photophysical conditions occurs and microorganisms become ineffective [20].

3. The applications of UV light in dairy industry

3.1. Disinfection of air in the production area

Clean and fresh air is necessary for food processing area. UV technology can be used for preventing the spread of airborne diseases by inhibition of airborne pathogenic microorganisms in the field of production, packaging, cooling, storage and ripening. For this purpose, low pressure mercury vapor lamps are successfully used as UV light sources. The efficiency of this process depends on the volume of the area and the power of the UV lamp.

3.2. Disinfection of water used during processing

UV-C light has been used to disinfect water for several years and has become a successful process that eliminates several types of microorganisms. UV-C technology is a good alternative to chlorine disinfection. In dairy industry, it is possible to use the UV systems for the disinfection of drinking water, process water, waste water and brine.

3.3. Surface applications of packaging materials and equipment

3.3.1. Packaging materials

In food industry, the use of UV light for decontamination of packaging material is becoming widespread. The number of microorganisms on the surfaces of packaging materials such as boxes, cartons, foils, films, wrappings, containers, bottles, caps, closures and lids can be reduced or eliminated by applying the appropriate UV light doses. The packages can be treated with UV light before filling or closing the lid or the packaged food can be exposed to UV-C light. The effectiveness of UV treatment is better on smooth surfaces. On the other hand, the UV light cannot reach every spot because of shadowing on irregular surfaces.

Plastic materials such as polyethylene terephthalate (PET), polyvinylchloride (PVC), polypropylene (PP) and polyethylene (PE) are increasingly being used as packaging materials for dairy products. These materials have many advantages such as availability, low cost, transparency, thermal adhesiveness and being a good barrier against oxygen, carbon dioxide, anhydrite and aromatic compounds [21]. Due to different constructions, thicknesses and various properties of these packages, their UV-C permeability is different. When the packaged food is UV treated, this permeability becomes more important. The UV permeability of PP/PP (50 μm), bone guard bags (BG) (25 μm), polyamide/polyethylene (PA/PP) (40 μm) and oriented polypropylene (OPP) (40 μm) were reported as 64, 67, 8 and 83%, respectively, by Manzocco and Nicoli [11]. However, there was no UV-C permeability of OPP/PE, PET/PE, Polyester and oriented polypropylene/cast polypropylene (OPP/CPP).

3.3.2. Food contact surfaces

The cross-contamination of microorganisms from equipment to the products is an important issue in dairy technology. UV light can be used to provide disinfection of surfaces of conveyor and other equipment used in preparation, production and, storage areas. For an effective inhibition, microorganisms must be exposed to UV light directly. There should be no obstruction between the UV source and the surface to be sterilized. The success of this application also depends on the cleanliness of the material surfaces because dirt would absorb the radiation and hence protect the bacteria. Therefore, it is possible to say that UV light must be applied after cleaning processes of the dairy equipment.

4. Efficacy of UV light on dairy products

4.1. Liquid dairy products

Raw milk from healthy cows contains relatively few bacteria, but can be contaminated easily during handling and/or storage from a variety of sources (persons, containers, machines, pipelines etc.). Milk is also suitable for the growth of many pathogenic microorganisms carrying potential risk of transferring diseases from animals to humans. The storage conditions of milk before further processing influence the microbial population. To limit the bacterial population in the raw milk, applying effective cooling and good hygiene practices are essential. Heat application is traditionally used to kill the pathogenic bacteria and reduce the others, and extend the shelf life of milk. The success and convenience of heat treatment is proved for milk. Thus, the alternative technologies to heat treatment cannot be integrated into dairy industry easily despite studies in this field.

In literature, the results of the application of UV light technology as an alternative to thermal processing are contradictory. Some authors reported that UV light can be used effectively for the reduction of certain bacterial pathogens in milk. Cilliers et al. [22] showed the similar level of microbial efficacy obtained in milk processed with pasteurization (high temperature short time), UV light and their combination. Similarly, Crook et al. [23] investigated the effect of UV-C light on the inactivation of seven milkborne pathogens such as *Listeria monocytogenes, Serratia marcescens, Salmonella senftenberg, Yersinia enterocolitica, Aeromonas hydrophila, Escherichia coli* and *Staphylococcus aureus*. Of the seven milkborne pathogens tested, *L. monocytogenes* was the most UV resistant, requiring 2000 J/L of UV-C exposure to reach a 5-log reduction, and the most sensitive bacteria was *S. aureus*, requiring only 1450 J/L to reach a 5-log reduction. Matak et al. [24] reported that UV-C treatment could be used for the reduction of *L. monocytogenes* in goat's milk and application of a cumulative UV dose of 15.8 ± 1.6 mJ/cm^2 to goat milk led to more than

5 log reduction in *L. monocytogenes*. Engin and Karagul Yuceer [25] reported the UV irradiation was as effective against certain microorganisms as heat treatment. The authors applied the UV light as an alternative to heat treatment to bovine milk using a custom-made UV system and the growth of coliform bacteria, *E. coli* and *Staphylococcus* spp. was completely reduced by UV treatment. Similar results were found for inactivation of *S. aureus* in milk using pulsed UV light treatment by Krishnamurthy et al. [26]. It was shown that the pulsed UV light can be used as an alternative method to inactivate *S. aureus* in milk. Choudhary et al. [27] showed that *E. coli* W1485 was reduced by 7.8 log in skimmed milk, but 4.1 log in full-fat raw milk with UV light treatment by using coiled tube reactor. They also reported that *Bacillus cereus* endospores were more resistant than *E. coli* W1485 and that these endospores were reduced by only 2.72 and 2.65 log in skimmed milk and full fat milk, respectively. In another study, inactivation of *E. coli* O157: H7 in bovine milk exposed at 254 nm was higher than at 222 and 282 nm at the same UV doses. The reductions in *E. coli* O157:H7 at 254 nm using the doses of 5, 10 and 20 mJ/cm^2 were 1.81, 2.38 and 2.95 log respectively [28].

UV light efficacy on the reduction of total number of microorganisms is also proved in different studies [29–31]. Reinemann et al. [29] reported that UV treatment to raw cow's milk achieved more than 3 log reduction in total numbers of bacteria. The highest reduction was found for coliform bacteria followed by pyschrotrophs, thermodurics and spore formers. Microbial counts of UV treated milk (continuous turbulent flow system, 880 and 1760 J/L doses) were lower compared to those of control milk [30]. UV-C treatment of raw cow milk was capable of reducing total viable count by 2.3 log [31]. UV light treatment in milk can be used as a method to reduce the number of psychrotrophic bacteria to prolong the storage period of cooled raw milk [9, 22, 26, 32]. In contrast, Altic et al. [33] and Donaghy et al. [34] concluded that the UV light technology cannot be an alternative to current pasteurization process for milk. The authors found less than 1 log reduction in *Mycobacterium avium* ssp. *paratuberculosis* in milk by UV treatment. In both studies, the use of UV light was not very effective in reducing the number of *Mycobacterium avium* ssp. *paratuberculosis*.

UV radiation may be used for an alternative to pasteurization of cheese whey, valuable liquid dairy product, if the lamp fouling problem is solved [35]. In their study, for destruction of microbial population of 5.95×10^6 cells/ml in cheese whey, more than 3.3, 2.1 and 0.8 h residence times were needed in the first, second and third UV reactors, respectively. However, fouling was seen as a major problem when the temperature of cheese whey increased. As a solution to the fouling problem, coil reactor series were recommended instead of conventional reactor by Singh and Ghaly [36].

Table 2 summarizes the microbial inactivation and technical characteristics of UV light system used for milk that were reported in the studies cited above.

4.2. Surface applications of dairy products

Surface of dairy products such as cheese, yoghurt, etc. is the primary location for microbial access and quality depletion during processing and storage period. Most of the chemical, oxidative, microbial and enzymatic reactions take place on the surface of the dairy product

	Type of UV reactor	UV treatment	Test microorganisms	Results/achieved inactivation	Studies
Bovine milk-full cream	Surepure40 turbulent flow commercial system	**Dose:** 430 mJ/cm^2	Aerobic plate count Coliform bacteria *E. coli* Aerobic mesophilic spores Anaerobic mesophilic spores Aerobic thermophilic spores Anaerobic thermophilic spores	Similar level of microbial efficacy with high temperature short time heat treatment	[22]
Milk	Thin-film turbulent flow-through pilot system	**Dose:** 0–5000 J/L **Flow rate:** 4300 L/h	*Listeria monocytogenes* *Serratia marcescens* *Salmonella senftenberg* *Yersinia enterocolitica* *Aeromonas hydrophila*	Potential as a non-thermal method to reduce microorganisms	[23]
Goat milk	CiderSure 3500 apparatus	**Doses:** 0–20 mJ/cm^2	*Listeria monocytogenes*	Suggested for the reduction of *L. monocytogenes* in goat's milk	[24]
Bovine milk	Custom-made	**Intensity:** 13.87 J/mL (per single pass) **Flow rate:** 1090 mL/min	Mesophilic aerobics Coliform bacteria *E. coli* *Staphylococcus* spp. Yeasts/Molds	A major effect on total coliforms, *E. coli* and *Staphylococcus* spp.	[25]
Raw milk	Pulsed light sterilization system	**Flow rates:** 20, 30, 40 ml/min *Polychromatic 100–1100 nm*	*Staphylococcus aureus*	A potential method for inactivation of *Staphylococcus aureus* in milk	[26]
Full fat raw milk and skimmed milk	Coiled tube	**Dose:** 11.187 mJ/cm^2 **Intensity:** 1.375 mW/cm^2	*Escherichia coli* W1485, *Bacillus cereus* endospores	Higher resistance of *B. cereus* endospores to UV than *E. coli* W1485 cells, Higher inactivation efficiencies of both bacteria in skimmed milk than full fat raw milk	[27]
Bovine milk	—	**Dose:** 5–20 mJ/cm^2 **Wavelength:** *222, 254, 282 nm*	*E. coli* O157:H7	Higher inactivation efficiency and lower reactivation ratio at 254 nm than 222 and 282 nm	[28]
Raw cow milk	Pure UV system	**Doses:** 0.23, 0.46, 0.93, 1.9, 3.7, 7.4 and 1.5 kJ/L **Flow rate:** 1.1 L/s	Total viable count, Psychrotrophics Coliform bacteria Thermodurics	Suggested for reducing of bacteria not susceptible to thermal treatment and psychrotrophic in refrigerated milk stored for prolonged periods	[29]
Cow's Milk	Continuous turbulent flow	**Doses:** 880 and 1760 J/L	Aerobic plate count Aerobic sporeformers Coliform bacteria	Lower counts in UV-treated milk	[30]
Raw cow milk	Continuous flow coiled tube	**Dose:** 16.822 mJ/cm^2 **Intensity:** 1.375 mW/cm^2	Total viable count	2.3 log reduction	[31]

	Type of UV reactor	UV treatment	Test microorganisms	Results/achieved inactivation	Studies
Whole and semiskim milk	Laboratory-scale	**Dose:** 1000 mJ/ml **Flow rate:** 168 ml/min	*Mycobacterium avium* subsp. *paratuberculosis*	Not an alternative to current pasteurization	[33]
UHT milk	Pilot-scale	**Doses:** 0–1836 mJ/ml **Flow rate:** 4000 l/h *30 W UV C output*	*Mycobacterium avium* ssp. *paratuberculosis*	Not an alternative to current pasteurization	[34]
Cheese whey	Tubular-type	**Gap sizes:** 18, 13, and 6 mm	Total viable count	May be used on-line sterilization of whey if the proper reactor gap size and the appropriate residence time are used	[35]
Sterile whole milk	Pilot-scale UV light continuous flow-through unit	**Dose:** 45 J/cm^2 **Flow rate:** 65 l/min	*Listeria innocua* *Mycobacterium smegmatis,* *Salmonella serovar typhimurium* *E. coli* *S. aureus* *Streptococcus agalactiae* *Acinetobacter baumannii*	Significant reduction for all bacterial species tested except *M. smegmatis.*	[37]

Table 2. Efficacy of UV light application for liquid dairy products.

and cause undesirable changes that may reduce shelf life of the product. To prolong shelf life and reduce microbial growth and oxidative degradation of dairy products, some types of preservatives are used according to legislation limits. However, a negative public reaction is growing over the addition of chemical preservatives to foods. Although UV light application is limited for liquid dairy products because of the confirmed success of heat treatment, it is very promising for the surface applications of dairy products instead of using chemicals.

Light exposure of solid foods affects only a thin surface layer of the product, while a minimum light dose can reach its internal part [11]. Due to low penetration depth, UV light is suitable for inactivation of surface microorganisms to ensure product safety and extend shelf life with minor effects on chemical and nutritional values in dairy products. However, limited data are available on the effects of UV light on the surface decontamination, quality and organoleptic properties of dairy products.

In the surface applications of UV light, all targeted surfaces of the food must be exposed to UV light. For this purpose, flat products can be turned to allow exposure of both sides or placed on a supporting net or a film. Additional lamps can also be placed on the product sides [11].

One of the most common problems in cheese technology is molding on the surface. Application of UV light on cheese surface just before packaging can be a good solution to prevent mold growth. Lacivita et al. [38] reported 1–2 log reduction on *Pseudomonas* spp. and *Enterobacteriaceae* by applying UV light on the surface of cheese without changes in color, texture and surface appearance. Authors concluded that this treatment showed an interesting surface microbial decontamination and prolonged cheese shelf-life with minimum transmittance inside the product. Similarly, Sık et al. [39] used different UV doses on the surface of Kashar cheese and application of UV-C (≥1.926 kJ/m^2) was able to achieve approximately 2–3 log reduction in mold population. Can et al. [40] investigated the efficacy of pulsed UV light for inactivation of inoculated *Penicillium roqueforti* and *Listeria monocytogenes* of hard cheeses packaged and unpackaged. The reduction of *P. roqueforti* was 1.32 log and 1.24 log in packaged and unpackaged cheeses, respectively. *L. monocytogenes* was reduced by over 2.8 log for packaged and unpackaged cheeses. They reported that pulsed UV light has potential to inactivate *P. roqueforti* and *L. monocytogenes* on the surface of hard cheeses. Proulx et al. [41] examined the effectiveness of pulsed-light (PL) treatment on the inactivation of the spoilage microorganisms on cheese surface in order to determine the effects of inoculum level and cheese surface topography and the presence of clear polyethylene packaging. Inoculated cheese samples were exposed to PL doses of 1.02–12.29 J/cm^2. *Listeria innocua* was the least sensitive with a maximum inactivation level of 3.37 log, followed by *P. fluorescens* with a maximum inactivation of 3.74 log and *Escherichia coli* ATCC 25922 with a maximum reduction of 5.41 log. The inactivation reached a plateau after three pulses (3.07 J/cm^2). The authors concluded that PL treatments through UV-transparent packaging and without packaging consistently resulted in similar inactivation levels.

After packaging of cheese, application of UV-C would be a good safety method to inactivate hazardous microorganisms on cheese surfaces. For this application, the transmission of UV light

Dairy product	UV treatment	Test microorganisms	Results/achieved inactivation	Studies
Sliced cheddar cheese	5 UV-C lamps **Intensity:** 3.04 mW/cm^2 **Treatment time:** 1 min	*Escherichia coli* O157: H7, *Salmonella Typhimurium, Listeria monocytogenes*	Suggested use of PP or PE films in conjunction with UV-C radiation for controlling foodborne pathogens	[21]
Fiordilatte cheese	**Intensity:** 20 W/m^2 **Treatment time:** up to 750 s	*Pseudomonas* spp., Enterobacteriaceae	About 1–2 log reduction without changes in color, texture and surface appearance	[38]
Kashar cheese	**Intensity:** 32.1 W/m^2 **Treatment time:** up to 300 s	Molds	Promising for surface mold reduction of pasta-filata cheese, but off-flavor at high doses	[39]
White American cheese	Pulsed Light Sterilization System **Distances:** 5, 8, and 13 cm **Treatment time:** up to 60 s	*Penicillium roqueforti, Listeria monocytogenes*	Suggested use of pulsed UV light for inactivation of *P. roqueforti* and *L. monocytogenes* on the surface of hard cheeses	[40]
Cheddar, process cheese	Bench top pulsed light unit **Doses:** 1.02 to 12.29 J/cm2	*Pseudomonas fluorescens*, *Escherichia coli ATCC 25922, Listeria innocua*	Suggested application for PL for decontamination of the cheese surface through UV-transparent packaging and without packaging	[41]
Set-type yoghurt	Batch UV light cabinet **Intensity:** 32.1 W/m^2 **Treatment time:** up to 600 s	Molds	Promising for surface mold reduction of yoghurt, but increased oxidation levels and off-flavor at high doses	[42]

Table 3. Effects of surface application of UV light on different dairy products.

through plastic film packaging and the thickness of packaging film are important parameters for eliminating or controlling growth of foodborne pathogens on the surfaces. Ha et al. [21] applied UV-C light for inactivation of food-borne pathogens on sliced cheese packaged with different types and thicknesses of plastic films. The authors' results showed that adjusted 0.07 mm thick PP or PE film packaging in conjunction with UV-C radiation can be effectively used for controlling foodborne pathogens including *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes*.

There has been really limited research carried on the surface decontamination of other dairy products with UV-light. Similar to cheese, post-processing contamination of the mold on set type yoghurt shortens its shelf life. That is why, the surface of set-type yoghurt samples contaminated naturally were exposed to UV light at different doses in a batch UV light cabinet to inactivate the mold at Ege University by chapter authors Koca and Saatli [42]. They indicated that UV light can be promising for mold inactivation of surface set-type of yoghurt and that higher doses of UV light increased oxidation levels slightly in yoghurt. Studies about the surface application of UV light to dairy products are summarized in **Table 3**.

5. Quality effects of UV light on dairy products

Milk is rich in protein, unsaturated fatty acids, metal ions, oxidases and other pro-oxidants that induce oxidative changes for lipids or protein in raw milk [43]. Dairy products are known as light sensitive products and light may decrease the nutritional value, the content of unsaturated fatty acids and vitamins especially riboflavin and α-tocopherol of the product [44, 45]. Figuring out the suitable UV doses which reduce the microbial growth enough without causing any sensorial defects is challenging. Consumer acceptance of UV treated dairy product will ultimately determine the acceptability of UV technology as an alternative or adjunct to commercial thermal treatment.

Limited research has been carried out on the effects of UV treatment on a biochemical and chemical perspective of dairy products. Some authors concluded that chemical composition of milk is not significantly affected by UV light application [43, 46]. Similarly, Cilliers et al. [22] concluded that UV light application to bovine milk did not affect most of the macro and micro-components, but reduced the cholesterol level compared to pasteurized milk. UV light application produced no change in raw milk with regard to the composition, free fatty acid profile, oxidation, or protein profile [46]. Another study showed that UV treatment to raw milk increased pH and reduced lightness, but did not change soluble solids content [43].

Lipid oxidation is known to be dependent on light exposure. In general, as the UV light dose increases, the oxidation degree and accordingly off-flavor increase in dairy products. In relation to oxidative changes of milk with UV light, increase in UV dose resulted in an increase in TBARs and acid degree values of the goat milk samples [47]. Similarly, higher values of malondialdehyde and other reactive substances in UV-treated raw cow milk were reported as an indication of oxidative degradation by Bandla et al. [31]. In contrast, Hu et al. [43] found no change in the values of TBARs of UV-C treated raw milk (11.8 W/m^2 dose), but an increase in its protein oxidation.

The nutritional value and sensory attributes of dairy products may change with the light exposure depending on the oxidation of lipids and protein and light sensitivity. Jung et al. [48] reported 'sunlight' flavor, which is characterized by a burnt and oxidized odor in milk after 2 or 3 days of UV application. Oxidized flavor in milk perceived as off-flavor results from oxidation of unsaturated fatty acid residues in milk lipids and phospholipids. The photodegradation of proteins also results in off-flavors and organoleptic changes in milk [14].

UV-C treatment has the potential to accelerate the formation of the volatile compounds in milk. In fact, Hu et al. [49] found an increase in the variety and content of volatile compounds of cow milk by the application of UV light (at 254 nm, 11.8 W/m^2). Nevertheless, no major differences were observed in terms of aroma-active compounds of milk following the UV treatment, but some new volatiles were generated [25]. In another study, no difference was found between the odor of untreated and UV treated cow milk but after 1 day of storage the UV-C treated sample had a significantly different smell from that of untreated milk [31]. The flavor defects in cow milk were clearly differentiated by panelists [30]. Cilliers et al. [22] noted the 'tallowy' flavor descriptor for the UV treated milk. In another study, odor of UV treated milk was described by panelists as manure, stinky, barnyard, and goaty [47].

Vitamin A, carotenes, vitamin B12, vitamin D, folic acid, vitamin K, riboflavin (vitamin B2) tocopherols (vitamin E), tryptophan, and unsaturated fatty acid residues in oils, solid fats, and phospholipids are well known as light sensitive nutrients [50]. The first research was carried out the increase in Vitamin D in milk. European Food Safety Authority (EFSA) concluded that the treatment of the pasteurized milk with UV radiation results in an increase in Vitamin D. The effects of UV light on vitamins A, B2, C, and E in cow and goat milk were assessed by Guneser and Karagul Yüceer [51]. UV light sensitivities of vitamins for the milk samples were found as C > E > A > B2. Authors concluded that UV light application reduces the vitamin content and their reduction levels depend on the initial amount of vitamins and the number of passes through the system. In contrast to most research, Cappozzo et al. [46] found that UV light, HTST and UHT processing of raw milk caused to decrease in vitamin D content to undetectable levels. UV light treatment reduced the content of vitamin A from 24.5 at 1045 J/L to 14.9% at 2090 J/L, but HTST and UHT processes resulted in a large reduction (96.8 and 100%, respectively). In bovine milk, vitamin B12 and riboflavin were not reduced by UV application in contrast to thermal treatment [22].

Protein oxidation in dairy systems has an important effect on protein properties and functionalities. UV light can cause the degradation or modification of proteins that lead to changes in solubility, sensitivity to heat, mechanical properties, and digestion by proteases [14]. In fact, Semagoto et al. [52] found changes in the solubility and color of milk protein concentrate. UV induced photo-oxidation decreased the solubility and contributed to the discoloration of milk protein concentrate during storage. Furthermore, exposure to UV irradiation resulted in denaturation of whey proteins but this denaturation degree is low when compared to UHT or HTST [53].

Application of UV light to raw milk used in the production of dairy products may also influence the quality of product. Some changes in rheological properties of yoghurt from UV treated milk were generated by UV treatment [25]. In this research, higher viscosity and lower syneresis were found in the sample made from UV-treated milk compared to that of heat treated milk due to the effects of UV light on the molecular properties of proteins in milk sample. It is noted that UV treatment to raw milk limits the inactivation of native enzymes and the denaturation of whey proteins and the defects in products related to high initial bacterial counts, and shortens the ripening period of cheese. In contrast, Cilliers et al. [22] found no significant differences in the enzyme activity, α-amino acid contents and protein profiles of UV treated and pasteurized milk.

There are few data on the quality changes for surface application of UV light on dairy products such as cheese and yoghurt. Cheese treated with pulsed light at moderate (30 s at 8 cm) and extreme (40 s at 5 cm) conditions had higher values of TBARs compared to mild (5 s at 13 cm) treated and untreated samples, and the changes in color and chemical quality of cheeses were not significantly different after mild treatments. Additionally, when compared with packaged samples, unpackaged samples had slightly higher malondialdehyde values [40]. The application of UV light to surface of Kashar cheese slightly increased redness and yellowness values as the dosage of UV light increased, but these slight changes were not perceptible by the panelists [39]. However, they found that exposure of higher doses (9.630 kJ/m^2) of UV-C light led to photo-oxidation and accordingly caused flavor defects. In the other study, UV light application in batch UV cabinet to set-type yoghurt surface did not cause any significant changes with respect to hardness and color parameters [42]. On the other hand, the off-flavor was detected by panelists for the yoghurt samples treated at high dosages of UV light.

6. Legislations on UV light application in the production, processing and handling of food

The Food and Drug Administration, Department of Health and Human Services (US FDA) approved the use of UV radiation for controlling surface microorganisms of food or food product, sterilization of water used in production and reduction of human pathogens and other microorganisms in juice products under specific conditions defined by Code 21CFR179.39 [54]. These conditions are limited to the use of low pressure mercury lamps emitting 90% of the emission at a wavelength of 253.7 nm. If the pulsed UV is considered, in code 21CFR179.41, US FDA [55] approves the use of pulsed UV light for the surface microorganism control at doses not exceeding 12 J/cm^2 using xenon flashlamps, which are designed to emit broadband radiation consisting of wavelengths covering the range of 200–1100 nm, and operated no longer than 2 milliseconds for pulse duration. In addition, the minimum treatment required to obtain intended technical effect is used for food.

In European Union, UV light is accepted as irradiation [14]. The use of irradiation is limited but authorized in many European countries. According to European Commission, treating food with ionizing radiation may be authorized if there is reasonable technological need, it poses no health hazard and benefits consumers, and if it does not replace hygiene, health or good manufacturing or agricultural practice. Irradiated food or ingredients must be labeled. The UV-treated of pasteurized cow’s milk was authorized as novel food in market by EC because of the increase in vitamin D. It needs to be designated as “UV- treated milk” and also “contains vitamin D produced by UV-treatment” [2].

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