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Possibilities of using the continuous type of UV light on the surface of lor (whey) cheese: impacts on mould growth, oxidative stability, sensory and colour attributes during storage

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Research Article

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Abstract

This research paper addresses the hypothesis that the optimum doses of a continuous type of ultraviolet (UV) light applied to the surface of lor (whey) cheese needs to be identified to maximize mould inactivation and shelf life while minimizing quality deterioration. Therefore, the mould inactivation, protein and lipid oxidation products, sensory and colour attributes of lor cheese subjected to different doses of UV light (1.617, 4.018, and 36.832 kJ/m^2) in a continuous type of UV system were evaluated. UV treated samples presented mould counts lower than those of untreated ones. UV treatment at more than 4.018 kJ/m^2 allowed around 0.7–2.7 log reductions on mould growth during storage. The increase in UV light dose caused significant increases in primary and secondary lipid oxidation products. In particular, the highest doses applied to the surface of cheese samples had the highest values of protein carbonyls, as well as lipid oxidation products. Strong positive correlations were recorded between lipid and protein oxidation markers. Exposure to the highest doses of UV light increased foreign flavour perception, probably due to the oxidative reactions. The results indicated that the application of UV light to the lor cheese surface allowed delaying mould growth during storage but extreme doses could induce lipid and protein oxidation reactions, leading to quality deterioration.

Cheeses are nutrient-dense food items, containing high-quality proteins, lipids, vitamins, and minerals (Feeney *et al.*, 2021). As well as macro and micronutrients, some kinds of cheeses contain bioactive components, which have potential health benefits, whilst beneficial bacteria present in the cheese matrix can also potentially improve consumer health. Lor cheese, one of Turkey's traditional whey cheeses, is produced by heating the whey at a high temperature to precipitate the whey proteins. It is a fresh cheese and has a granular texture, soft consistency with a slightly perceptible flavour and uniform off-white or light-yellow colour (Kamber, 2008). It contributes to diet quality by providing substantial amounts of macronutrients (especially high-value proteins) and essential micronutrients (calcium, potassium, magnesium and vitamins). The contribution of its consumption exerts beneficial effects beyond its impact on healthy growth and development. However, studies showed that fresh whey cheeses are highly susceptible to the growth of spoilage microorganisms mainly represented by moulds and yeasts, due to their high moisture, protein and lactose contents, low salt concentration and pH around 6.0 (Pintado *et al.*, 2001; Papaioannoou *et al.*, 2007; Dermiki *et al.*, 2008; Irkın, 2011). Even if good hygienic practices and effective cooling are applied under strictly controlled conditions, this product has a limited shelf-life (7–10 d). Thus, the investigation of post-production decontamination methods, alternatives to thermal and chemical treatments, is required to guarantee its safety and quality during delivery and storage.

Non-thermal processing technologies have great potential for dairy products, as they can avoid contamination while maintaining quality, mainly due to their low temperature and short processing time (Rathod *et al.*, 2021; Ribeiro *et al.*, 2022; Ricciardi *et al.*, 2022). Among these technologies, it is possible to highlight ultraviolet (UV) light as a potential emerging technology for the processing of dairy products (Delorme *et al.*, 2020). Recently, UV light efficacy has been carried out to control spoilage on different kinds of cheese surfaces such as fresh kashar cheese, white American cheese, mozzarella cheese, sliced cheddar cheese and Fiordilatte cheese (Can *et al.*, 2014; Ha *et al.*, 2016; Lacivita *et al.*, 2016, 2018; Keklik *et al.*, 2019, Koca and Urgu Öztürk, 2020). Moreover, Ricciardi *et al.* (2020) reported that the shelf life of ricotta cheese exposed to UV light of between 200 and 300 nm wavelength (UV-C) was extended by 50%. However, exposure to high light intensities may promote physicochemical changes in components, such as lipid and protein oxidation processes, especially in the case of protein- and fat-rich dairy products. There is no overview study referring to a sufficient UV light dose to increase shelf life of lor cheese while maintaining the oxidative

and sensory quality as far as the author is aware. Moreover, no research has addressed interactions of protein-lipid oxidation products of UV light treated whey cheese. In this sense, the hypothesis and novelty of this study was to apply the continuous type of UV light on the surface of lor (whey) cheese for adapting it to the dairy industry and to evaluate the relationship between oxidative stability and other quality markers.

Materials and methods

Cheese samples

Lor cheese samples (total dry matter: 36.25 ± 0.39%, fat content: 18.75 ± 0.25%, protein content: 15.20 ± 0.08%, pH: 6.18 ± 0.03) were produced without adding any preservatives in a local dairy plant (Kırıkkaya Dairy Company, Izmir, Turkey). Briefly, the whey released from fresh kashar cheese was heat-treated under constant and gentle stirring at 85 °C until coagulation occurs. The process was continued until the formation of curd. The floating curd was collected from the tank above the whey surface into the thin clothes and left to remove the excess water in cold temperature. Pressure was applied to the product to remove the excess whey content in the curd. Thereafter, portions (250 g) of prepared lor cheese samples were packaged in the polyethylene terephthalate trays. Following the production, the cheeses were immediately brought to the laboratory and stored at 4 °C until the UV-C light application.

UV-C light treatments

The UV-C light treatments of lor cheese samples were performed at room temperature using the continuous UV-C disinfection system (UV STR400, UV RND, Izmir, Turkey). The system was equipped with 12 UV-C lamps (a diameter of 2.5 cm and a length of 45 cm) which were positioned above the surface of the sample at a 7.5 cm distance. UV-C light intensity, which was 54.37 W/m^2, was kept constant during all treatments, and the doses of the treatments (kJ/m^2) were calculated by multiplying the intensity (W/m^2) and treatment time (s). UV-C radiation treatment was carried out at three different band speeds of 4 m/min (29.74 s), 1.6 m/min (73.91 s), and 0.2 m/min (677.43 s), corresponding to exposure times of 1.617, 4.018, and 36.832 kJ/m^2, respectively. These UV-C conditions were selected based on the results of preliminary sensory studies. Untreated control and UV-C treated samples were stored at 4 °C for 14 d. Representative images from the UV light experiment are given in Supplementary Figure S1 and S2.

Mould count

Cheese samples were diluted with peptone water in a stomacher bag and homogenized using a Stomacher (BagMixer, France) for 2 min. Then, decimal dilutions of homogenates were prepared and plated on Potato Dextrose Agar (Merck, Darmstadt, Germany) in petri dishes. The plates were incubated for 5 d at 25 °C. The results were expressed as logarithmic colony forming units per gram (log cfu/g).

Lipid oxidation: peroxide value

The peroxide value (PV) was determined by a method based on the IDF standard (IDF standard 74A, 1991). Lipid extracted from 4 g of lor cheese was dissolved in a mixture of chloroform-methanol, then ammonium thiocyanate and iron(II) chloride were added. The PV was expressed as milliequivalent (meq) of oxygen per kilogram of lipid in the sample.

Lipid oxidation: 2-thiobarbituric acid reactive substances (TBARS) value

The analysis of 2-thiobarbituric acid reactive substances (TBARS) was carried out by spectrophotometry according to the method described by Kristensen and Skibsted (1999). Results were expressed as absorbance values at 450 and 532 nm per g of cheese.

Protein oxidation

The protein-bound carbonyl content is the most commonly used marker of protein oxidation (Dalle-Donne *et al.*, 2003). Protein carbonyls in cheese samples were measured following the procedure of Oliver *et al.* (1987). Results were expressed as nmol of carbonyls per mg of protein.

Colour

The colour parameters of the cheese samples were measured in terms of L^* (lightness to darkness), a^* (redness to greenness), and b^* (yellowness to blueness) using a portable colorimeter (Konica Minolta, CR-300, Osaka, Japan). The colour differences (ΔE), Chroma (colour intensity) and browning index (BI) values were calculated using the equation previously described by Askari *et al.* (2008).

Sensory evaluation

Sensory evaluations were undertaken by 10 trained panellists, expert in the evaluation of dairy products. Panellists received cheese samples simultaneously and randomly identified with a three-digit code. Appearance, colour and overall impression were evaluated using a 7-point unipolar scale (from the worst to the best). In addition, panellists were asked to judge the oxidized flavour and foreign flavour by using the same scale (1: representing none/absent and 7: representing the highest intensity). The sensory evaluation test was repeated twice.

Statistical analysis

Lor cheeses were produced twice on different days for each treatment, and all analyses were performed three times. Statistical analyses were performed using the statistical package program (SPSS ver.13.0, SPSS Inc., Chicago, IL, USA). The data were analysed using analysis of variance and the Duncan post hoc test. Pearson correlation tests were also used to measure the correlation between lipid and protein oxidation markers and colour attributes of lor cheese. The statistical significance was set at $P < 0.05$.

Results and discussion

Mould count

Control of mould spoilage is a major concern for the dairy industry, requiring efficient techniques to prevent and/or limit mould growth in dairy products. This is because mould spoilage may cause a deterioration of the quality resulting in off-flavour or

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Table 1. Mould counts of the lor cheese during the 14-d storage period

Item	Storage period (d)	LC–Control	LC–UV1	LC–UV2	LC–UV3
Mould count (log cfu/g)	0	$2.69 \pm 0.07^{d, A}$	$2.11 \pm 0.05^{c, A}$	$1.91 \pm 0.09^{b, A}$	$<1^{a, A}$
	7	$3.82 \pm 0.02^{d, B}$	$3.41 \pm 0.05^{c, B}$	$2.71 \pm 0.04^{b, B}$	$1.65 \pm 0.24^{a, B}$
	14	$4.43 \pm 0.05^{d, C}$	$4.26 \pm 0.03^{c, C}$	$3.73 \pm 0.02^{b, C}$	$2.57 \pm 0.05^{a, C}$

LC–Control, untreated control lor cheese; LC–UV1, lor cheese exposed to UV-C light doses of 1.617 kJ/m^2; LC–UV2, lor cheese exposed to UV-C light doses of 4.018 kJ/m^2; LC–UV3, lor cheese exposed to UV-C light doses of 36.832 kJ/m^2.
$^{a–d}$Means within a row for a given item with different superscripts differ ($P < 0.05$).
$^{A–C}$Means within a column with different superscripts differ ($P < 0.05$).

texture alterations through the production of lipolytic and proteolytic activities and so compromise shelf-life of the products (Garnier *et al.*, 2017). Therefore, it is important to retard the mould growth on the surfaces of the fresh whey cheeses which otherwise have only a short shelf life. Mould counts of lor cheese samples during the storage period are shown in Table 1. At the beginning of the storage, the mould counts were 2.69 ± 0.07, 2.11 ± 0.05 and 1.91 ± 0.09 log CFU/g in untreated control, LC-UV1, and LC-UV2 samples. The mould count of the sample exposed to the highest dose of UV light was below the detection limit. These results showed that all the treated samples presented mould loads lower than those of the untreated sample ($P < 0.05$), thus confirming literature data on the decontamination effect of UV light on several cheese samples (Can *et al.*, 2014; Lacivita *et al.*, 2016, 2018; Keklik *et al.*, 2019; Koca and Urgu Öztürk, 2020; Ricciardi *et al.*, 2020; Ricciardi *et al.*, 2021). All these authors have stated the potential of UV light in inactivating various microorganisms, such as *Pseudomonas* spp., *Enterobacteriaceae*, *Staphylococcus aureus*, *Escherichia coli* O157: H7, *Penicillium roqueforti*, *Listeria monocytogenes*. In spite of a continuous rise in the mould count of samples with an increase in the storage time ($P < 0.05$), UV light treatment decelerated the mould growth in lor cheese, which may have a positive impact on its shelf-life. It is evident from Table 1 that exposure of 36.832 kJ/m^2 doses of UV light provided more than around 2 log reduction (between 1.87 and 2.69 log CFU/g) throughout the storage period. Similar log reductions in mould counts were also reported by Can *et al.* (2014) and Koca and Urgu Öztürk (2020) for cheese samples treated with pulsed UV and batch system UV-C light, respectively.

Lipid oxidation

Lipid oxidation phenomena are known as the major causes of physical, sensory, and nutritional quality deterioration in dairy products. Since light is one of the main causes of oxidation susceptibility, investigation of changes in the oxidative quality of the light-induced dairy product is a noteworthy point. Initial stages in lipid oxidation were monitored by analysis of lipid peroxides (Fig. 1). The PV of lipid extracted from lor cheese samples exposed to 4.018 and 36.832 kJ/m^2 doses of UV light reached significantly higher levels during 14-d storage than those of the untreated control sample ($P < 0.05$). On the other hand, exposure to low UV light intensity (LC-UV1, 1.617 kJ/m^2) showed a less remarkable effect on PV compared to those of samples exposed to higher doses. Obtained results indicated that exposure to high UV light intensities was associated with a significant increase in the primary products of autoxidation. Similarly, Kristensen *et al.* (2001) reported significantly higher PV for processed cheese samples exposed to fluorescent light after 1 mo of storage at 5 °C compared to untreated samples, with PV quickly exceeding 1 meq O_2/kg lipid. As expected, PV of all samples significantly increased with an increase in the storage days ($P < 0.05$).

Thiobarbituric reactive substances (TBARS) are quantified to determine the secondary lipid oxidation products of dairy products. The oxidative stabilities of the lor cheese samples were compared in terms of their TBARS values measured at 450 and 532 nm throughout the storage period (Table 2). TBARS values of the cheese samples were significantly affected by the applied UV-C light doses ($P < 0.05$). Throughout the storage period, the lowest TBARS value was obtained for control sample, followed by the samples exposed to UV light at 1.617 kJ/m^2 dose ($P < 0.05$). In other words, increases in UV-C light fluence led to progressive increases in TBARS values and induced oxidative stress. Similar to our findings, in a study on fresh kashar cheese samples exposed to pulsed UV light, TBARS values tended to increase with the high fluence of pulsed UV light (Keklik *et al.*, 2019). In another study, Koca and Urgu Öztürk (2020) showed that kashar cheese samples exposed to batch type of UV light were more susceptible to lipid oxidation compared to untreated control cheese samples. In the present study, it was observed that storage of lor cheese samples for 14-d led to a significant increment in TBARS values of all samples ($P < 0.05$), showing that oxidation reactions increased with the storage period. The correlations evaluated between the oxidation parameters of the cheese samples are shown in online Supplementary Table S1. PV results showed a strong positive correlation ($r = 0.960$ for TBARS measured at 450 nm and $r = 0.885$ for TBARS measured at 532 nm) with TBARS values ($P < 0.05$), pointing out the increase in secondary oxidation products with the increase in primary ones.

Protein carbonyls

Light-induced oxidation of proteins is mainly caused by wavelengths of the UV region, although other bands of the spectrum can also be involved (Hollósy, 2002; Scheidegger *et al.*, 2010). Therefore, a certain degree of protein oxidation could be expected due to exposure to UV light. As a result of this protein oxidation, changes in physical characteristics of the protein, such as aggregation, loss of stability, and functionality could occur. For this reason, in this study, lor cheese samples were analysed for the carbonyl through the DNPH assay, which can be used as an indicator of oxidative degradation of proteins (Suzuki *et al.*, 2010). Figure 2 shows the carbonyl values of lor cheese samples exposed to increasing UV-C light dose. It was clearly seen that a significant increase in the protein carbonyls was observed with increasing doses of UV-C light ($P < 0.05$). LC-UV3 had the highest amount of carbonyls compared to other groups throughout the storage

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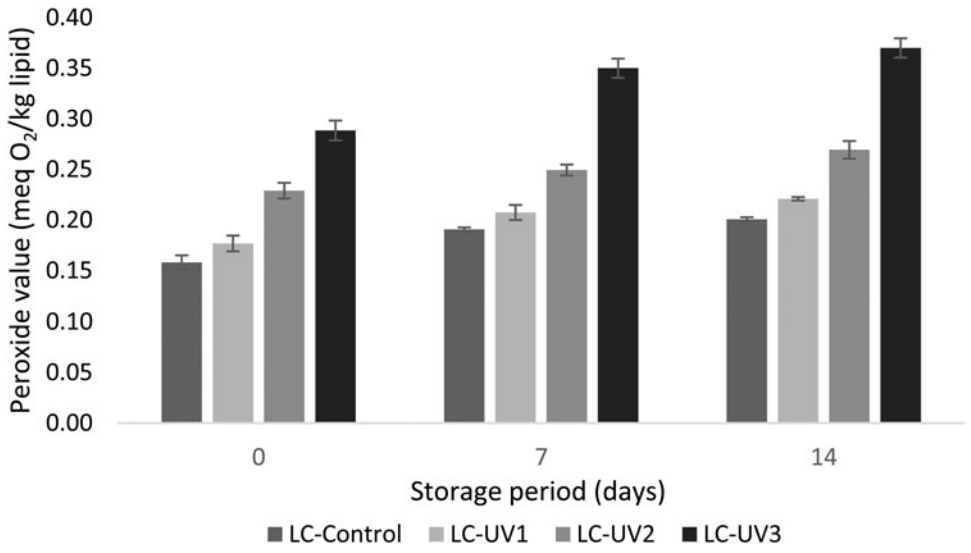

Fig. 1. Peroxide values of the lor cheese during the 14-d storage period. LC–Control, untreated control lor cheese, LC–UV1: lor cheese exposed to UV-C light doses of 1.617 kJ/m^2, LC–UV2: lor cheese exposed to UV-C light doses of 4.018 kJ/m^2; LC–UV3: lor cheese exposed to UV-C light doses of 36.832 kJ/m^2. The error bars represent standard deviation.

Table 2. The oxidation degree of the lor cheese determined by the TBA method at (a) 450 nm and (b) 532 nm during the 14-d storage period

Item	Storage period (d)	LC–Control	LC–UV1	LC–UV2	LC–UV3
TBA ($A_{450\ nm/g}$)	0	$0.035 \pm 0.001^{a,\ A}$	$0.037 \pm 0.001^{ab,\ A}$	$0.041 \pm 0.003^{b,\ A}$	$0.059 \pm 0.001^{c,\ A}$
	7	$0.036 \pm 0.001^{a,\ A}$	$0.038 \pm 0.002^{a,\ A}$	$0.046 \pm 0.001^{b,\ A}$	$0.061 \pm 0.001^{c,\ A}$
	14	$0.039 \pm 0.001^{a,\ B}$	$0.042 \pm 0.001^{b,\ B}$	$0.052 \pm 0.002^{c,\ B}$	$0.076 \pm 0.001^{d,\ B}$
TBA ($A_{532\ nm/g}$)	0	$0.020 \pm 0.003^{a,\ A}$	$0.020 \pm 0.001^{a,\ A}$	$0.023 \pm 0.001^{b,\ A}$	$0.029 \pm 0.001^{c,\ A}$
	7	$0.020 \pm 0.002^{a,\ A}$	$0.021 \pm 0.001^{a,\ A}$	$0.022 \pm 0.002^{a,\ A}$	$0.030 \pm 0.001^{b,\ A}$
	14	$0.024 \pm 0.002^{a,\ B}$	$0.028 \pm 0.001^{b,\ B}$	$0.029 \pm 0.002^{b,\ B}$	$0.036 \pm 0.002^{c,\ B}$

LC–Control, untreated control lor cheese; LC–UV1, lor cheese exposed to UV-C light doses of 1.617 kJ/m^2; LC–UV2, lor cheese exposed to UV-C light doses of 4.018 kJ/m^2; LC–UV3, lor cheese exposed to UV-C light doses of 36.832 kJ/m^2.
$^{a–d}$Means within a row for a given item with different superscripts differ ($P < 0.05$).
$^{A–B}$Means within a column with different superscripts differ ($P < 0.05$).

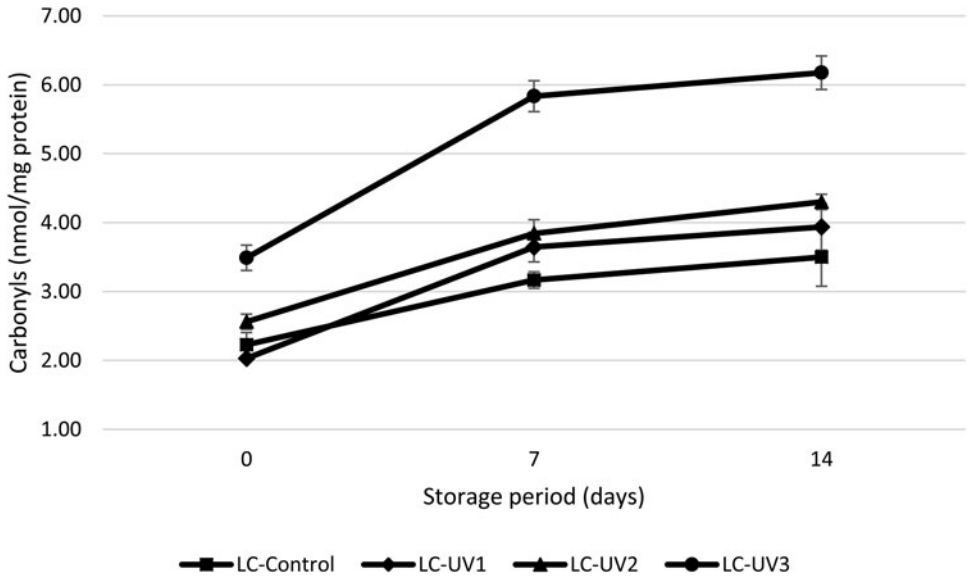

Fig. 2. Carbonyl values of the lor cheese during the 14-d storage period. LC–Control, untreated control lor cheese, LC–UV1: lor cheese exposed to UV-C light doses of 1.617 kJ/m^2, LC–UV2: lor cheese exposed to UV-C light doses of 4.018 kJ/m^2; LC–UV3: lor cheese exposed to UV-C light doses of 36.832 kJ/m^2. The error bars represent standard deviation.

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Table 3. Colour characteristics of the lor cheese during the 14-d storage period

Item	Storage period (d)	LC–Control	LC–UV1	LC–UV2	LC–UV3
L^*	0	$93.20 \pm 0.03^{a, B}$	$93.71 \pm 0.18^{a, C}$	$93.11 \pm 0.41^{a, A}$	$94.09 \pm 0.36^{a, C}$
	7	$91.54 \pm 0.06^{a, A}$	$92.05 \pm 0.11^{a, B}$	$91.93 \pm 0.16^{a, A}$	$91.31 \pm 0.29^{a, B}$
	14	$91.51 \pm 0.08^{b, A}$	$90.28 \pm 0.78^{ab, A}$	$90.61 \pm 0.37^{ab, A}$	$89.92 \pm 0.59^{a, A}$
a^*	0	$-1.56 \pm 0.04^{a, B}$	$-1.60 \pm 0.11^{a, A}$	$-1.61 \pm 0.02^{a, AB}$	$-1.52 \pm 0.04^{a, A}$
	7	$-1.67 \pm 0.21^{a, A}$	$-1.55 \pm 0.03^{bc, A}$	$-1.63 \pm 0.05^{ab, A}$	$-1.48 \pm 0.01^{c, A}$
	14	$-1.56 \pm 0.02^{a, B}$	$-1.53 \pm 0.06^{a, A}$	$-1.51 \pm 0.04^{a, B}$	$-1.46 \pm 0.04^{a, A}$
b^*	0	$11.67 \pm 0.13^{a, A}$	$11.78 \pm 0.17^{a, A}$	$11.97 \pm 0.21^{a, A}$	$13.51 \pm 0.47^{b, A}$
	7	$11.45 \pm 0.02^{a, A}$	$12.06 \pm 0.77^{ab, A}$	$12.89 \pm 0.62^{ab, A}$	$13.64 \pm 0.26^{b, A}$
	14	$11.72 \pm 0.37^{a, A}$	$12.42 \pm 0.21^{ab, A}$	$13.40 \pm 0.57^{bc, A}$	$13.70 \pm 0.15^{c, A}$
ΔE	0	–	$0.57 \pm 0.08^{a, A}$	$1.04 \pm 0.22^{ab, A}$	$1.54 \pm 0.38^{b, A}$
	7	–	$1.12 \pm 0.08^{a, A}$	$1.51 \pm 0.65^{a, A}$	$2.31 \pm 0.36^{a, AB}$
	14	–	$1.46 \pm 0.52^{a, A}$	$1.94 \pm 0.04^{ab, A}$	$2.57 \pm 0.15^{b, B}$
Chroma	0	$11.78 \pm 0.13^{a, A}$	$11.89 \pm 0.16^{a, A}$	$12.08 \pm 0.21^{ab, A}$	$13.30 \pm 0.88^{b, A}$
	7	$11.57 \pm 0.02^{a, A}$	$12.16 \pm 0.76^{a, A}$	$12.99 \pm 0.62^{ab, A}$	$13.72 \pm 0.26^{b, A}$
	14	$11.83 \pm 0.36^{a, A}$	$12.51 \pm 0.21^{ab, A}$	$13.48 \pm 0.57^{bc, A}$	$13.78 \pm 0.15^{c, A}$
BI	0	$11.82 \pm 0.12^{a, A}$	$11.85 \pm 0.31^{a, A}$	$12.15 \pm 0.44^{a, A}$	$13.22 \pm 0.16^{a, A}$
	7	$11.68 \pm 0.10^{a, A}$	$12.45 \pm 0.98^{a, A}$	$13.43 \pm 0.69^{ab, AB}$	$14.58 \pm 0.37^{b, A}$
	14	$12.11 \pm 0.46^{a, A}$	$13.18 \pm 0.33^{ab, A}$	$14.38 \pm 0.69^{bc, B}$	$14.92 \pm 0.26^{c, A}$

LC–Control, untreated control lor cheese; LC–UV1, lor cheese exposed to UV-C light doses of 1.617 kJ/m^2; LC–UV2, lor cheese exposed to UV-C light doses of 4.018 kJ/m^2, and LC–UV3, lor cheese exposed to UV-C light doses of 36.832 kJ/m^2; L^*, lightness-darkness; a^*, red-green colour; b^*, yellow-blue colour; ΔE, colour difference with untreated control lor cheese as a reference; BI, browning index.

$^{a–c}$Means within a row for a given item with different superscripts differ ($P < 0.05$).

$^{A–C}$Means within a column with different superscripts differ ($P < 0.05$).

($P < 0.05$). These data underline the considerable impacts of UV-C light on generating protein oxidation, which may promote carbonylation reactions and a rearrangement of protein structure. Similar results were obtained by Ricciardi *et al.* (2021), who found that pulsed light treatments of ricotta cheese could promote photo-induced oxidation of proteins. Fernández *et al.* (2014) reported that carbonyl amounts of processed cheese slices treated with more than 8.4 J/cm^2 pulsed light fluences were significantly higher than untreated ones, which were also increased during storage. Moreover, in the current study the storage period significantly increased the protein carbonyls of each lor cheese group. Thus, both the applied doses of UV-C light and the storage period showed noticeable effects on the increment of protein carbonyls of lor cheese.

Strong positive correlations were recorded between carbonyl contents and PV ($r = 0.859$) and TBARS ($r = 0.814$ for 450 nm and $r = 0.807$ for 532 nm) ($P < 0.05$) (online Supplementary Table S1), which indicated that protein carbonyls increased with increases in both primary and secondary lipid oxidation products. This result emphasizes the probable interaction between the lipid and protein oxidation mechanisms in the cheese matrix. This interaction was previously indicated by Dalsgaard *et al.* (2010), who reported that lipid radicals are probable promoters for the generation of protein oxidation in cheese.

Colour

The colour characteristics of dairy products are the most important visual attributes that affect consumer preferences. Since the colour may change upon the application of UV light treatment and the storage period, the variations in the colour parameters of lor cheese were evaluated (Table 3). Significant changes in some colour features were observed with the application of UV light ($P < 0.05$). Although almost no significant changes were noted among samples in terms of L^* and a^* values, the highest b^* values were detected in the sample exposed to the highest dose of UV-C light during the storage period. This may be due to lipid oxidation, which can be initiated by light exposure. It is well known that light may be detrimental due to its ability to degrade light-sensitive micronutrients, such as riboflavin (Deger and Ashoor, 1987). When the relationship between oxidation markers and colour parameters of products was evaluated, it was recorded that b^* values had a significant positive correlation with both lipid oxidation and protein carbonyls ($P < 0.05$). Therefore, an increase in the UV light doses can induce oxidation reactions, leading to an increase in the yellowness of the product. Although an increase in colour differences was observed with an increase in the applied doses of UV light, values were found below 3, indicating that these differences could not be detected by the human eye (Quintanilla *et al.*, 2019). The chroma and BI values showed similar trends with primary colour measurements. Control samples had the lowest chroma and BI values, while LC-UV3 had the highest values because of its highest b^* value. It was inferred that the variations in the colour differences, BI and Chroma values of lor cheese samples were mainly influenced by b^* values. Besides, strong positive correlations were recorded between these parameters ($P < 0.05$) (online Supplementary Table S1). These results suggest that the application of high

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Table 4. Sensory scores of the lor cheese during the 14-d storage period

Item	Storage period (d)	LC–Control	LC–UV1	LC–UV2	LC–UV3
Appearance	0	$6.60 \pm 0.21^{a, B}$	6.48 ± 0.07^{a}	6.48 ± 0.13^{a}	6.33 ± 0.06^{a}
	7	$6.30 \pm 0.09^{a, A}$	6.25 ± 0.10^{a}	6.20 ± 0.06^{a}	6.22 ± 0.12^{a}
	14	$6.26 \pm 0.08^{a, B}$	6.23 ± 0.32^{a}	6.20 ± 0.12^{a}	6.16 ± 0.06^{a}
Colour	0	6.39 ± 0.10^{a}	6.30 ± 0.04^{a}	6.25 ± 0.11^{a}	6.23 ± 0.13^{a}
	7	6.48 ± 0.16^{a}	6.39 ± 0.12^{a}	6.25 ± 0.06^{a}	6.19 ± 0.19^{a}
	14	6.34 ± 0.21^{a}	6.34 ± 0.35^{a}	6.24 ± 0.15^{a}	6.25 ± 0.22^{a}
Foreign flavour	0	1.07 ± 0.09^{a}	1.14 ± 0.19^{a}	2.38 ± 0.26^{b}	3.59 ± 0.03^{c}
	7	1.11 ± 0.16^{a}	1.16 ± 0.18^{a}	2.59 ± 0.19^{b}	3.81 ± 0.06^{c}
	14	1.18 ± 0.26^{a}	1.48 ± 0.24^{a}	2.84 ± 0.16^{b}	3.92 ± 0.25^{c}
Overall impression	0	6.36 ± 0.13^{c}	6.27 ± 0.16^{c}	5.78 ± 0.10^{b}	3.50 ± 0.03^{a}
	7	6.30 ± 0.06^{c}	6.21 ± 0.10^{c}	5.65 ± 0.20^{b}	3.13 ± 0.32^{a}
	14	6.05 ± 0.32^{c}	5.99 ± 0.13^{c}	5.53 ± 0.10^{b}	3.28 ± 0.32^{a}

LC–Control, untreated control lor cheese; LC–UV1, lor cheese exposed to UV-C light doses of 1.617 kJ/m^2; LC–UV2, lor cheese exposed to UV-C light doses of 4.018 kJ/m^2; LC–UV3, lor cheese exposed to UV-C light doses of 36.832 kJ/m^2.
$^{a–c}$Means within a row for a given item with different superscripts differ ($P < 0.05$).
$^{A–B}$Means within a column with different superscripts differ ($P < 0.05$).

doses of UV light treatment strongly affected the colour features of cheese samples and led to the production of more yellow and brown compound(s).

Sensory quality

Where effects of UV light on sensory quality are concerned, Table 4 reports data recorded from the panel test. The judges were asked to give product evaluation taking into account the following sensory attributes: appearance, colour, oxidized flavour, foreign flavour and overall impression. Panellists did not perceive any oxidized flavour in samples. All samples were considered at nearly the best scores (~6.16–6.60) for appearance and colour attributes during the storage period. Data listed in Table 4 also indicate quite clearly that a decrease in overall impression was observed in samples exposed to UV light more than 4.018 kJ/m^2. Exposure to high UV light doses caused foreign flavour which was defined as 'burnt feather'. In particular, LC–UV3 lost its acceptability due to its unpleasant flavour. A possible explanation of these findings can be ascribed to the action of UV produced during treatments because these rays can promote photo-induced changes in lipids (Koca and Urgu Öztürk, 2020). Considering that lor cheese composition is mainly constituted by whey proteins, photo-induced effects on proteins, as well as chemical one on lipids, cannot be excluded. A previous study has evaluated the sensorial perception of sliced Prato cheese subjected to UV-C light (Delorme *et al*., 2021). Authors claimed that consumers' acceptance of UV-C-treated cheeses was only improved when a claim was labelled in the package providing information about the technology to consumers. In this sense, evaluating consumer perception and descriptive sensory properties are also required to help identify barriers that affect the sensory quality and improve the strategies to adopt this technology industrial scale.

Dairy industries should consider that UV light processing technique has some advantages and disadvantages like other preservation techniques. The outcome of research proves that UV light has significant capability for eliminating or controlling the post-processing contamination by surface application in whey cheeses. At the same time, it demonstrates the applicability of UV light in a variety of dairy matrices. This technology exhibits no toxic effects, no waste generation and guarantees surface decontamination without using chemicals in the food system. Furthermore, it provides advantages for small-scale factories especially in developing countries, due to its low maintenance, installation, and operational costs. However, this technology has limited application due to its low penetration ability. Moreover, its efficiency may mainly depend on the processing parameters and physical attributes of the product. In some cases, negative impacts may be seen with respect to oxidative deterioration and flavour changes. In brief, the future is positive for UV light technology but needs implementation on a large scale. In particular, the efficacy and effects of UV light treatments needs to be proven for other dairy products and negative effects can be worked upon by further optimization and controlled experimental conditions by large-scale dairy product manufacturers.

As a conclusion, the findings of the present study offer a practical approach to decontaminate the surface of highly perishable dairy products, such as lor (whey) cheese, potentially allowing shelf-life extension. The results indicated that the application of continuous UV light treatments could retard the mould growth on the cheese surface. However, UV light treatments exceeding a dose of 4.018 kJ/m^2 could promote quality depletion, mainly associated with photo-induced modification of lipids and proteins. Oxidation markers indicated that strong interactions between lipid and protein oxidation mechanisms were revealed in the cheese matrix due to the high doses of UV light, which may lead to quality deterioration. Further studies are required for different dairy products, which will take a further look into the relationship between these complex oxidation mechanisms and flavour characteristics.

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