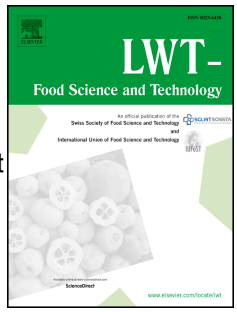
Journal Pre-proof



Application of a LED-UV based light technology for decontamination of chicken breast fillets: impact on microbiota and quality attributes

Arturo B. Soro, Paul Whyte, Declan J. Bolton, Brijesh K. Tiwari

PII: S0023-6438(21)00450-3

DOI: https://doi.org/10.1016/j.lwt.2021.111297

Reference: YFSTL 111297

To appear in: *LWT - Food Science and Technology*

Received Date: 1 November 2020

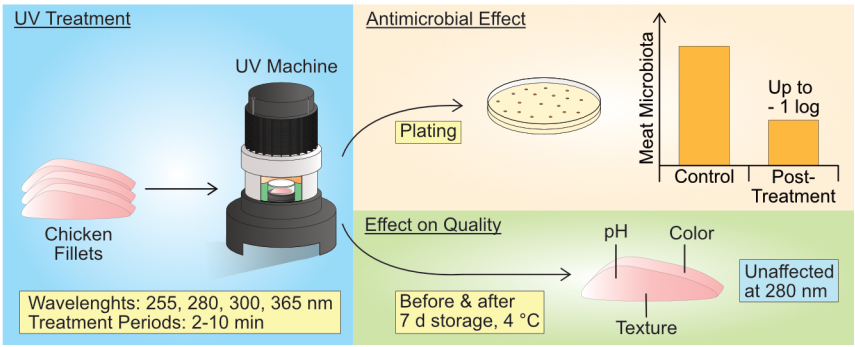
Revised Date: 4 March 2021

Accepted Date: 10 March 2021

Please cite this article as: Soro, A.B., Whyte, P., Bolton, D.J., Tiwari, B.K., Application of a LED-UV based light technology for decontamination of chicken breast fillets: impact on microbiota and quality attributes, *LWT - Food Science and Technology*, https://doi.org/10.1016/j.lwt.2021.111297.

CRediT authorship contribution statement

Arturo B. Soro: Conceptualization, Methodology, Software, Data curation, Validation, Writing- Original Draft preparation and Editing. **Paul Whyte:** Supervision and Writing- Review and Editing. **Declan J. Bolton:** Supervision and Writing- Review and Editing. **Brijesh K. Tiwari:** Supervision, Writing- Review and Editing, Project administration and Funding acquisition.



Application of a LED-UV based light technology for decontamination of chicken breast fillets: impact on microbiota and quality attributes

Arturo B. Soro[1, 2], Paul Whyte[2], Declan J. Bolton[3], Brijesh K. Tiwari[1]

[1]Department of Food Chemistry and Technology, Teagasc Food Research Centre, Ashtown, Dublin 15, Ireland.

[2]UCD School of Veterinary Medicine, University College Dublin, Belfield, Dublin 4, Ireland.

[3]Department of Food Safety, Teagasc Food Research Centre, Ashtown, Dublin 15, Ireland.

Contact information for corresponding author: Brijesh K. Tiwari, Teagasc Food Research Centre, Ashtown, Dublin D15 KN3k, Ireland, brijesh.tiwari@teagasc.ie

Email addresses: Arturo B. Soro: arturoblazsor@hotmail.com

Paul Whyte: paul.whyte@ucd.ie

Declan J. Bolton: declan.bolton@teagasc.ie

Abstract

Light-emitting diode (LED) technologies are economical and efficient devices that could be considered in poultry processing as disinfection strategies. This study evaluated the efficacy of a LED-based device to reduce the microbial load on chicken meat and investigated it's impact on selected quality parameters. Quality parameters including pH, texture and color after LED-UV exposure and during subsequent storage for 7 days at 4℃ were investigated. Diced chicken breast fillets were exposed to UV light wavelengths of 255, 280, 300 and 365 nm for 2, 4, 6, 8 and 10 min. A microbiological analysis was conducted on chicken samples to enumerate bacterial counts. Reductions between 1.17 and 1.67 log CFU/g for total viable counts of mesophilic, psychrophilic bacteria and total Enterobacteriaceae counts were observed, whereas, up to 2 log CFU/g was obtained for *Pseudomonas* and lactic acid bacteria groups after treatment with wavelengths of 280, 300 and 365 nm. Furthermore, color, texture and pH were not affected by exposure to UV light at 280 nm even following 7 days storage. Thus, LED-based technologies could be applied on poultry meat to reduce the levels of spoilage bacteria while maintaining quality attributes.

Keywords

Ultraviolet light, decontamination, poultry processing, novel technologies, food safety

1. Introduction

The food industry has evaluated and optimized new processes and technologies for improving food safety and preventing a deterioration in quality caused by current industrial processes (Morales-de la Peña, Welti-Chanes, & Martín-Belloso, 2019). The poultry industry is currently searching for novel alternative technologies to replace chemical or heat based methods (Umaraw, Prajapati, Verma, Pathak, & Singh, 2018). As a consequence, novel non-thermal technologies such as ultrasound, cold plasma, pulsed electric fields, among others, have recently been considered as decontamination and preservation techniques that could potentially be applied in the food industry and especially in poultry processing. Therefore, these emerging technologies could assure the safety while also improving the quality of food products (Režek Jambrak, Vukušić, Donsi, Paniwnyk, & Djekic, 2018).

In particular, ultraviolet (UV) light has been widely employed for decontamination purposes in water, air and surfaces. Along the light spectrum, UV irradiation is situated near visible light between 100 and 400 nm and can be divided into three different regions: UV-A (315-400 nm), B (280-315 nm) and C (200-280 nm). The UV-C spectrum has been associated with the capacity to damage and/or destroy bacterial structures which are required for growth and replication (Guerrero-Beltrán & Barbosa-Cánovas, 2016). Although the germicidal effects of UV light have been extensively studied during the past decades, the efficacy and impact of this technology when applied in complex matrices like food requires further investigation (Koutchma, 2009).

Decontamination of poultry meat with UV light at a wavelength of 254 nm has been carried out previously to control pathogens like *Salmonella*, *Listeria monocytogenes*, *Escherichia coli* and *Campylobacter* (Chun, Kim, Lee, Yu, & Song, 2010; Haughton et al., 2011; McLeod et al., 2018; Sommers, Scullen, & Sheen, 2016; Yang, Sadekuzzaman, & Ha, 2017). All of these authors studied the effect of UV light emitted by lamps in a specific wavelength. In recent years, light-emitting diodes (LED) based on light transmission through two terminals have appeared as an alternative to UV lamps as a result of their lower power consumption and heat emissions, reduced cost, compact and robust design and higher efficiency. Haughton et al. (2012) evaluated the use of a LED-based technology at a wavelength of 395 nm to inactivate *Campylobacter*. These authors observed the potential of LED technology for the decontamination of chicken meat and demonstrated the antimicrobial effect of an UV wavelength outside the UV-C spectral region. Thus, further information is

needed to select the best wavelength(s) or spectral region of UV light to maximize microbial inactivation while minimizing any deterioration in the quality of chicken meat. LED-UV light devices offer an opportunity to evaluate the effect of several wavelengths and could be applied to the food chain as a result of them not producing any toxic by-products, their cost effectiveness and easy scale-up potential (Hinds, O'Donnell, Akhter, & Tiwari, 2019).

Furthermore, authors such as McLeod et al. (2018), Haughton et al. (2012) and Lazaro et al. (2014) have investigated the impact of UV light on spoilage bacteria and the quality of poultry meat. However, there is currently insufficient information about the efficacy of LED devices for the inactivation of spoilage bacteria present in chicken meat that can grow at refrigeration temperatures. Technological advances have allowed more powerful and efficient UV light devices to be developed, and thus, it is necessary that these alternatives be considered (Koutchma, 2019). Furthermore, the impact of this technology on the quality of poultry meat should also be investigated. Koutchma, Forney and Moraru (2009) demonstrated that UV light at 254 nm can affect the color and texture of food products due to the generation of free radicals and concluded that UV light can be absorbed by food structures within a wavelength range with negative repercussions on food quality. In the literature, there is a lack of evidence showing the effect of different spectral regions on the quality attributes of chicken meat.

Cold plasma is another technology that can be applied to decontaminate poultry meat. This technology has been demonstrated to minimize the negative quality effects on chicken meat when treatment parameters are optimized. Additionally, non-thermal cold plasma may be comparable to UV light in terms of mechanisms of action to inactivate microorganisms and effects on meat quality. However, there are some limitations associated with cold plasma, in particular their manufacture and potential for scaling-up (Gavahian, Chu, & Jo, 2019).

Incorporation of a LED-based technology in poultry processing could effectively reduce the levels of spoilage bacteria in the final product while maintaining desirable quality attributes. In addition, the easy scaling-up process and low price of this technology, among other benefits, could facilitate its implementation in the poultry industry. The aim of the present study was to investigate the application of several UV light wavelengths with different time points using a LED device in order to establish an effective treatment in which the microbial burden on chicken could be reduced while not adversely affecting quality parameters. Therefore, the specific objectives of this study were to: 1) determine the

effectiveness of the LED-UV based technology at different wavelengths and time points to reduce total viable counts of mesophilic (TVCm) and psychrophilic (TVCp) bacteria, total Enterobacteriaceae counts (TEC), *Pseudomonas* and lactic acid bacteria (LAB), and 2) evaluate the impact of the selected UV treatments on quality parameters of chicken meat such as pH, texture and color.

2.Materials and methods

2.1 Samples

Skinless chicken breast fillets were purchased 2-3 days before their best-before date at a local supermarket (SuperValu) in Dublin (Ireland). Chicken trays were stored at 4 ˚C and used within 3 h of purchase.

2.2 UV-LED equipment

The LED device (PearlLab Beam, Aquisense technologies, NC, USA) consisted of a LED head or UVinaire™, UV homogenizing tube and control box as Figure 1 shows. In the LED head, the light source was protected by a quartz emission window and directly coupled with a cooling fan which prevented overheating. This equipment was connected to a UV homogenizing tube or chamber where samples were positioned and treated. The treatment chamber was completely closed to avoid the passage of visible light and potential interference. To select the UV light wavelength, four switches were in place in the control box corresponding to three different wavelengths and a shutter switch, with the latter serving as a safety measure (the off position prevented operation of the equipment). From both devices, wavelengths of 255 ± 1, 280 ± 1, 300 ± 4 and 365 ± 3 nm were selected and presented a full bandwidth of 12.3, 12.4, 16.9 and 8.9 nm at half of the maximum, respectively. In addition, the fluence rate of the applied light was measured in W/cm^2 using a UV radiometer (Opticalmeter, model ILT2400, International light technologies, MA, USA) on the surface of glass petri dishes, which was 0.003 W/cm^2 at 255 nm, 0.068 W/cm^2 at 280 nm, 0.049 W/cm^2 at 300 nm, and 0.043 W/cm^2 at 365 nm. The UV fluence rate of each wavelength on the surface of chicken samples were also determined as presented in Table 1. The UV light dose (D) of each fluence rate measured on the surface of meat was calculated using the equation 1:

Eq. 1) $D = F \times t$,

where the D is the UV light dose in W x min x cm^{-2}, F is fluence rate in W/cm^2 and t is the treatment time in minutes.

INSERT FIGURE 1 HERE

INSERT TABLE 1 HERE

2.3 Effect of UV light on the chicken microbiota

Chicken fillets were cut into square pieces of approximately 10-15 g and thickness of 1-1.6 cm under aseptic conditions. In the meantime, samples were kept at 4℃ covered with plastic petri dishes. Every piece of chicken was centrally placed inside of two glass petri dishes 5 cm from the source and treated with UV light in a sterile and dark chamber (Figure 1). Glass petri dishes were employed to prevent cross-contamination between samples and protect the meat samples from drying. In addition, to maximize the effect of UV light, samples were treated on both sides which consisted of aseptically inverting the chicken pieces following the procedure of Haughton et al. (2012). The previously stated wavelengths were evaluated at time points of 2, 4, 6, 8, and 10 min and untreated samples stored aseptically at 4℃ were used as controls. Treatments were performed in triplicate and three independent experiments were carried out. Finally, the temperature of the samples was measured before and after each treatment with a temperature probe (Total-range digital thermometer, Traceable, VWR, USA) to determine possible temperature increases. Observed increases in temperature of the chicken pieces were no greater than 2℃.

2.3.1 Microbiological analysis

Treated and control samples were stomached (Star Blender, LB 400, VWR, USA) for 90 s in maximum recovery diluent (MRD, Oxoid, UK) in a 1/10 (w/v) proportion and ten-fold serial dilutions were prepared. Afterwards, an inoculum of 0.1 mL of each dilution was spread plated in duplicate onto plate count agar (PCA, Oxoid, UK), *Pseudomonas* agar base (PSA, Oxoid, UK) with *Pseudomonas* CFC selective agar supplement (Oxoid, UK), and Man, Rogosa and Sharpe agar (MRS, Oxoid, UK) for enumeration of TVCm/TVCp, *Pseudomonas* and LAB, respectively. Moreover, following the ISO method for enumeration of *Enterobacteriaceae*, a double layer of violet red bile

glucose agar (VRBGA, Oxoid, UK) was poured onto petri dishes with 1 mL of inoculum of the sample. The inoculated plates of PCA, VRBGA, PSA and MRS were incubated at 30 ℃ for 2 d (TVCm) and 6.5 ℃ for 10 d (TVCp), 37 ℃ for 1 d, 25 ℃ for 2 d and 30 ℃ for 3 d, respectively. After incubation, bacterial colonies were counted and mean values were calculated and expressed as $\log_{10}$ CFU per g of chicken meat. The presented results are showed as logarithmic reduction units calculated by subtracting mean bacterial levels of controls and treatments.

2.4 Effect of UV light on the quality parameters of chicken meat

Similar procedures were carried out in treated and control samples when chicken quality parameters were evaluated. Treatments of UV light with wavelengths of 280 and 365 nm were selected and assessed for 6 and 10 min on chicken pieces of 10-15 g with 8 samples replicates per treatment. The pH, color and texture were analyzed for treated samples and controls on the same day (day 0) and after 7 days' storage at 4 ℃ (day 7) inside sterile plastic petri dishes.

2.4.1 Measurement of pH

The pH of the meat surface was measured in duplicate in all samples using a pH electrode (Foodcare pH and temperature electrode, FC2323, Hanna Instruments, Bedfordshire, UK) and portable pH meter (Hanna, model HI 98163, Hanna Instruments, Bedfordshire, UK). Measurements were performed before and after treatment and subsequent storage for 7 days under refrigeration conditions.

2.4.2 Instrumental color analysis

The effect of UV light on the color of chicken meat was evaluated after treatment and storage for 7 days at 4^{o}C. Color analysis was performed with a portable colorimeter (Chroma meter CR-400, Konica Minolta, UK) with an illumination area of 8 mm and 2º standard observer. Moreover, Hunter values of *L**, *a** and *b** were determined as indicators of luminosity, redness and yellowness, respectively. Standardization was carried out with a blank standard plate. Color measurements in

chicken samples were taken in 8 locations per sample and treatments were carried out in triplicate. Additionally, ΔE values were calculated with the equation 2 to determine total differences in meat color.

Eq. 2) $\Delta E = \sqrt[2]{(\Delta L)^2} + \sqrt[2]{(\Delta a)^2} + \sqrt[2]{(\Delta b)^2}$

where ΔL, Δa and Δb are calculated by subtracting the Hunter values of the samples after storage from the controls.

2.4.3 Texture Profile Analysis (TPA)

The texture of raw chicken pieces was evaluated using an Instron Universal testing machine (Instron, Model No. 5543, UK) following the procedure of Inguglia, Burgess, Kerry and Tiwari (2019). In order to assess the effect of UV light on texture, a TPA was carried out with a flat circular probe of 35 mm which was attached to a stainless steel cell of 500 N. A one-time measure was executed for each chicken piece (1-1.5 cm height) and consisted of a double compression cycle up to 60% of the original portion height. Eight replicates of each treatment were performed and TPA parameters such as hardness, springiness, cohesiveness, gumminess and chewiness were obtained as measurable values. Hence, hardness (N) is the maximum force reached in the first compression cycle, springiness (mm) is the recovered distance between compressions, cohesiveness (dimensionless) is the ratio of the two areas of compression, gumminess is calculated as hardness x cohesiveness and chewiness is the result of multiplying springiness and gumminess.

2.5 Statistical analysis

Treatments in triplicate and three independent experiments (n = 9) were carried out for the study evaluating the antimicrobial effect of UV light on the chicken microbiota. To assess the impact of UV irradiation on the quality parameters of chicken meat, treatments were analyzed using 8 duplicates (N = 8). In particular, color analysis was evaluated in duplicates of 8 measures per sample and treatments in triplicate (N = 24). The average band standard deviation was calculated from data obtained from these experiments. A comparison between samples and controls was carried out using factorial analysis of variance (ANOVA) and statistical differences were detected with the Tukey *post*

hoc test at $\alpha < 0.05$ level. GraphPad Prism 7.0 for Windows (GraphPad software Inc, San Diego, CA, USA) was used as statistical and graph creator program.

3.Results

3.1 Microbiological analysis

Mean bacterial concentrations of the target bacteria were obtained in untreated chicken breast samples. TVCm and TVCp (mesophilic and psychrophilic), TEC, *Pseudomonas* and LAB were 3.57, 3.91, 1.81, 3.21 and 3.05 log CFU/g, respectively (Appendix A). In general, the applied wavelengths had a significant influence on the levels of the various bacterial groups examined as shown in Figure 2. Conversely, the 255-nm wavelength was notably less effective when compared to the other wavelengths. In particular, the application of UV light treatment on chicken fillets for 6 min resulted in significant reductions in TVCm of 1.67 log CFU/g at a 300 nm wavelength ($p < 0.01$) and 1.43 log CFU/g at a 280 nm wavelength ($p < 0.001$) (Figure 2 A). Although lower bacterial reductions were observed after 8 and 10 min treatments using 300 and 280 nm wavelengths, the reductions were not statistically different between treatment times ($p \geq 0.05$). However, chicken samples assessed for 4 min using a 365 nm wavelength had significantly higher reductions of 1.17 log CFU/g for TVCm ($p < 0.001$) compared to 0.42 log CFU/g after 10 min treatment. Similar reductions of 1.37 and 1.55 log CFU/g in TVCp ($p < 0.001$) were observed in chicken meat when UV light was applied at 280 nm and 300 for 6 min and 10 min, respectively (Figure 2.B). In addition, a significant decrease in TVCp reductions was detected in chicken samples treated with 365 nm for 8 min in comparison with treatment times of 6 and 10 min for the same wavelength ($p < 0.05$).

INSERT FIGURE 2 HERE

TEC bacteria showed a similar pattern to TVCm on samples treated for 6 min with 365 nm light where a reduction of 1.54 log CFU/g was achieved (Figure 2 C) ($p < 0.0001$). Furthermore, wavelengths of 300 and 280 nm significantly reduced concentrations of TEC by 1.54 and 1.17 log CFU/g ($p < 0.0001$) when the same treatment time was applied. *Pseudomonas* and LAB groups were the most susceptible to UV irradiation among the organisms assessed in the current study. The most effective treatments were 300 nm for 8 min and 280 nm for 10 min resulting in reductions of 2.16 and 2.50 log CFU/g for *Pseudomonas* and LAB concentrations, respectively (Figure 2 D and E) ($p < 0.0001$). In

contrast, greater reductions in LAB were observed when longer UV treatments were applied. Even when the 255 nm light was applied, a maximum reduction of 0.80 log CFU/g ($p < 0.05$) was achieved for LAB which was the highest inactivation observed in the study at this wavelength. Although bacterial reductions in LAB counts were higher than those achieved for TVCp using the same treatment parameters, lower levels of inactivation were also detected in TVCp after longer UV light treatments such as 8 min at 365 nm in chicken meat. Consequently, the stability of the UV light intensity was investigated as a result of these generalized effects on the target bacteria within the chicken. The intensity of the light in the different wavelengths did not vary during the treatment period (data not shown).

3.2 Effect of UV light on the quality parameters of chicken meat

The impact of UV light at wavelengths of 280 and 300 nm for 6 and 10 min on chicken meat was analyzed for changes in pH, color and texture based on the microbial inactivation data (see section 3.1). The average pH of non-treated chicken meat was 5.64 on raw fillets and increased through storage up to a maximum of 6.50 (Table 2). In contrast, all UV treated samples showed slow rate of pH increase compared to control during the studied storage period. In particular, samples treated with 280 nm had a final pH of 5.90-5.98, which was significantly lower compared to control samples ($p < 0.05$).

INSERT TABLE 2 HERE

In addition, the color of chicken meat was not significantly altered by any of the UV light treatments compared to controls as presented in Table 3. At the end of storage, significant reductions ($p < 0.05$) in *L** (lightness) and *a** (redness) values were observed for control samples, while the *b** (yellowness) parameter remained unchanged (Table 4). Chicken samples treated with 365 nm light for 6 and 10 min resulted in the development of darker colored meat compared to control. These changes in total color of chicken meat were confirmed with the calculation of ΔE values (Table 4). Thus, differences in color can be classified as highly perceived ($\Delta E > 3$), perceived ($1.5 < \Delta E < 3$) and small differences ($\Delta E < 1.5$) (Tiwari, Muthukumarappan, O'Donnell, & Cullen, 2008). The storage period had a negative impact in the color of meat in controls and samples exposed to 365 nm which showed ΔE values up to

3. Lastly, it is worth noting that the *L**, *a** and *b** values of the broiler meat did not change significantly during storage for samples treated with 280 nm and thus, meat color was preserved up to 7 days. Furthermore, storage time and UV light treatment did not have an effect on the texture of chicken fillets, except for an increase in the cohesiveness of treated meat at 280 nm for 6 min (Table 5) ($p < 0.05$). Nevertheless, this variation in cohesiveness was not observed following storage and may have been due to variability between samples.

INSERT TABLE 3 HERE

INSERT TABLE 4 HERE

INSERT TABLE 5 HERE

4.Discussion

4.1 Microbiological analysis

In the literature, the effect of UV light has been extensively studied as a disinfection strategy for poultry meat. However, most of the authors have focused mainly on the application of UV light at a wavelength of 254 nm for inoculated bacteria on chicken meat (Haughton et al., 2011; Sommers, Scullen, & Sheen, 2016; Sommers, & Sheen, 2015, Yang, Sadekuzzaman, & Ha, 2017). Little information is available on the effect of other wavelengths situated outside the UV-C spectral region. Furthermore, none of the former studies have evaluated LED-based technologies as a potential hygiene measure that could be applied during broiler processing (Soro, Whyte, Bolton, & Tiwari, 2021).

Haughton et al. (2012) examined the efficacy of a LED-UV light system using a specific wavelength of 395 nm to reduce *Campylobacter*, TVCm and TEC levels on poultry meat. Bacterial counts were reduced by between 1 and 3 log CFU/g with treatment times of 5 (0.15 W min/cm^2) and 10 min (0.30 W min/cm^2). In the present study, similar results were observed in bacterial reductions of TVCm and TEC (1 log CFU/g) when UV light at 365 nm was applied for 6 min (0.23 W min/cm^2) on chicken meat. Thus, this research group demonstrated that it is necessary to consider other wavelengths within the UV light spectrum to assess the full potential of this technology for disinfection purposes. Moreover, variability in the levels of reduction achieved for naturally contaminated bacteria after UV exposure was also found by Haughton et al. (2012). Hence, different bacterial concentrations in chicken

306 batches, the wide variety of microorganisms and differences in resistance to UV light among bacterial
307 strains could account for some of the variability observed. However, more research is required to
308 understand the resistance mechanisms of bacteria against UV light and the differences of resistance
309 between strains within the same species (Gayán, Condón, & Álvarez, 2013).
310 Additionally, few studies have considered UV light for the decontamination of TVCm and TEC on
311 chicken meat (Haughton et al., 2012; Haughton et al., 2011; Lazaro et al., 2014). In particular, Lazaro
312 et al. (2014) applied UV light at 254 nm during a 90 s treatment (0.003 W min/cm^2) on chicken fillets
313 at a distance of 14 cm from the light source and obtained reductions of less than 1 log CFU/g in these
314 bacterial groups. In agreement with the latter, our study observed an inactivation effect below 0.80 log
315 CFU/g in all target bacteria following UV light treatment at 255 nm for 10 min (0.010 W min/cm^2). In
316 contrast, Haughton et al. (2011) achieved reductions of 1.76 and 1.29 log CFU/g in TVCm and TEC,
317 respectively, with UV light at 254 nm for 32 s (0.003 W min/cm^2) on chicken breasts at a distance of
318 6.5 cm from the source. These results differed significantly from those obtained in the present study
319 with bacterial reductions expected to be higher in chicken samples exposed to 255 nm light. Factors
320 associated with the device configuration and type of reactor are strongly dependent variables on the
321 effectiveness of the treatment and could affect the UV process (Hinds et al., 2019). Therefore,
322 optimization of each UV light device is required for determining it's microbial decontamination
323 potential.
324 In the present study, initial counts of TVCm (3.57 log CFU/g) and TEC (1.81 log CFU/g) on chicken
325 fillets were reduced by between 1.2 and 1.7 log CFU/g when treatments using 280, 300 and 365 nm
326 for 6 min were carried out. Similar reductions were obtained in different studies which inoculated
327 foodborne pathogens, including *Salmonella*, *E. coli*, *Campylobacter* and *L. monocytogenes* on
328 chicken meat (Chun et al., 2010; Haughton et al., 2012; Haughton et al., 2011; McLeod et al., 2018;
329 Yang, Sadekuzzaman, & Ha, 2017). This indicates that a significant proportion of the total mesophilic
330 bacteria has been potentially inactivated by UV light. The LED-technology could be evaluated in order
331 to assess if it is capable of reducing levels of common foodborne pathogens on poultry meat. In
332 particular, *Campylobacter* has raised public health concerns in the last decades due to it's high
333 prevalence in poultry meat and the number of campylobacteriosis cases associated with meat
334 consumption (EFSA, 2010). Soro, Whyte, Bolton, and Tiwari (2020) reviewed the potential application

of UV light against *Campylobacter* and highlighted it's promising results, low cost and potential for scaling-up in a food processing environment.

To the best of our knowledge, there is a lack of data available on the effect of UV light on TVCp, *Pseudomonas* and LAB in broiler meat. Cichoski et al. (2015) studied the impact of this technology on psychrophilic bacteria and achieved reductions of approximately 0.9 log CFU/g with UV light at 254 nm for 7 min (0.946 W min/cm^2) on chicken drumsticks. In this study, bacterial reductions of 0.41 CFU/g in TVCp were obtained after exposure to UV light (254 nm) for 8 min (0.008 W min/cm^2). Wavelengths of 280, 300, 365 nm were more effective against TVCp, *Pseudomonas* and LAB with increased reductions in the latter two groups of bacteria (2 log CFU/g).

According to Rouger, Tresse, and Zagorec (2017), these bacterial groups are spoilage bacteria which cause quality issues in meat during refrigerated storage. Thus, psychrophilic species can become more prevalent in chicken meat during storage and TVCp should be considered when evaluating the microbial shelf-life of chicken meat (Rouger, Remenant, Prevost, & Zagorec, 2017).

4.2 Effect of UV light on the quality parameters of chicken meat

The second part of this study examined the impact of UV light on parameters such as pH, texture and color of broiler meat. No adverse effects in color were observed after immediate exposure to UV light at 280 nm for 6 or 10 min, and at the end of a storage period of 7 days at 4℃. Chun et al. (2010), McLeod et al. (2018), Yang, Sadekuzzaman, and Ha, (2017) reported similar results when UV light at 254 nm was applied. However, some authors described significant differences in the color values of treated samples in comparison to controls during refrigerated storage (Park & Ha, 2014; Lazaro et al., 2014). For instance, Lazaro et al. (2014) showed a decrease in *L** and *b** value after 9 days storage in samples treated with UV light at 254 nm for a maximum of 2 min (0.195 W min/cm^2). In the present study, significant decreases in *L** and increases in *b** values were detected in chicken samples exposed to UV light at 365 nm for 6 (0.234 W min/cm^2) and 10 min (0.390 W min/cm^2) after the 7-day storage period. In contrast, Haughton et al. (2012) observed an increase in *L** when UV light at 395 nm for 10 min was directly applied to chicken meat at a distance of 3 cm. However, changes in meat color were observed immediately after UV treatment, unlike the present study in which color variations were noted only after storage.

Moreover, meat texture is a quality parameter that has not yet been considered in the literature for the evaluation of UV light. Nevertheless, a sensorial panel carried out by Park and Ha (2014) identified a softer meat texture in chicken fillets after extensive exposure to UV light at 260 nm (3.6 W min/cm^2). The current study assessed the texture of chicken samples treated with UV light at 280 and 365 nm and showed no alteration in texture parameters after UV irradiation and storage at refrigeration temperature. Additionally, the pH of meat slightly changed post-treatment with UV light at 280 nm. However, these treated chicken samples showed a significantly lower increase in pH than controls after storage. Slight changes in the pH of meat after storage were also found by Chun et al. (2010) and Lazaro et al. (2014) in chicken samples treated with UV light. This study has not considered other factors such as protein and lipid oxidation, lipid profile, amine formation and water holding capacity, for example. Little information is currently available in the literature about these parameters (Chun et al., 2010; Cichoski et al., 2015; Lazaro et al., 2014; Park & Ha, 2014). Therefore, further investigation is required to evaluate these parameters in chicken meat before considering implementation of this technology in the poultry industry.

5. Conclusion

In the current study, the LED-based device demonstrated an inactivation effect on chicken for all of the bacterial groups examined when wavelengths of 280, 300 and 365 nm were applied. Specifically, *Pseudomonas* and LAB showed the largest reductions and therefore, were the most susceptible bacterial groups to UV light. Furthermore, a number of quality parameters of chicken such as color, texture and pH did not change significantly when exposed to a UV light wavelength of 280 nm and 7-day storage period at 4℃. Therefore, LED-based technology using previously optimized conditions could be used within poultry processing facilities to reduce levels of spoilage bacteria on chicken breast fillets while maintaining quality attributes such as color, pH and texture.

Acknowledgments

The present work was supported by the Teagasc Walsh Fellowship program, Department of Agriculture, Food, and Marine (DAFM) under the Food Institutional Research Measure (FIRM)

program [Grant number: DAFM/17/F/275]. The authors wish to acknowledge Daniel Ekhlas, Teagasc Food Research Centre Ashtown, for illustrating the Graphical Abstract and Figure 1.

Conflict of interest declaration

The authors declare no conflict of interest.

6. References

Chun, H. H., Kim, J. Y., Lee, B. D., Yu, D. J., & Song, K. B. (2010). Effect of UV-C irradiation on the inactivation of inoculated pathogens and quality of chicken breasts during storage. Food Control, 21(3), 276-280. https://doi.org/10.1016/j.foodcont.2009.06.006

Cichoski, A. J., Moura, H. C., Silva, M. S., Rampelotto, C., Wagner, R., Barin, J. S., . . . Dalla Costa, M. A. (2015). Oxidative and microbiological profiles of chicken drumsticks treated with ultraviolet-C radiation. Journal of Food Processing and Preservation, 39(6), 2780-2791. https://doi.org/10.1111/jfpp.12529

EFSA. (2010). Analysis of the baseline survey on the prevalence of Campylobacter in broiler batches and of Campylobacter and Salmonella on broiler carcasses in the EU, 2008 - Part A: Campylobacter and Salmonella prevalence estimates. EFSA Journal, 8(3). https://doi.org/10.2903/j.efsa.2010.1503

Gavahian, M., Chu, Y-H., Jo, C. (2019). Prospective applications of cold plasma for processing poultry products: Benefits, effects on quality attributes, and limitations. Comprehensive Reviews in Food Science and Food Safety, 18: 1292-1309. https://doi.org/10.1111/1541-4337.12460

Gayán, E., Condón, S., & Álvarez, I. (2013). Biological aspects in food preservation by ultraviolet light: a review. Food and Bioprocess Technology, 7(1), 1-20. https://doi.org/10.1007/s11947-013-1168-7

Guerrero-Beltrán, J. A., & Barbosa-Cánovas, G. V. (2016). Advantages and Limitations on Processing Foods by UV Light. Food Science and Technology International, 10(3), 137-147. https://doi.org/10.1177/1082013204044359

Haughton, P. N., Grau, E. G., Lyng, J., Cronin, D., Fanning, S., & Whyte, P. (2012). Susceptibility of Campylobacter to high intensity near ultraviolet/visible 395+/-5nm light and its effectiveness for the decontamination of raw chicken and contact surfaces. International Journal of Food Microbiolology, 159(3), 267-273. https://doi.org/10.1016/j.ijfoodmicro.2012.09.006

Haughton, P. N., Lyng, J. G., Cronin, D. A., Morgan, D. J., Fanning, S., & Whyte, P. (2011). Efficacy of UV light treatment for the microbiological decontamination of chicken, associated packaging, and contact surfaces. Journal of Food Protection, 74(4), 565-572. https://doi.org/10.4315/0362-028X.JFP-10-356

Hinds, L. M., O'Donnell, C. P., Akhter, M., & Tiwari, B. K. (2019). Principles and mechanisms of ultraviolet light emitting diode technology for food industry applications. Innovative Food Science & Emerging Technologies, 56. https://doi.org/10.1016/j.ifset.2019.04.006

Inguglia, E. S., Burgess, C. M., Kerry, J. P., & Tiwari, B. K. (2019). Ultrasound-assissted marination: Role of frequencies and treatment time on the quality of sodium-reduced poultry meat. Foods, 8(10), 473. https://doi.org/10.3390/foods8100473

Koutchma, T., L. Forney, and C. Moraru. 2009. Principles and applications of UV technology. Pages 1–32 in Ultraviolet Light in Food Technology. T. Koutchma, L. Forney, and C. Moraru, ed. CRC Press, Boca Raton, FL.

Koutchma, T. (2009). Advances in ultraviolet light technology for non-thermal processing of liquid foods. Food and Bioprocess Technology, 2(2), 138-155. https://doi.org/10.1007/s11947-008-0178-3

Koutchma, T. (2019). Ultraviolet light in food technology: principles and applications (Vol. 2): CRC press. https://doi.org/10.1201/9781420059519.ch4

Lazaro, C. A., Conte-Junior, C. A., Monteiro, M. L., Canto, A. C., Costa-Lima, B. R., Mano, S. B., & Franco, R. M. (2014). Effects of ultraviolet light on biogenic amines and other quality indicators of chicken meat during refrigerated storage. Poultry Science, 93(9), 2304-2313. https://doi.org/10.3382/ps.2013-03642

McLeod, A., Hovde Liland, K., Haugen, J.-E., Sørheim, O., Myhrer, K. S., & Holck, A. L. (2018). Chicken fillets subjected to UV-C and pulsed UV light: Reduction of pathogenic and spoilage bacteria, and changes in sensory quality. Journal of Food Safety, 38(1). https://doi.org/10.1111/jfs.12421

Morales-de la Peña, M., Welti-Chanes, J., & Martín-Belloso, O. (2019). Novel technologies to improve food safety and quality. Current Opinion in Food Science, 30, 1-7. https://doi.org/10.1016/j.cofs.2018.10.009

Park, S. Y., & Ha, S.-D. (2014). Ultraviolet-C radiation on the fresh chicken breast: Inactivation of major foodborne viruses and changes in physicochemical and sensory qualities of product. Food and Bioprocess Technology, 8(4), 895-906. https://doi.org/10.1007/s11947-014-1452-1

Režek Jambrak, A., Vukušić, T., Donsi, F., Paniwnyk, L., & Djekic, I. (2018). Three pillars of novel nonthermal food technologies: Food safety, quality, and environment. Journal of Food Quality, 2018, 1-18. https://doi.org/10.1155/2018/8619707

Rouger, A., Remenant, B., Prevost, H., & Zagorec, M. (2017). A method to isolate bacterial communities and characterize ecosystems from food products: Validation and utilization in as a reproducible chicken meat model. International Journal of Food Microbiology, 247, 38-47. https://doi.org/10.1016/j.ijfoodmicro.2016.04.028

Rouger, A., Tresse, O., & Zagorec, M. (2017). Bacterial contaminants of poultry meat: Sources, species, and dynamics. Microorganisms, 5(3). https://doi.org/10.3390/microorganisms5030050

Sommers, C. H., Scullen, O. J., & Sheen, S. (2016). Inactivation of uropathogenic *Escherichia coli* in ground chicken meat using high pressure processing and gamma radiation, and in purge and chicken meat surfaces by ultraviolet light. Frontiers in Microbiology, 7(413). https://doi.org/10.3389/fmicb.2016.00413

Sommers, C. H., & Sheen, S. (2015). Inactivation of avirulent *Yersinia pestis* on food and food contact surfaces by ultraviolet light and freezing. Food microbiology, 50, 1-4. https://doi.org/10.1016/j.fm.2015.02.008

Soro, A. B., Whyte, P., Bolton, D. J., & Tiwari, B. K. (2020). Strategies and novel technologies to control Campylobacter in the poultry chain: A review. Comprehensive Reviews in Food Science and Food Safety, 19(4), 1353-1377. https://doi.org/10.1111/1541-4337.12544

Soro, A. B., Whyte, P., Bolton, D. J., & Tiwari, B. K. (2021). Modelling the effect of UV light at different wavelenghts and treatment combinations on the inactivation of *Campylobacter jejuni.* Innovative Food Science & Emerging Technologies, 69, 102626. https://doi.org/10.1016/j.ifset.2021.102626

Tiwari, B. K., Muthukumarappan, K., O'Donnell, C. P., & Cullen, P. J. (2008). Effects of sonication on the kinetics of orange juice quality parameters. Journal of Agricultural and Food Chemistry, 56, 2423-2428.

Umaraw, P., Prajapati, A., Verma, A. K., Pathak, V., & Singh, V. P. (2018). Control of Cmpylobacter in poultry industry from farm to poultry processing unit: A review. Critical Reviews in Food Science and Nutrition, 54(4), 659-665. https://doi.org/10.1080/10408398.2014.935847

Yang, S., Sadekuzzaman, M., Ha, S.-D. Reduction of *Listeria monocytogenes* on chicken breasts by combined treatment with UV-C light and bacteriophage ListShield. *LWT, 86*, 193-200. https://doi.org/10.1016/j.lwt.2017.07.060

Tables

Table 1. UV light fluence rate (W/cm^2) on chicken samples measured by radiometer and doses of UV light (W x min x cm^{-2}) calculated for each wavelength and time point.

			UV light Dose (W x min x cm^{-2})				
		Fluence rate (W/cm^2)	2	4	6	8	10
Wavelength (nm)	255	0.001	0.002	0.004	0.006	0.008	0.010
	280	0.041	0.082	0.164	0.246	0.328	0.410
	300	0.039	0.078	0.156	0.234	0.312	0.390
	365	0.039	0.078	0.156	0.234	0.312	0.390

Table 2. Evaluation of pH in broiler meat after treatments with UV light at 280 and 365 nm for 6 and 10 min (day 0) and at the end of the storage period (day 7) at 4℃.

	Storage period (days)	
Treatment	0	7
Control	5.64 ± 0.07	6.50 ± 0.14
280 nm/6 min	5.52 ± 0.04 *	5.90 ± 0.03 *
280 nm/10 min	5.78 ± 0.06 *	5.98 ± 0.15 *
365 nm/6 min	5.67 ± 0.09	6.24 ± 0.07 *
365 nm/10 min	5.62 ± 0.03	6.17 ± 0.12 *

Results expressed as Mean ± Standard Deviation.

Denotes statistically significant differences between controls and various treated samples in each column (*p < 0.05)

Table 3. Determination of the effect of UV light on the color of chicken meat following treatments at 280 and 365 nm for 6 and 10 min.

Treatment	Color measure	*L**	*a**	*b**	ΔE
Control	-	59.02 ± 1.75	2.55 ± 1.13	8.35 ± 0.85	-
280 nm/6 min	Before	56.80 ± 1.98	1.31 ± 0.43	6.74 ± 1.55	1.27
	After	55.58 ± 2.04	0.98 ± 0.36	6.87 ± 1.34	
280 nm/10 min	Before	60.26 ± 1.72	1.31 ± 0.41	8.93 ± 9.15	1.33
	After	59.03 ± 1.09	0.84 ± 0.48	9.15 ± 0.63	
365 nm/6 min	Before	56.26 ± 1.86	2.29 ± 0.73	7.52 ± 0.68	1.18
	After	55.31 ± 1.96	1.92 ± 0.43	6.92 ± 0.84	
365 nm/10 min	Before	59.16 ± 3.63	1.39 ± 0.73	8.47 ± 2.36	1.20
	After	58.58 ± 3.67	0.84 ± 0.39	7.57 ± 2.57	

Results expressed as Mean ± Standard Deviation.

Where *L*, a** and *b** values represent the luminosity, redness and yellowness, respectively.

No significant differences were found.

Table 4. Study of the influence of UV light on the color of broiler meat after treatment with 280 and 365 nm for 5 and 10 min and storage for 7 days at 4℃

Treatment	Storage period (days)	*L**	*a**	*b**	ΔE
Control	0	59.02 ± 1.75	2.55 ± 1.13	8.35 ± 0.85	3.32
	7	55.97 ± 2.11*	1.90 ± 0.75*	9.50 ± 1.77	
280 nm/6 min	0	55.58 ± 2.04	0.98 ± 0.36	6.87 ± 1.34	1.02
	7	54.56 ± 2.46	0.96 ± 0.39	6.87 ± 1.71	
280 nm/10 min	0	59.03 ± 1.09	0.84 ± 0.48	9.15 ± 0.63	0.91
	7	58.16 ± 1.86	0.57 ± 0.31	9.26 ± 0.62	
365 nm/6 min	0	55.31 ± 1.96	1.92 ± 0.43	6.92 ± 0.84	4.43
	7	51.31 ± 5.16*	1.85 ± 0.67	8.82 ± 1.85*	
365 nm/10 min	0	58.58 ± 3.67	0.84 ± 0.39	7.57 ± 2.57	3.56
	7	55.05 ± 3.53*	1.13 ± 0.72	7.91 ± 2.22	

Results expressed as Mean ± Standard Deviation.

Where *L*, a** and *b** values represent the luminosity, redness and yellowness, respectively.

The observed significant differences were of $p^* < 0.05$ compared to controls.

Table 5. Analysis of meat texture after treatment with UV light at 280 and 365 nm for 6 and 10 min (day 0) and at the end of the storage period (day 7) at 4℃.

TPA parameters	Storage period (days)	Control	280 nm/6 min	280 nm/10 min	365 nm/6 min	365 nm/10 min
Hardness	0	139.40 ± 29.59	109.32 ± 30.65	130.63 ± 24.81	124.14 ± 21.65	132.22 ± 8.26
	7	96.85 ± 31.90	137.74 ± 17.06	127.81 ± 39.41	122.00 ± 25.09	102.13 ± 38.82
Springiness	0	1.94 ± 0.39	2.23 ± 0.21	2.30 ± 0.48	2.28 ± 0.25	2.13 ± 0.27
	7	2.39 ± 0.59	2.66 ± 1.25	2.52 ± 0.23	2.30 ± 0.38	2.19 ± 0.26
Cohesiveness	0	0.14 ± 0.05	0.23 ± 0.05*	0.20 ± 0.05	0.21 ± 0.05	0.19 ± 0.04
	7	0.22 ± 0.09	0.22 ± 0.04	0.25 ± 0.06	0.19 ± 0.07	0.19 ± 0.05
Gumminess	0	24.89 ± 8.67	25.55 ± 9.88	24.88 ± 5.09	25.90 ± 6.29	23.03 ± 6.65
	7	21.97 ± 12.88	29.53 ± 5.83	32.97 ± 14.49	23.85 ± 11.23	19.92 ± 11.70
Chewiness	0	39.98 ± 22.52	57.08 ± 29.44	56.83 ± 19.32	59.56 ± 17.14	49.67 ± 16.94
	7	56.41 ± 36.42	74.54 ± 21.12	84.14 ± 38.72	57.77 ± 34.68	44.24 ± 30.54

532 Results expressed as Mean ± Standard Deviation.

533 The observed significant difference was of $p^* < 0.05$ compared to controls for each texture

534 parameter.

535

536

537

538

539

540

541

542

543

544

Figure captions

Figure 1. Illustration of a LED device in which the LED head (A), UV collimating tube (B) and control box (C) are represented. Sample position inside the UV chamber is also indicated as distance from the source of 5 cm.

Figure 2. Bacterial reductions (Log CFU/g) of TVCm (A), TVCp (B), TEC (C), Pseudomonas (D) and LAB (E) achieved with UV light treatments at wavelengths of 255, 280, 300 and 365 nm for each treatment period (2, 4, 6, 8 and 10 min) on chicken compared to untreated controls. Results were calculated as the mean and standard deviation of 9 replicates in 3 independent experiments. Significant different between samples and controls were of p* < 0.05, p** < 0.01, ***p < 0.001, p**** < 0.0001.

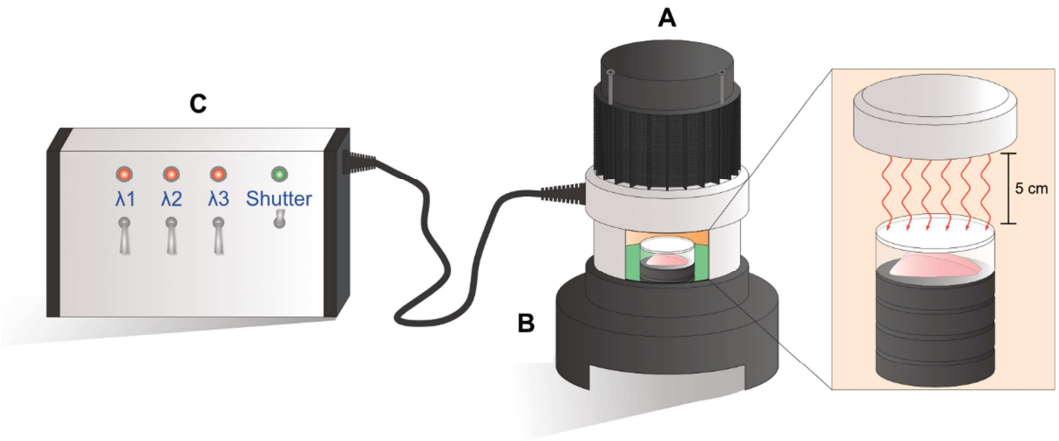
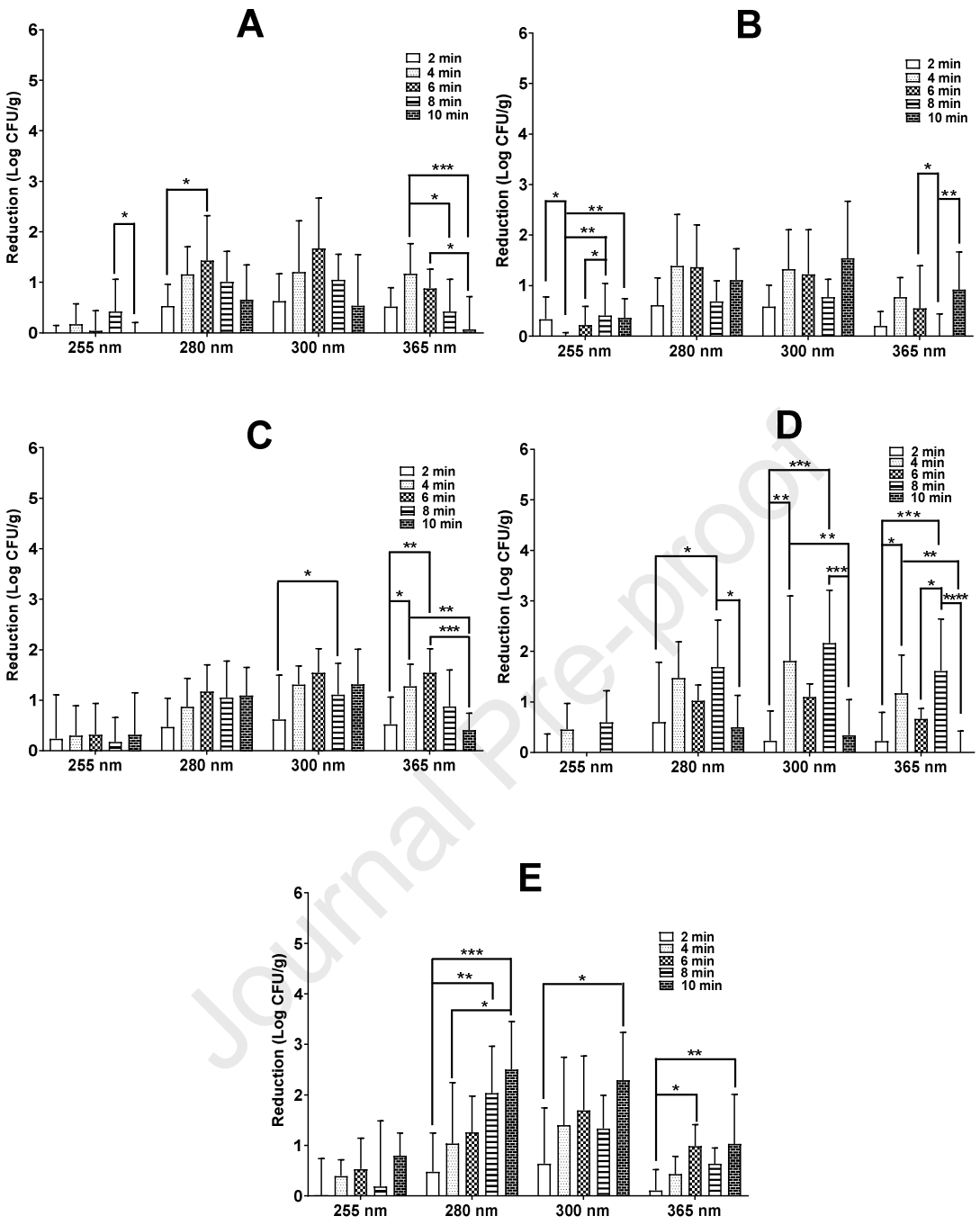


Figure 1. (color online only)



583

584 **Figure 2.**

585

586

587

588

Appendix

Table A.1 Initial concentration of TVCm and TEC and achieved bacterial reductions after the application of UV light at different wavelengths and treatment times.

Type of bacteria	Wavelength (nm)	Time (min)	Bacterial reduction (Log. CFU/g)	Initial concentration (Log. CFU/g)
TVC mesophiles	255	2	- 0.19 ± 0.34	3.57 ± 0.27
		4	0.17 ± 0.40	
		6	0.04 ± 0.39	
		8	-0.32 ± 0.48	
		10	-0.36 ± 0.56	
	280	2	0.53 ± 0.44	
		4	1.16 ± 0.55	
		6	1.43 ± 0.89	
		8	1.01 ± 0.60	
		10	0.66 ± 0.69	
	300	2	0.63 ± 0.54	
		4	1.21 ± 1.01	
		6	1.67 ± 1.00	
		8	1.05 ± 0.50	
		10	0.54 ± 1.02	
	365	2	0.52 ± 0.38	
		4	1.17 ± 0.60	
		6	0.88 ± 0.38	
		8	0.42 ± 0.64	
		10	0.07 ± 0.65	
Enterobacteriaceae	255	2	0.24 ± 0.87	1.81 ± 0.15
		4	0.30 ± 0.59	
		6	0.32 ± 0.62	
		8	-0.17 ± 0.49	
		10	0.32 ± 0.83	
	280	2	0.47 ± 0.57	
		4	0.87 ± 0.56	
		6	1.17 ± 0.53	
		8	1.06 ± 0.72	
		10	1.09 ± 0.56	
	300	2	0.62 ± 0.88	
		4	1.31 ± 0.37	
		6	1.54 ± 0.48	
		8	1.11 ± 0.62	
		10	1.31 ± 0.70	
	365	2	0.53 ± 0.54	
		4	1.28 ± 0.44	

		6	1.54 ± 0.48	
		8	0.88 ± 0.72	
		10	0.41 ± 0.34	

592

593 **Table A.2** Initial concentration of *Pseudomonas* and LAB and achieved bacterial results after the
594 application of UV light at different wavelengths and treatment times.

Type of bacteria	Wavelength (nm)	Time (min)	Bacterial reduction (Log. CFU/g)	Initial concentration (Log. CFU/g)
Pseudomonas	255	2	-0.30 ± 0.66	3.21 ± 0.20
		4	-0.45 ± 0.59	
		6	-0.60 ± 0.49	
		8	-0.60 ± 0.63	
		10	-0.67 ± 0.65	
	280	2	0.60 ± 1.18	
		4	1.47 ± 0.72	
		6	1.02 ± 0.31	
		8	1.69 ± 0.93	
		10	0.50 ± 0.63	
	300	2	0.23 ± 0.59	
		4	1.81 ± 1.29	
		6	1.10 ± 0.26	
		8	2.16 ± 1.05	
		10	0.34 ± 0.71	
	365	2	0.22 ± 0.57	
		4	1.17 ± 0.78	
		6	0.67 ± 0.21	
		8	1.61 ± 1.03	
		10	-0.02 ± 0.44	
Lactic acid bacteria	255	2	0.01 ± 0.73	3.05 ± 0.25
		4	0.39 ± 0.32	
		6	0.53 ± 0.61	
		8	0.19 ± 1.30	
		10	0.80 ± 0.45	
	280	2	0.48 ± 0.76	
		4	1.03 ± 1.21	
		6	1.26 ± 0.72	
		8	2.04 ± 0.93	
		10	2.50 ± 0.95	
	300	2	0.64 ± 1.10	
		4	1.40 ± 1.35	
		6	1.69 ± 1.08	

		8	1.34 ± 0.66
		10	2.29 ± 0.95
	365	2	0.11 ± 0.41
		4	0.43 ± 0.35
		6	0.98 ± 0.43
		8	0.64 ± 0.31
		10	1.03 ± 0.98

595

596 **Table A.3** Initial concentration of TVCp and reductions achieved after the application of UV light at
597 different wavelengths and treatment times.

Type of bacteria	Wavelength (nm)	Time (min)	Bacterial reduction (log. CFU/g)	Initial concentration (Log. CFU/g)
TVC psychrophiles	255	2	0.34 ± 0.44	3.92 ± 0.39
		4	-0.37 ± 0.27	
		6	-0.22 ± 0.37	
		8	0.41 ± 0.64	
		10	0.36 ± 0.38	
	280	2	0.61 ± 0.54	
		4	1.39 ± 1.02	
		6	1.37 ± 0.83	
		8	0.69 ± 0.41	
		10	1.11 ± 0.62	
	300	2	0.58 ± 0.43	
		4	1.33 ± 0.78	
		6	1.23 ± 0.88	
		8	0.77 ± 0.35	
		10	1.55 ± 1.13	
	365	2	0.21 ± 0.28	
		4	0.78 ± 0.38	
		6	0.55 ± 0.84	
		8	-0.09 ± 0.53	
		10	0.92 ± 0.74	

598

599

600

601

Highlights

- Wavelengths of 280, 300 and 365 nm obtained the best inactivation results.
- The most affected bacteria were the *Pseudomonas* genus and lactic acid bacteria.
- Application of UV light at 280 min and storage did not alter pH, color and texture.
- LED-UV based technology is a potential disinfection strategy of chicken fillets.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: