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Surface decontamination of white cheese by pulsed UV light treatment

Oberflächendekontamination von Weißkäse durch gepulste UV-Lichtbehandlung

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Summary

Surface contamination of cheese varieties with pathogenic microorganisms is a potential risk in dairy industry. Pulsed UV (PUV) light is a method, which provides rapid inactivation of a wide range of microorganisms on foods. In this study, white cheese inoculated on top surface with *Staphylococcus aureus* or *Escherichia coli* O157:H7 was exposed to PUV light. Treatment parameters were time (5, 15, 30, 45, 60 s) and distance from the quartz window of xenon lamp (5, 8, 13 cm). The 60 s-8 cm treatment (91.22 J/cm^2) resulted in the highest inactivation level without visually altering the appearance of white cheese. After this treatment, approximately 1.31 and 2.20 $\log_{10}$ reductions (cfu/cm^2) were obtained for *S. aureus* and *E. coli* O157:H7, respectively. Lipid oxidation, pH, and moisture content, except the color parameters, remained unchanged ($p>0.05$) after the 60 s-8 cm treatment. Only 1.75 % of the PUV light reached to a depth of 0.5 cm in white cheese after treatment at 5 cm. These findings indicate that although PUV light is able to reduce pathogen counts of white cheese, this technology can only be utilized for surface decontamination.

Keywords: *Escherichia coli* O157:H7, *Staphylococcus aureus,* microbial inactivation, pulsed UV light, white cheese

Introduction

Being one of the most versatile and most consumed dairy products in the world, cheese may pose a significant health risk if microbial contamination occurs during processing and/or post-processing steps. The pathogens of concern in cheese include *Listeria monocytogenes, Staphylococcus aureus, Escherichia coli* O157:H7 and *Salmonella* spp. (O'Brien and O'Connor, 2007; Kousta et al., 2010; Kim et al., 2018). Pathogenic microorganisms may be present in raw milk, which might survive during the cheesemaking process, or transferred to cheese from workers, utensils, or equipment due to poor sanitation practices (Okpala et al., 2009; D'Amico and Donnelly, 2017). In fact, the risk of product contamination in cheese plants is considered to be higher during processing compared to fluid milk production due to the increased exposure to the environment (D'Amico, 2014).

The use of antimicrobials is a common practice in cheese industry to prevent or delay microbial growth in the product. Preservatives such as sorbic acid, sorbates, nisin, nitrates, propionic acid and propionates, lysozyme, and natamycin are allowed to be used for a variety of cheeses (Codex Alimentarius, 2008). However, there are still concerns arising from the use of antimicrobials in foods. For example, the consumption of antimicrobials was found to be positively associated with the antimicrobial resistance in both animals and humans (ECDC, EFSA, and EMA, 2017). Also, consumers tend to avoid foods containing additives and prefer foods that are supposed to be natural (Bearth et al., 2014; Szücs et al., 2014; Román et al., 2017).

Researchers continue to focus on preservation methods that allow the foods to be processed without heat or chemical additives. Among these methods, plasma-based techniques (Yong et al., 2015a; Yong et al., 2015b), UV-C light (Ha et al., 2016; Kim et al., 2016; Lacivita et al., 2016), and high hydrostatic pressure processing (Ávila et al., 2016) have been applied to various cheeses. Pulsed UV (PUV) light is another emerging technology, which is considered to be non-thermal for short treatment times (Keklik et al., 2009). PUV light technology utilizes an inert gas lamp energized to deliver intense light pulses in the spectrum from deep-UV to infrared wavelengths. The intense light pulses are capable of inactivating a broad range of microorganisms by photochemical, photophysical, and photothermal mechanisms (Wekhof, 2000; Fine and Gervais, 2004; Krishnamurthy et al., 2010). Pulsed light has been applied to cottage cheese (Dunn et al., 1991), white cheddar cheese (Proulx et al., 2015, 2017a), white American cheese (Can et al., 2014; Proulx et al., 2015), mozzarella (Lacivita et al., 2018), Gouda and Manchego (Fernández et al., 2016).

White cheese is the most commonly consumed cheese in Turkey (Temelli et al., 2006; Hayaloglu et al., 2008; Akan & Kinik, 2018). It is a soft or semi-hard cheese manufactured from sheep or cow's milk (Öner et al., 2006). Fresh white cheese is produced from pasteurized milk using a starter culture and ripened in brine (12–16 % NaCl) for 1–2 months before being sold (Kirkin et al., 2013). On the other hand, aged white cheese is produced from raw or mildly heat treated milk using no starter culture and ripened in brine for at least 3 months before being sold (Kirkin et al., 2013). The objective of this study is to evaluate the efficacy of PUV light on *S. aureus* and *E. coli* O157:H7 on white cheese. In order to evaluate if this technique is only effective on the cheese surface, the PUV-light transmittance was investigated. In addition, the effects of PUV light on the quality parameters of fresh white cheese were examined.

Material and Methods

Preparation of bacterial inoculum

Staphylococcus aureus (ATCC 25923) and *Escherichia coli* O157:H7 (NCTC 12900) were used to prepare the inocula. *Staphylococcus aureus* was obtained from the American Type Culture Collection (Manassas, VA, USA). *Escherichia coli* O157:H7 was obtained from the National Collection of Type Cultures (Public Health England, UK). The cultures were revived by following the supplier's directions, and then maintained at 4 °C on slants of tryptic soy agar (Biolife, Milano, Italy) containing 0.6 % yeast extract (TSAYE). Subculturing was done every two weeks to maintain the viability of bacterial cells. On the day of the experiment, one loopful of culture (*S. aureus* or *E. coli* O157:H7) was transferred to 10 mL tryptic soy broth (Lab M, Lancashire, UK) containing 0.6 % yeast extract (TSBYE). After incubation at 37 °C for 24 h, the culture was centrifuged at 1448 x g at 4 °C for 12 min, and washed with 10 mL physiological saline solution (PSS) (0.85 % NaCl). The inoculum, which was obtained by suspending the pellet in 10 mL PSS, attained a concentration of 10^8–10^9 cfu/mL.

Inoculation of cheese

Fresh white cheese produced from cow's milk was purchased from a local grocery store, and kept at 4 °C until it is used within two weeks. The cheese was allowed to stand at room temperature for 2 h prior to the experiment. After the cheese was aseptically cut into 4 x 4 x 2 cm samples, each sample was placed onto a sterile aluminum tray. The top surface (4 x 4 cm) of the cheese sample was then inoculated with 0.1 mL of inoculum (*S. aureus* or *E. coli* O157:H7). The inoculated cheese samples were allowed to stand at room temperature for 45 min to facilitate the attachment of microbial cells to the surface.

Application of PUV light

A PUV light system (SteriPulse-XL RS-3000C, Xenon Corporation, Wilmington, MA, USA) operating with a xenon gas lamp was used to apply PUV light to the cheese samples. The system consists of four main sections: a lamp housing with 16" linear quartz flashlamp, a stainless steel sterilization chamber located under the lamp housing, a controller unit providing operator control and power to lamp housing, and a blower kit for cooling the lamp housing. The quartz window of the lamp housing is located 5.8 cm below the flashlamp. A portable shelf allows the application of PUV light to materials at different distances from the quartz window. With the input voltage of 3800 V, the system yields a pulse rate of 3 flashes per s and pulse width of 360 µs. The light pulses consist of polychromatic light (200–1100 nm) over the UV, visible, and infrared spectra. Treatment parameters were 5, 15, 30, 45, 60 s durations and 5, 8, 13 cm distances from the quartz window. In order to monitor the temperature of cheese samples during treatments, a K-type thermocouple was inserted 1–2 mm below the surface of the cheese sample (uninoculated), and the data was collected and transferred to a computer by a datalogger (HD200, Extech Instruments, Nashua, NH, USA).

Measurement of energy and penetration depth

The PUV energy levels (J/s/cm^2) obtained during treatments were determined by using a laser power and energy meter (NOVA II, Ophir Optronics, Jerusalem, Israel) connected to a pyroelectric sensor (PE50-DIF-C, Ophir Optronics), which was located exactly at the same level

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as the cheese surface. The power was averaged over 10 s by the energy meter. The penetrability of PUV light into white cheese was determined by placing 0.5, 1.0, 1.5 and 2.0-cm thick cheese cuts onto the pyroelectric sensor, and then measuring the energy at the exact treatment levels. The fraction of PUV energy transmitted by white cheese was calculated by dividing the energy value detected by the sensor under the cheese by that detected by only the sensor. The final results were expressed as % transmittance.

Enumeration of *Staphylococcus aureus* and *Escherichia coli* O157:H7

After PUV-light treatment, each cheese sample was homogenized in 90 mL buffered peptone water (BPW) (Merck, Darmstadt, Germany) for 2 min using a stomacher (Bag-Mixer 400, Interscience, Saint Nom, France). Following serial decimal dilutions, 0.3 mL of each dilution was spread-plated onto Baird-Parker agar (BPA) (Biolife) and sorbitol MacConkey II agar with cefixime and tellurite (SMAC-CT) (Himedia, Mumbai, India) for *S. aureus* and *E. coli* O157: H7, respectively. The plates were then incubated at 37 °C for 48 h for *S. aureus* and 24 h for *E. coli* O157:H7. Duplicate plates were used to calculate the average plate counts. In order to make sure the cheese was not previously contaminated; untreated uninoculated control samples were analyzed. Untreated, inoculated controls were used to obtain the initial microbial populations before the treatments. The reduction in microbial load was expressed as log (cfu cm^{-2}). *S. aureus* latex test kit (Plasmatec, Bridport, UK) and the *E. coli* O157: H7 latex test kit (Microgen Bioproducts, Surrey, UK) were used to confirm the colonies.

Quality evaluations of PUV treated white cheese

Immediately after PUV-light treatments, the analyses of pH, color, moisture content, and lipid oxidation were performed on the treated white cheese. The treatments that were chosen were the 5-s treatment at 13 cm (i.e. the lowest energy level), the 30-s treatment at 8 cm (i.e. the moderate energy level), the 60-s treatment at 5 cm (i.e. the highest energy level), and the treatment that yielded the highest microbial reduction in shortest time without visually altering the appearance of white cheese. The untreated cheese samples were analyzed as controls.

Lipid oxidation

The thiobarbituric acid reactive substances (TBARS) test using a modified method of Ouattara et al. (2002) was carried out to determine the levels of lipid oxidation in white cheese. Briefly the procedure was as follows: The cheese sample (~10 g) was homogenized for 1 min in a Waring blender with 50 mL of distilled water and 10 mL of 15% (w/v) trichloroacetic acid (Sigma-Aldrich, Taufkirchen, Germany). After the mixture was filtered through a Whatman no. 4 filter paper, 6 mL of the filtered solution was mixed with 2 mL of 0.06 M 2-thiobarbituric acid (TBA, Sigma-Aldrich) in a test tube, which was then capped and kept in boiling water for 45 min in a water bath. The blank was prepared similarly without the cheese sample. After the test tube was chilled in ice, the absorbance was measured at 450 nm in a spectrophotometer (SP-3000 plus, Optima, Tokyo, Japan) and expressed as absorbance units per g cheese (Kristensen and Skibsted, 1999).

pH

White cheese was crushed using a mortar and pestle. After calibration, the pH probe (HI 1131, Hanna Instruments, Woonsocket, RI, USA) was submerged into the cheese. The pH was measured at three different points with a pH meter (HI 2221) before an average value was calculated.

Moisture content

After being crushed using a mortar and pestle, the white cheese sample was dried at 105 ± 2 °C in a dry aluminum dish until constant weight was obtained. The moisture content was calculated as the percent of the initial weight.

Color

A chroma meter (CM-600d, Konica Minolta, Tokyo, Japan) was used to determine the color parameters for white cheese. CIELAB color parameters L*, -a*, + a*, -b*, and + b* indicate lightness, green, red, blue, and yellow colors, respectively. The average value of the parameter was calculated after making measurements at three random points on cheese. By taking the difference between the values obtained just before and after PUV treatments, the change in the color parameter was determined. The total color difference (ΔE) was also calculated from the equation: $\Delta E = [(\Delta L^*)^2+(\Delta a^*)^2+ (\Delta b^*)^2)]^{1/2}$.

Statistical analysis

Each treatment was replicated in triplicate. The data obtained for microbial reductions, energy levels, pH, color, moisture content, and lipid oxidation were analyzed by using ANOVA-General Linear Model in the statistical software MINITAB (Version 17, Minitab Inc., State College, PA, USA). The mean differences were compared using Tukey's method at 95 % confidence interval.

Results and Discussion

Microbial reductions

The mean log reduction of *S. aureus* obtained from all treatment times (5, 15, 30, 45, 60 s) at 5 cm was found to be significantly higher ($p<0.05$) than that obtained at 13 cm. On the other hand, the mean log reductions of *S. aureus* obtained from all treatment distances (5, 8, 13 cm) for 45-s and 60-s treatments were significantly higher ($p<0.05$) than those for the shorter treatments.

As seen in Table 1, inactivation levels for *S. aureus* on white cheese ranged from 0.50±0.14 to 1.33±0.23 $\log_{10}$ reduction (cfu/cm^2) obtained after the 5 s-13 cm and the 60 s-5 cm treatments, respectively. Higher inactivation was obtained as the treatment time prolonged and the distance from the lamp decreased. At any treatment distance, the 30-s, 45-s, and 60-s treatments produced statistically similar ($p>0.05$) log reduction.

The mean log reduction of *E. coli* O157: H7 obtained from all treatment times (5, 15, 25, 35, 45 s) at 5 cm was significantly higher ($p<0.05$) than that obtained at 13 cm. The mean log reductions of *E. coli* O157: H7 obtained from all treatment distances (5, 8, 13 cm) were significantly different ($p<0.05$) between treatment times, except 15 s, for which the reduction was not significantly different ($p>0.05$) from either 5 s or 30 s.

Inactivation levels of *E. coli* O157: H7 ranged from 0.41±0.07 to 2.20±0.21 log reduction (cfu/cm^2), which were yielded by 5 s-13 cm and 60 s-8 cm treatments, respectively (Table 1). At 5 cm, the 45-s and 60-s treatments resulted in significantly higher ($p<0.05$) log reduction compared to the shorter treatments. At either 8 cm or 13 cm, the 60-s treatment produced significantly higher ($p<0.05$) log reduction

than the shorter treatments. Among the 45-s treatments, the treatment at 5 cm yielded significantly higher ($p<0.05$) log reduction than that at 13 cm.

As seen from Table 1, PUV light was generally more effective on *E. coli* O157:H7 compared to *S. aureus* after treatments at the same conditions. The overall mean log reduction of *E. coli* O157:H7 was found to be significantly higher ($p<0.05$) than that of *S. aureus.* This is expected because gram positive cells are known to be more resistant to PUV light compared to gram negative cells (Rowan et al., 1999; Valdivia-Nájar et al., 2017).

When the surfaces of white cheese exposed to pulsed UV-light were examined visually, mild yellowing and softening was observed on cheese surface after the 60 s-5 cm treatment, which is the treatment that produced the highest energy dose (123.69 J/cm^2). Other treatments did not cause visually distinguishable changes on the surface of white cheese.

According to these findings, the treatment that resulted in the highest log reduction of *S. aureus* in the shortest time without leading to any visual deformation on cheese surface was the 30 s-5 cm treatment, which was not significantly different from the 60-s treatment in terms of the microbial inactivation. However, the highest reduction of *E. coli* O157:H7 without any change observed in visual appearance was obtained after the 60 s-8 cm treatment, which was significantly different from the 45-s treatments. Therefore, the favorable PUV treatment for the inactivation of both *S. aureus* and *E. coli* O157:H7 on white cheese was selected as the 60 s-8 cm treatment, which resulted in log reductions of 1.31 and 2.20 (cfu/cm^2) for *S. aureus* and *E. coli* O157:H7, respectively.

Proulx et al. (2017b) observed about 2.8 log reduction (estimated from Fig 2b of Proulx et al. (2017b)) of *E. coli* ATCC 25922 (a surrogate for *E. coli* O157:H7) at initial inoculum level of 7 log cfu/slice on Cheddar cheese after pulsed light treatment at 12.29 J/cm^2. In our study, at a similar energy dose (14.66 J/cm^2) the reduction of *E. coli* O157:H7 was only 0.59 log (cfu/cm^2). Since the same type of PUV-light system was used in both studies, the difference between the microbial reductions may be partly attributed to the surface characteristics of cheddar and white cheese. The surface of white cheese is rougher and softer than cheddar cheese, and thus may have facilitated the avoidance of microbial cells from PUV light. For example, Fernández et al. (2016) applied pulsed light (0.9–8.4 J/cm^2) to two cheese varieties with different surface features: Gouda (smooth and shiny) and Manchego (porous and matte) for the inactivation of *Listeria innocua.* The treatment was less effective on Manchego compared to Gouda. While 3 log cfu/cm^2 was obtained with 0.9 J/cm^2 on Gouda, the maximum inactivation obtained on Manchego slices was lower than 1 log cfu/cm^2 even at the highest fluence used (Fernández et al., 2016).

Temperature profile during PUV treatment

The temperature of white cheese increased during PUV treatments. The average temperature of white cheese prior to treatments was determined as 20.5±1.0 °C. As shown in Table 1; temperature increased with longer treatment time and shorter distance from the lamp. The maximum temperature was 47.2 °C, which was observed after the 60 s-5 cm treatment. The favorable treatment (60 s-8 cm) raised the temperature of white cheese to 41.8°C.

TABLE 1: *Energy doses, temperatures, and reductions of S. aureus and E. coli O157:H7 on white cheese after PUV treatments.*

Distance from the quartz window (cm)	Treatment time (s)	Energy dose (J/cm^2)	Temperature (°C)*	Log_{10} reduction (cfu/cm^2)**	
				S. aureus	*E. coli* O157:H7
5	5	10.31±0.02	22.7±0.2	0.61±0.13^{aA}	0.52± 0.16^{aA}
	15	30.92±0.07	26.7±0.5	0.68±0.13^{aA}	0.79± 0.14^{aA}
	30	61.84±0.14	33.9±1.5	0.89±0.07^{abA}	0.95± 0.07^{aA}
	45	92.76±0.21	40.6±1.6	1.28±0.27^{bA}	1.69± 0.24^{bA}
	60	123.69±0.28	47.2±1.1	1.33±0.23^{bA}	2.15± 0.27^{bA}
8	5	7.60±0.02	23.3±0.5	0.53±0.09^{aA}	0.55±0.11^{aA}
	15	22.80±0.05	26.7±0.8	0.64±0.16^{aA}	0.63±0.07^{aA}
	30	45.61±0.09	32.3±1.0	0.85±0.11^{abA}	0.89±0.19^{abA}
	45	68.41±0.14	37.2±1.0	1.28±0.15^{bA}	1.34±0.17^{bAB}
	60	91.22±0.18	41.8±1.3	1.31±0.13^{bA}	2.20±0.21^{cA}
13	5	4.89±0.01	20.8±0.6	0.50±0.14^{aA}	0.41±0.07^{aA}
	15	14.66±0.02	22.0±1.0	0.63±0.18^{abA}	0.59±0.15^{aA}
	30	29.31±0.03	24.7±1.3	0.71±0.11^{abcA}	0.85±0.14^{abA}
	45	43.97±0.05	27.3±1.5	1.08±0.13^{bcA}	1.18±0.24^{bB}
	60	58.62±0.06	30.1±1.8	1.14±0.19^{cA}	1.99±0.11^{cA}

*: The initial average temperature of white cheese was 20.5±1.0 °C. **: In the same column, different lowercase letters indicate significant difference ($p<0.05$) among the values within the same treatment distance, while different uppercase letters indicate significant difference ($p<0.05$) among the values within the same treatment time.

TABLE 2: *Lipid oxidation, pH, and moisture content of white cheese before and after PUV treatments.**

Treatment	Abs units (A450nm)** per g cheese	pH	Moisture content (%)
Control	0.0077±0.0005^{a}	4.20±0.06^{a}	60.4±1.2^{a}
5 s-13 cm	0.0079±0.0004^{a}	4.14±0.01^{a}	61.4±0.2^{a}
30 s-8 cm	0.0087±0.0004^{a}	4.13±0.02^{a}	60.9±0.8^{a}
60 s-8 cm (favorable)	0.0088±0.0002^{a}	4.13±0.03^{a}	61.0±0.3^{a}
60 s-5 cm	0.0090±0.0013^{a}	4.14±0.04^{a}	61.1±1.1^{a}

*: In a column, values that do not share the same letter are significantly different ($p<0.05$). **: Higher absorbance value indicates higher lipid oxidation level.

Dose and transmission of PUV energy

The energy doses obtained at each treatment level are shown in Table 1. Accordingly, the energy dose ranged from 4.89 to 123.69 J/cm^2, which were obtained after the 5 s-13 cm, and 60 s-5 cm treatments, respectively. The favorable treatment (60 s-8 cm) yielded 91.22 J/cm^2. The energy dose decreased significantly ($p<0.05$) with greater distance from the lamp. Longer treatments at the same distance produced higher energy doses, as expected.

Although PUV light treatment not exceeding 12 J/cm^2 is allowed by FDA (1996) for food decontamination, there are many studies which investigated the effects of much higher energy doses on the microbial load of foods (Fine and Gervais, 2004; Bialka and Demirci, 2008; Keklik et al., 2009). High energy doses were included in the present study to broadly evaluate the extent of the capability of PUV-light to inactivate the target microorganisms.

As seen from Table 1, some treatments with similar energy doses (e.g. ca. 60 J/cm^2 at 30 s-5 cm and 60 s-13 cm) produced quite different log reductions of both *S. aureus* (0.89 vs. 1.14) and *E. coli* (0.95 vs. 1.99). This indicates that the energy dose itself is not a sufficient predictor for expected bacterial reductions. Other factors such as treatment distance, time, and temperature may each affect the

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inactivation level. As an example, in the study of Keklik et al. (2012), microbial reductions were modeled for poultry products with respect to PUV-light energy doses below 70 J/cm^2. The fit of models to inactivation data revealed that distinct inactivation curves were observed at different treatment distances, even if similar energy dose was attained.

At 8 and 13-cm treatment distances, there was no PUV transmission from white cheese of varying thicknesses (0.5–2.0 cm). The transmission was solely observed from the 0.5-cm-thick white cheese at 5-cm treatment distance, and found to be 1.75±0.08 %. This finding suggests that the ability of white cheese to transmit PUV energy is very low, and PUV light may not reach and eradicate microorganisms present in layers deeper than 0.5 cm.

Quality evaluations of pulsed UV treated white cheese

Table 2 demonstrates the levels of TBARS in white cheese, which ranged between 0.0077 and 0.0090 abs unit/g for the control and sample treated for 60 s at 5 cm, respectively. The favorable treatment (60 s-8 cm) resulted in lipid oxidation level of 0.0088 abs unit/g cheese in white cheese. Although the level of lipid oxidation increased with treatment severity, there was no significant difference ($p>0.05$) between the control and treatments. The characteristic yellow color of dairy products observed in TBARS test with max. absorbance at 450 nm is due to the fact that saturated and monounsaturated fatty acids, which are present in high amounts in milk fat, form monounsaturated aldehydes during oxidation (Hoyland and Taylor, 1991; Kristensen and Skibsted, 1999).

The pH of white cheese was 4.20 for control, which dropped to 4.14 after the 60 s-5 cm treatment (Table 2). The cheese treated at the favorable conditions (60 s-8 cm) had a pH of 4.13. However, the treatments did not cause a significant change ($p>0.05$) in pH of white cheese. Similarly, Fernández et al. (2016) did not observe a significant change in pH of sliced Gouda and Manchego cheeses treated with pulsed light (0.9–8.4 J/cm^2).

Moisture contents of white cheese samples are shown in Table 2. Control (untreated) sample had a moisture content of 60.4 %. Moisture content of white cheese after the favorable treatment (60 s-8 cm) was found to be 61.0 %. The most severe treatment (60 s-5 cm) resulted in a moisture content of 61.1 %. There was no significant difference between the control and treatments in terms of moisture content ($p>0.05$). The moisture contents obtained in this study are in agreement with Turkish Food Codex (2015), according to which the moisture content of fresh white cheese may not exceed 65 (wt/wt). Overall, none of the PUV treatments caused significant changes in lipid oxidation, pH, or moisture content of white cheese.

Color

The control sample was found to have an L* value of 94.13±0.52, a* value of –0.33±0.11, and b* value of 10.31±0.65. The changes in color parameters of white cheese treated with PUV light are provided in Fig. 1. After the least severe treatment (5 s-13 cm), lightness decreased ($\Delta L^* = -0.12$), while redness ($\Delta a^* = 0.17$) and blueness ($\Delta b^* = -0.72$) increased. However, after the most severe treatment (60 s-5 cm), lightness ($\Delta L^* = -0.76$) decreased, while greenness ($\Delta a^* = -0.58$) and yellowness ($\Delta b^* = 2.58$) increased. Likewise, the favorable treatment (60 s-8 cm) resulted in a decrease in lightness ($\Delta L^* = -0.52$), and increase in both greenness ($\Delta a^* = -0.32$), and yellowness ($\Delta b^* = 1.40$).

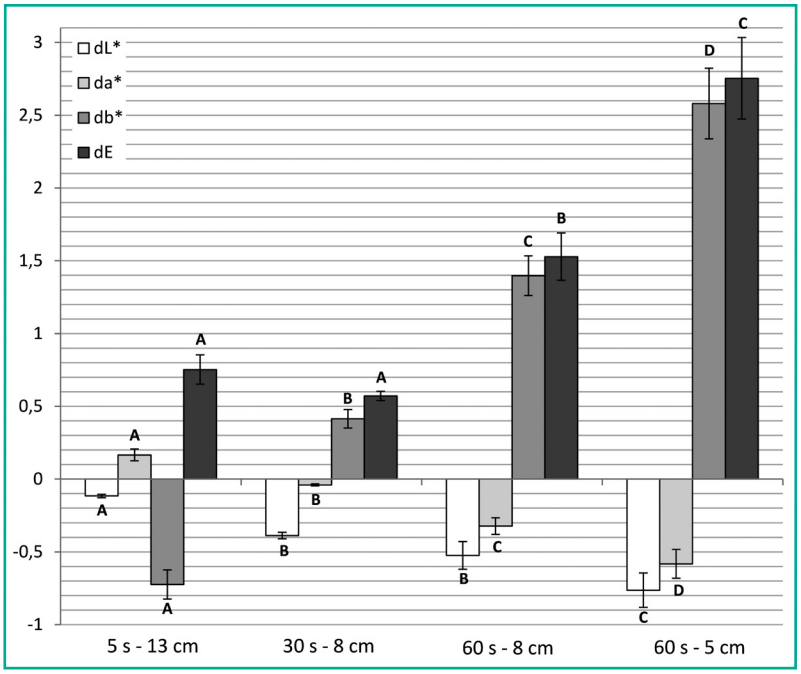

FIGURE 1: *Changes in color parameters of white cheese after PUV treatments (For the same color parameter, the vertical bars denoted by the same letter indicate the values are not significantly different ($p>0.05$).)*

These findings indicate that there was an increase in redness and blueness after the least severe treatment, while the opposite was observed after the more severe treatments, i.e. the greennness and yellowness increased. The temperature increase was minimal (~1 °C) in the least severe treatment (5 s- 13 cm). Compared to the 5 s-13 cm treatment, there was about 20 and 27-fold increase in temperature after the 60 s-8 cm and 60 s-5 cm treatments, respectively (Table 1). Therefore, in more severe treatments, the effect of temperature increase on color may have become more prominent.

For ΔL* values; the control was significantly different ($p<0.05$) from other treatments except the 5 s-13 cm treatment. There was no significant difference ($p>0.05$) between the 30 s-8 cm and 60 s-8 cm treatments. The 60 s-5 cm treatment was significantly different ($p<0.05$) from other treatments. For Δa* and Δb* values; each treatment was significantly different ($p<0.05$) from each other and the control. Only the 30 s-8 cm treatment did not cause a significantly different ($p>0.05$) Δa* value from the control.

ΔE values of white cheese were found to be significantly different ($p<0.05$) between treatments and the control. Only the 5 s-13 cm and 30 s-8 cm treatments did not produce significantly different ($p>0.05$) ΔE values. These findings indicate that PUV treatment resulted in significant changes ($p<0.05$) in color of white cheese.

Conclusions

PUV-light treatments were effective on *S. aureus* and *E. coli* O157:H7 inoculated on white cheese. The 60 s-5 cm treatment, which yielded the highest energy dose (123.69

J/cm^2), resulted in reduction of 1.33 and 2.15 log cfu/cm^2 for *S. aureus* and *E. coli* O157:H7, respectively. The temperature increased to about 47.2 °C. Probably, in part due to this temperature increase, visual changes were observed on the surface of white cheese after this treatment. Therefore, the favorable treatment, which was the treatment that yielded the highest microbial inactivation in the shortest time without causing any visual deformation on cheese surface, was identified as the 60 s-8 cm treatment. This favorable treatment, which produced an energy dose of 91.22 J/cm^2 and a temperature of 41.8 °C, resulted in reductions of 1.31 and 2.20 log cfu/cm^2 for *S. aureus* and *E. coli* O157:H7, respectively. Since PUV energy is applied to a food sample instantanously, temperature begins to decrease as soon as the energy is cut. However, the temperature of white cheese reached at the end of the favorable treatment (41.8 °C) falls in the optimal range of 20–45 °C for the growth of mesophilic bacteria (Jay, 2000) including *S. aureus* and *E. coli* O157:H7. Thus, it may be required to monitor the rate of temperature drop after PUV-light treatments, and to assess if there is a need to rapidly cool the food to prevent the remaining bacteria from growing.

None of the PUV treatments carried out in this study resulted in significant changes in lipid oxidation, pH, or moisture content of white cheese. However, color parameters were affected by the treatments significantly. Even the least severe treatment (5 s-13 cm) at 4.89 J/cm^2 caused significant changes in a* and b* values. However, no change of visual appearance was observed after treatments, except the most severe treatment (60 s-5 cm).

PUV-light transmission from white cheese was poor. The 0.5-cm-thick white cheese transmitted about 1.75 % of energy at 5-cm distance from the quartz window. Thus, PUV light seems to be applicable for only surface treatment of white cheese. The energy that was not transmitted from white cheese was either absorbed by cheese or reflected from the surface. The color of white cheese suggests that a considerable amount of energy may have been reflected.

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Conflict of interest

The authors declared no conflict of interest.

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