

Efficacy of UV-C LED Irradiation in Reducing Foodborne Pathogenic Contamination on Japanese Quail Eggs

Japon Bildircin Yumurtalarında Gıda Kaynaklı Patojenik Kontaminasyonun Azaltılmasında UV-C Led Işınlamasının Etkinliği

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ABSTRACT

Japanese quail eggs, like other avian eggs, are susceptible to contamination by various foodborne pathogens, particularly on the shell surface during laying, handling, and storage. This study evaluated the effectiveness of Ultraviolet-C (UV-C) irradiation in reducing surface contamination by *Salmonella Typhimurium*, *Listeria monocytogenes*, and *Escherichia coli* common foodborne pathogens found on Japanese quail eggshells. Twenty-four eggs were used in total; six were analyzed to establish the baseline microbial load on the eggshell surface, while the remaining 18 were artificially inoculated and treated UV-C treatment using a commercial LED-based sterilization box at two exposure durations: 1 minute (27.24 mJ/cm²) and 3 minutes (81.72 mJ/cm²). The initial microbial loads on untreated quail eggs were 5.04 ± 0.49 log₁₀ CFU/eggshell for total mesophilic aerobic bacteria and 2.31 ± 1.29 log₁₀ CFU/eggshell for total coliforms. Microbial enumeration revealed a significant, dose-dependent reduction in pathogen loads (*P* < .05). A 1-minute treatment resulted in around 3 log reductions for all pathogens, while the 3-minute treatment achieved up to 4.5 log reductions, particularly for *E. coli* and *S. typhimurium*. These findings indicate that UV-C irradiation is a promising non-thermal and residue-free intervention to enhance the microbial safety of quail eggs; however, surface structure and exposure geometry remain critical considerations for effective optimization.

Keywords: *Escherichia coli*, *Listeria monocytogenes*, microbial reduction, *Salmonella typhimurium*, UV-C irradiation

ÖZ

Bu çalışma, ultraviyole-C (UV-C) ışınımının Japon bildircin yumurtalarının kabuk yüzeyinde *Salmonella Typhimurium*, *Listeria monocytogenes* ve *Escherichia coli* kontaminasyonunu azaltmadaki etkinliğini araştırmıştır. Toplamda 24 yumurta kullanılmıştır; bunlardan altısı yumurta kabuğu üzerindeki başlangıç mikrobiyal yükü belirlemek için analiz edilmiş, geri kalan 18'i ise patojenlerle kontamine edilerek ticari bir LED tabanlı sterilizatör ile UV-C uygulamasına tabi tutulmuştur. UV-C uygulaması iki farklı süreyle gerçekleştirilmiştir: 1 dakika (27,24 mJ/cm²) ve 3 dakika (81,72 mJ/cm²). UV-C uygulanmamış bildircin yumurtalarında başlangıçta belirlenen mikrobiyal yük, toplam mezofilik aerobik bakteri için 5,04 ± 0,49 log₁₀ CFU/yumurta kabuğu ve toplam koliform bakteriler için 2,31 ± 1,29 log₁₀ CFU/yumurta kabuğu olarak tespit edilmiştir. Mikrobiyal sayımlar, patojen yüklerinde anlamlı ve doza bağlı bir azalma olduğunu göstermiştir (*P* < ,05). Bir dakikalık uygulama tüm patojenler için yaklaşık 3,0 log₁₀ azalma sağlarken, 3 dakikalık uygulama özellikle *E. coli* ve *S. typhimurium* için 4,5 log₁₀'a kadar azalma elde edilmesini sağlamıştır. Bu bulgular, UV-C ışınımının bildircin yumurtalarının mikrobiyal güvenliğini artırmak için umut vadeden, ısıl olmayan ve kalıntı bırakmayan bir müdahale yöntemi olduğunu göstermektedir. Ancak yüzey yapısı ve ışığın yüzeye ulaşma geometrisi gibi etkenlerin, etkinliğin optimize edilmesinde kritik öneme sahip olduğu da unutulmamalıdır.

Anahtar Kelimeler: *Escherichia coli*, *Listeria monocytogenes*, mikrobiyal azalım, *Salmonella typhimurium*, UV-C ışınımı

INTRODUCTION

Japanese quails (*Coturnix coturnix japonica*) are an important source of both meat and eggs. Although quail eggs weigh only about 20% of a typical chicken egg, they are considerably more nutritious, containing higher concentrations of protein, antioxidants, calcium, iron, and phosphorus.^{1,2} Furthermore, quail egg production presents a promising opportunity for income generation. Quails offer several advantages over chickens, including greater disease resistance, lower space requirements, earlier sexual maturity, and the potential to produce nearly 320 eggs during their laying period.²⁻⁴

Despite these benefits, quail eggs like other avian eggs are susceptible to contamination by various foodborne pathogens, particularly on the shell surface during laying, handling, and storage. Due to its porous nature, the eggshell is prone to microbial adhesion and penetration, posing a substantial risk for the transmission of pathogens such as *Salmonella enterica*, *Listeria monocytogenes*, and *Escherichia coli*.^{5,6} These bacteria are known to cause serious foodborne illnesses, and their presence on egg surfaces represents a major public health concern. To mitigate microbial contamination, a range of decontamination strategies have been investigated, including chemical sanitization, heat treatment, and irradiation. Among these, ultraviolet-C (UV-C) light, operating within the 200–280 nm wavelength range, has emerged as a promising non-thermal, residue-free, and efficient method for decontaminating food and food-contact surfaces.^{7,8}

UV-C radiation is a non-thermal technology that inactivates microorganisms by inducing DNA damage, primarily through thymine dimer formation, thereby disrupting microbial replication and transcription.^{7,9,10} Its application to solid food surfaces, such as eggshells, is advantageous due to the absence of chemical residues and low energy requirements. However, the effectiveness of UV-C treatment can be influenced by the curvature and porosity of the eggshell surface, which may limit uniform exposure due to shading effects. Recent studies emphasize the importance of precisely controlling exposure geometry and treatment dose to achieve effective microbial inactivation while preserving product quality.^{9,11,12} Although UV-C treatment has been studied for chicken eggs, limited research has focused on its efficacy in reducing microbial contamination on quail egg shells. Moreover, standardized protocols, exposure doses, and treatment durations remain underexplored, especially under practical and commercially available conditions. Accordingly, this study aimed to assess the effectiveness of UV-C light, delivered via a commercial

UVC LED sterilizing box, in reducing surface contamination of *S. typhimurium*, *L. monocytogenes*, and *E. coli* on artificially inoculated quail eggshells. The findings are expected to support improved handling and processing practices for quail eggs in both domestic and commercial settings.

MATERIALS AND METHODS

This research was exemption from Kastamonu University local ethics committee (Date: May 23, 2025, Number of Sessions: 2025/29-08).

Quail Egg Samples Preparation

Twenty-four fresh Japanese quail eggs (*Coturnix coturnix japonica*), approximately uniform in size and shape, were procured from a local market in Kastamonu, Türkiye. The eggs were supplied in two trays containing 12 eggs each, resulting in a total of 24 eggs. Eggs were visually inspected to exclude cracked or defective samples. Subsequently, six eggs (three from each tray) were selected to assess the baseline microbiological characteristics, including total mesophilic aerobic bacteria and total coliform counts. The remaining 18 eggs were randomly divided into three experimental groups (n=6 per group) according to the UV-C treatment duration. All eggs were stored at room temperature (22 ± 1°C) prior to the experiments.

Common Foodborne Pathogens Inoculation of Eggs

Three reference strains of common foodborne pathogens *Salmonella enterica* subsp. *enterica* serovar Typhimurium (ATCC 14028), *Listeria monocytogenes* (ATCC 19115), and *Escherichia coli* (ATCC 25922) were used in this experiment. Each bacterial strain was individually cultured in tryptic soy broth (TSB; Merck, Germany) at 37°C for 18–24 hours to reach the late logarithmic phase. The bacterial cultures were adjusted to 0.5 McFarland standard, corresponding to approximately 1.5.10⁸ CFU/mL, and combined same volume to prepare a mixed suspension. Artificial inoculation was used to ensure standardized bacterial loading and reproducibility. For standardized inoculation, a 1 × 1 cm adhesive tape frame, sterilized with alcohol, was gently affixed to the eggshell surface to delineate a defined application area. Each quail egg was spot-inoculated with 100 µL of the cocktail on the shell surface using a micropipette and allowed to air-dry at room temperature for 30 minutes to facilitate bacterial attachment. For the control group, the same procedure was followed using 100 µL of sterile distilled water instead of the bacterial suspension, to account for any potential mechanical or procedural effects unrelated to pathogen exposure (Figure 1). For microbial recovery, a non-destructive swabbing method, rather than rinsing, was employed to maximize bacterial release while preserving eggshell integrity.



Figure 1. The visual representation of quail eggs prepared for experimental pathogen inoculation. The red tape indicates the 1 × 1 cm adhesive frame used to standardize the inoculation and sampling area.

Ultraviolet Irradiation (UV-C) Application

Ultraviolet-C (UV-C) irradiation was carried out using the 59S® UVC LED Sterilizing Box, a commercial device equipped with 40 UVC LEDs emitting light in the 260–280 nm wavelength range. The sterilization box was designed to provide uniform UV-C exposure, with internal reflection features and a built-in timing system. Eggs were placed on a sterile stainless steel mesh platform inside the chamber, ensuring no overlap or contact. The distance between the UV-C source and the egg surface was maintained at 10 cm. At this distance, the average irradiance was measured as 454 $\mu\text{W}/\text{cm}^2$ (0.454 mW/cm^2) according to the manufacturer's specifications. Although a 1 × 1 cm area was defined for inoculation and recovery, the UV-C treatment was applied to the entire eggshell surface, as eggs were exposed on all sides inside the sterilizing box. The samples were divided into three treatment groups (n=6 per group) according to different UV-C exposure durations: Control group: 0 minutes (no UV-C exposure); Group-1: 1 minutes; 27,24 mJ/cm^2 , Group-2: 3 minutes; 81,72 mJ/cm^2 . The UV-C dose was calculated using Equation 1: $\text{UV-C Dose (mJ}/\text{cm}^2) = \text{Irradiance (mW}/\text{cm}^2) \times \text{Time (s)}$

To minimize the risk of cross-contamination, each egg was handled separately, and hands were disinfected with 70% ethanol before placing the next sample. The stainless-steel mesh platform on which the eggs were placed was wiped with 70% ethanol between experimental runs to avoid cross-contamination.

Microbiological Analysis

For the determination of the basic microbiological characteristics of quail eggs, six eggs (three from each tray) were randomly selected prior to the all treatment. These samples were analyzed to determine total mesophilic

aerobic bacterial (TMAB) and total coliform levels. To assess microbial contamination on the surface of quail eggshells, a non-destructive surface swabbing method was employed. Each egg was swabbed using sterile gauze moistened with 10 mL of 0.1% peptone water (PW) at room temperature. The entire eggshell surface was thoroughly swabbed to ensure uniform coverage. After sampling, the gauze was transferred into a sterile stomacher bag containing an additional 15 mL of 0.1% PW, resulting in a final suspension volume of 25 mL. The samples were homogenized using a Stomacher 400 (Bagmixer) for 1 minute to release the adhered microorganisms into the solution. Serial tenfold dilutions were prepared in 0.1% PW, and 0.1 mL aliquots from appropriate dilutions were spread onto selective media. Plate Count Agar (PCA) (Merck, Darmstadt, Germany) was used for total mesophilic aerobic bacteria (TMAB) (35±2 °C 24–48 h) and Violet Red Bile Lactose Agar (VRBL) was used for total coliform bacteria (35±2°C for 24–48 h).^{13,14}

Following initial microbiological assessment, the remaining 18 eggs were randomly assigned to three experimental groups (n = 6 per group) based on UV-C exposure duration. Following the completion of all UV-C treatments, the eggs that had been experimentally contaminated with the bacterial cocktail were sampled using the same non-destructive swabbing method as previously described. For post-treatment pathogen enumeration, *Salmonella* Typhimurium, *Listeria monocytogenes*, and *Escherichia coli* were enumerated on Xylose Lysine Deoxycholate (XLD) agar (Merck, Darmstadt, Germany), PALCAM agar, and Sorbitol MacConkey (SMAC) agar, respectively. The inoculated plates were incubated at 35±2°C for 24–48 hours. Colonies displaying characteristic morphology were counted manually, and microbial loads were expressed as \log_{10} colony-forming units per eggshell (\log_{10} CFU/eggshell).

Statistical Analysis

Prior to statistical evaluation, the data were tested for normality using the Shapiro–Wilk test and for homogeneity of variances using Levene’s test. To evaluate the effect of UV-C treatment duration on microbial counts, a one-way analysis of variance (ANOVA) was conducted using SPSS software (IBM SPSS Corp., Armonk, NY, USA, Statistics Version 27). When significant differences were detected ($P < .05$), Tukey’s HSD post hoc test was applied to identify pairwise differences between treatment groups. Microbial counts were log-transformed (\log_{10} CFU/eggshell) prior to analysis to stabilize variance and normalize the distribution. For each pathogen (*Salmonella* Typhimurium, *Listeria monocytogenes*, and *Escherichia coli*), group-wise comparisons were performed across control, 1 minute, and 3 minute UV-C treatment groups. The results were expressed as mean \pm standard deviation (SD)

RESULTS

Although each experimental group comprised a modest

sample size ($n = 6$), the low standard deviations, normal distribution (Shapiro–Wilk, $P > .05$), and homogeneous variances (Levene’s test, $P > .05$) indicate that experimental variability was well controlled. A coefficient of variation (CV%) below 10% further supports the internal consistency of the experimental design and validates the reliability of the observed treatment effects.

Basic Microbiological Characteristics of Quail Eggs

The average total mesophilic aerobic bacteria (TMAB) and coliform counts in the control group were 5.04 ± 0.49 and $2.31 \pm 1.29 \log_{10}$ CFU/eggshell, respectively.

Pathogen enumeration

Figure 2 presents the \log_{10} CFU/eggshell counts of *Listeria monocytogenes*, *Salmonella* Typhimurium, and *Escherichia coli* on quail eggs after inoculation and UV-C treatment (1 min, 27.24 mJ/cm²; 3 min, 81.72 mJ/cm²). As shown in Figure 2, different uppercase letters (A–C) indicate statistically significant differences at $P < .05$.

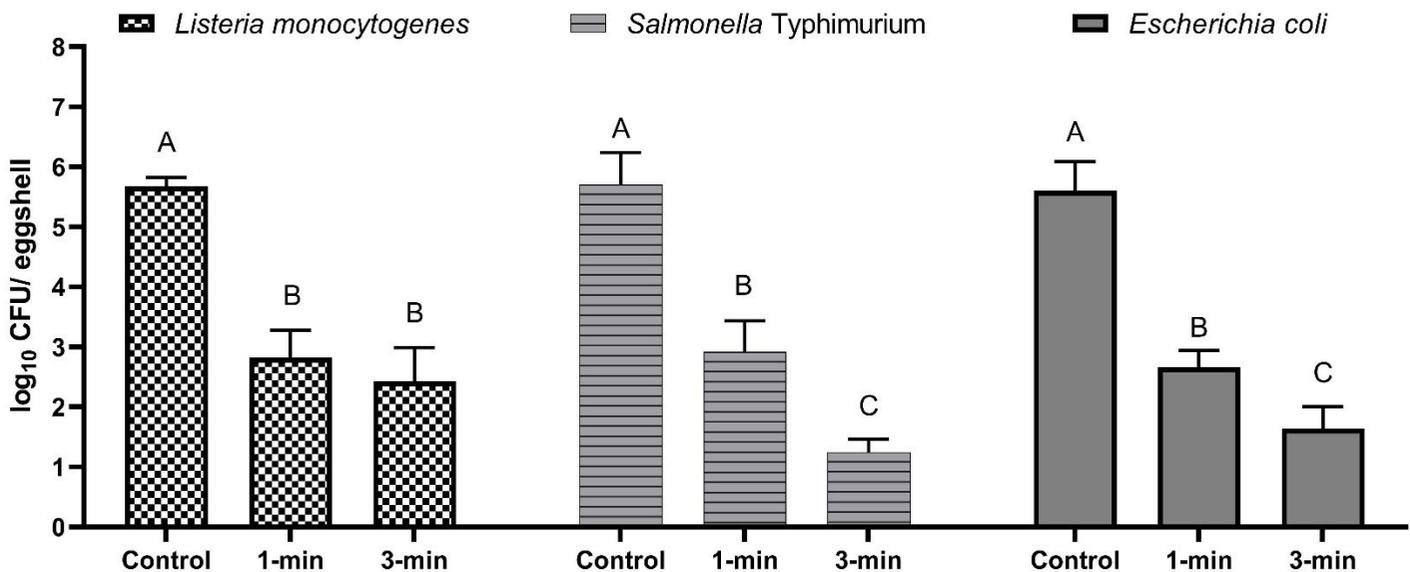


Figure 2. Bacterial counts (\log_{10} CFU/eggshell) of *Listeria monocytogenes*, *Salmonella* Typhimurium, and *Escherichia coli* on quail eggs after inoculation and subsequent different letters (A, B, C) indicate statistically significant differences between treatment groups ($P < .05$).

DISCUSSION

The average total mesophilic aerobic bacteria (TMAB) and coliform counts in the control group were 5.04 ± 0.49 and $2.31 \pm 1.29 \log_{10}$ CFU/eggshell, respectively. Northcutt et al.¹⁵ reported a microbial load of $4.3 \pm 0.6 \log_{10}$ CFU/egg on the surface of quail eggs. He et al.¹⁶ observed a contamination level of $4.30 \pm 0.47 \log_{10}$ CFU/egg on quail eggshells. In contrast, Oliveira et al.¹⁷ reported a lower microbial load of

$2.81 \pm 0.21 \log_{10}$ CFU/egg on quail eggshell surfaces. In addition, M. El Malt¹⁸ reported a total coliform count of $2.27 \log_{10}$ CFU/eggshell. Comparable microbial contamination levels have also been reported in the eggs of other poultry species. Researchers reported a total microbial load of $5.30 \pm 0.19 \log_{10}$ CFU on chicken eggshells and $5.40 \pm 0.16 \log_{10}$ CFU on goose eggshells. The same study also found that the total coliform count on goose eggshells was $1.76 \pm 0.23 \log_{10}$ CFU.^{19–21} Microbial

contamination of eggs typically occurs post-oviposition, with potential sources including dust, bedding materials, and fecal matter within the poultry environment. Given the constant environmental exposure of eggshell surfaces, average microbial loads around $5.0 \log_{10}$ CFU/eggshell are expected and generally considered typical.²¹ These results underline the importance of post-laying interventions to ensure microbial safety of quail eggs.

UV-C treatment significantly reduced the microbial load of all three foodborne pathogens investigated in this study (*Listeria monocytogenes*, *E. coli*, and *Salmonella* Typhimurium), demonstrating a clear dose-dependent effect. Statistical results confirmed that differences among treatment groups (control, 1 min, and 3 min) were statistically significant for all pathogens ($P < .001$). The most pronounced reductions were observed in *E. coli* and *Salmonella* Typhimurium counts, especially following the 3-minute treatment, indicating high sensitivity of these organisms to UV-C radiation. The average count of *Listeria monocytogenes* in the control group was $5.68 \pm 0.14 \log_{10}$ CFU/egg, which decreased to $2.82 \pm 0.46 \log_{10}$ CFU/egg after 1 minute and $2.42 \pm 0.57 \log_{10}$ CFU/egg after 3 minutes of UV-C exposure (Figure 2). Although reductions were significant between the control and treatment groups, no statistically significant difference was observed between the 1-minute and 3-minute treatments ($P = .275$), indicating that the majority of microbial inactivation occurred within the first minute. As shown in Figure 2, bars with different uppercase letters indicate statistically significant differences at $P < .05$.

The observed variation in UV-C sensitivity among the tested pathogens may be attributed to structural and physiological differences. *L. monocytogenes*, as a Gram-positive bacterium, possesses a thicker peptidoglycan layer that can provide partial shielding from UV penetration, whereas Gram-negative bacteria such as *E. coli* and *Salmonella* Typhimurium have thinner peptidoglycan but an additional outer membrane that influences permeability and susceptibility.^{22,23} In addition to cell wall structure, DNA repair capacity plays a crucial role. *E. coli* is able to tolerate UV-induced DNA damage via translesion synthesis (TLS) mediated by DNA polymerase V, enabling replication to bypass UV-induced lesions. This may partly explain why *E. coli* exhibited comparatively lower inactivation under certain fluence levels. By contrast, *Listeria monocytogenes* relies on nucleotide excision repair and general stress response pathways, which may contribute to its survival but result in different resistance dynamics compared to Gram-negative bacteria.²⁴

One possible explanation is that *Listeria* cells located on more exposed surface areas were rapidly inactivated within

the first minute, while residual populations located in micro-crevices or shaded areas remained protected from subsequent irradiation.²⁵

Escherichia coli showed the highest sensitivity to UV-C, with reductions from $5.60 \pm 0.49 \log_{10}$ CFU/egg (control) to $2.66 \pm 0.28 \log_{10}$ CFU/egg and $1.64 \pm 0.36 \log_{10}$ CFU/egg after 1 and 3 minutes, respectively. All pairwise comparisons were statistically significant ($P < .001$).

Similarly, *Salmonella* Typhimurium counts were reduced from $5.70 \pm 0.54 \log_{10}$ CFU/egg (control) to $2.92 \pm 0.51 \log_{10}$ CFU/egg after 1 minute and to $1.25 \pm 0.21 \log_{10}$ CFU/egg after 3 minutes of UV-C exposure, with all reductions being statistically significant. Homogeneity of variances was also confirmed ($P = .247$). The results clearly demonstrated a dose-dependent reduction in the microbial load of all three tested pathogens following UV-C treatment. After 1 minute of exposure (27.24 mJ/cm^2), *Salmonella* Typhimurium, *Listeria monocytogenes*, and *Escherichia coli* exhibited reductions of 2.78, 2.86, and 2.94 \log_{10} CFU/egg, respectively. These findings suggest that even brief UV-C exposure can achieve nearly a 3-log reduction in microbial load on quail eggshell surfaces.

The log reductions observed in this study are consistent with previous findings in various food matrices exposed to UV-C radiation. For instance, Gabriel et al.²⁶ reported more than 3 log CFU/g inactivation of *Salmonella enterica* on dehydrated coconut flakes at UV-C doses comparable to those applied in this study. Similarly, Atik and Gumus²⁷ achieved 2–3 log CFU/mL reductions for *E. coli*, *L. monocytogenes*, and *S. Typhimurium* in raw milk using UV-C doses ranging from 60 to 217 J/mL.

Notably, the UV-C doses applied in our study (27.24 and 81.72 mJ/cm^2) were considerably lower than those used by Hassan et al.²⁸, who employed doses ranging from 350 to 1040 mJ/cm^2 (3.5 to 10.4 kJ/m^2) to achieve up to 3 log CFU/g reductions in *E. coli*, *Salmonella* spp., and spoilage organisms on ground spices. Despite the substantially lower UV-C doses applied in this study, microbial inactivation levels comparable to or exceeding those in previous studies were achieved, particularly for *Salmonella* Typhimurium and *E. coli*. This outcome may be attributed to the relatively small and smooth surface of quail eggshells, as well as the uniform exposure provided by the LED-based UV-C chamber. These results suggest that the efficiency of UV-C treatment is influenced not only by the applied dose but also by the physical characteristics and exposure geometry of the treated surface.

In addition to structural and methodological considerations, several intrinsic and extrinsic factors may influence the

efficacy of UV-C treatment applied to food products. Irregular or non-uniform surfaces, such as those of solid food matrices or eggshells, may hinder UV-C effectiveness due to shadowing, curvature, or microbial aggregation that protects inner cells from direct exposure.¹¹

As a result, although this study demonstrated significant reductions in microbial loads on quail eggshells through UV-C irradiation, certain limitations must be acknowledged to contextualize the results. The experimental setup was highly controlled, involving clean, uniformly sized eggs and standardized bacterial inoculation confined to a defined surface area. However, under real-world conditions, variations in eggshell cleanliness, texture, and curvature may compromise the uniformity of UV-C exposure due to shadowing effects and microbial aggregation. A short exposure of 1 minute (27.24 mJ/cm²) was sufficient to achieve reductions of nearly 3-log CFU for all tested pathogens, and prolonged exposure (3 minutes; 81.72 mJ/cm²) further enhanced microbial inactivation, particularly for *E. coli* and *S. Typhimurium*, reaching reductions of up to 4.5 log CFU/egg. Despite the application of sterilization-level UV-C doses, the recovery of viable bacteria may be due to the porous and irregular nature of the eggshell surface, which can create microenvironments that protect microorganisms from direct UV exposure. These findings underscore the importance of accounting for surface topology and exposure geometry in the design and optimization of UV-C decontamination protocols. From a practical perspective, UV-C irradiation offers a microbial safety of quail eggs in both retail and household settings. To support broader application, future studies should evaluate treatment efficacy under diverse field conditions, examine potential synergistic interventions (e.g., pulsed UV-C or combined hurdle approaches), and incorporate predictive microbial modeling to better elucidate inactivation kinetics and optimize process control. Ultimately, UV-C technology represents a valuable intervention in the quail egg production chain, contributing to improved food safety without compromising product quality.

Ethics Committee Approval: This research was exemption from Kastamonu University local ethics committee (Date: May 23, 2025, Number of Sessions: 2025/29-08).

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REFERENCES

1. Bao Z, Kang D, Li C, Zhang F, Lin S. Effect of salting on the water migration, physicochemical and textural characteristics, and microstructure of quail eggs. *Lwt*. 2020;132:109847.
2. Güngören A, Güngören G, Şimşek ÜG, Yılmaz Ö, Bahşi M, Aslan S. Quality properties and fatty acids composition of breast meat from Japanese quails with different varieties grown under warm climate. *Veterinaria*. 2023;72(2):163-173.
3. Brasil YL, Cruz-Tirado JP, Barbin DF. Fast online estimation of quail eggs freshness using portable NIR spectrometer and machine learning. *Food Control*. 2022;131:108418.
4. Oliveira G da S, McManus C, Salgado CB, et al. Antimicrobial Coating Based on Tahiti Lemon Essential Oil and Green Banana Flour to Preserve the Internal Quality of Quail Eggs. *Animals*. 2023;13(13):2123.
5. Jung SJ, Park SY, Ha SD. Synergistic effect of X-ray

- irradiation and sodium hypochlorite against *Salmonella enterica* serovar Typhimurium biofilms on quail eggshells. *Food Res Int.* 2018;107:496-502.
6. Park SY, Jung SJ, Ha SD. Bildircin yumurtası kabuklarındaki *Salmonella* Typhimurium biyofilmine karşı kombine X-ışını ve sulu klor dioksit uygulamalarının sinerjik etkileri. *Lwt.* 2018;92:54-60.
7. Gayán E, Condón S, Álvarez I. Biological Aspects in Food Preservation by Ultraviolet Light: a Review. *Food Bioprocess Technol.* 2014;7(1):1-20.
8. Rodriguez-Romo LA, Yousef AE. Inactivation of *Salmonella enterica* Serovar Enteritidis on Shell Eggs by Ozone and UV Radiation. *J Food Protection.* 2005;68(4):711-717.
9. Koutchma T. *Ultraviolet Light in Food Technology: Principles and Applications.* 2nd ed. CRC Press; 2019.
10. Calle A, Fernandez M, Montoya B, Schmidt M, Thompson J. UV-C LED Irradiation Reduces Salmonella on Chicken and Food Contact Surfaces. *Foods.* 2021;10(7):1459.
11. Ramos GLPA, Esper LMR, Gonzalez AGM. A review on the application of UV-C treatment on food and food surfaces: association with food microbiology, predictive microbiology and quantitative microbial risk assessment. *Int J Food Sci Technol.* 2024;59(3):1187-1196.
12. Pihen C, Mani-López E, Franco-Vega A, Jiménez-Munguía MT, López-Malo A, Ramírez-Corona N. Performance of UV-LED and UV-C treatments for the inactivation of *Escherichia coli* ATCC 25922 in food model solutions: Influence of optical and physical sample characteristics. *Innovative Food Sci Emerg Technol.* 2023;85:103314.
13. ISO 4832:2006. ISO. Accessed May 15, 2025. <https://www.iso.org/standard/38282.html>
14. Bacteriological Analytical Manual (BAM) | FDA. Accessed May 15, 2025. <https://www.fda.gov/food/laboratory-methods-food/bacteriological-analytical-manual-bam>
15. Northcutt JK, Buyukyavuz A, Dawson PL. Quality of Japanese quail (*Coturnix coturnix japonica*) eggs after extended refrigerated storage. *J Applied Poultry Res.* 2022;31(3):100280.
16. He Z, Chen X, Shi X, et al. Acetic acid, vinegar, and citric acid as washing materials for cuticle removal to improve hatching performance of quail eggs. *Poultry Sci.* 2020;99(8):3865-3876.
17. Oliveira G da S, Vale IRR, de Jesus LM, et al. Coating Quail Eggs with a Bioactive Solution of Corn Starch and Green Propolis Extract. *Coatings.* 2025;15(5):573.
18. M. El Malt L. An Assessment of the Microbiological Risks Involved with Quail Egg Qena City, Upper Egypt. *Assiut Vet Med J.* 2013; 59(139):99-106.
19. Eroglu M, Erisir Z, Simsek UG, et al. Investigating the disinfecting efficacy of acetic and boric acid used by spraying on hatching goose eggs. *Eur Poultry Sci.* 2024;88:1-9.
20. Eroglu M, Erisir Z, Simsek U, et al. Effects of washing dirty eggs of geese with boric acid and vinegar on hatchability and microbial loads. *J Animal Plant Sci.* 2025;35(2):354-363.
21. İncili GK, Durmuşoğlu H, Güngören A, İlhak Oİ. Elazığ İlinde Satışa Sunulan Konvansiyonel (kafes tipi) ve Köy Yumurtalarının Mikrobiyolojik Kalitesinin Araştırılması. *Dicle Üniv Vet Fak Derg.* 2019;12(2):97-102.
22. Sun W, Jing Z, Zhao Z, et al. Dose-Response Behavior of Pathogens and Surrogate Microorganisms across the Ultraviolet-C Spectrum: Inactivation Efficiencies, Action Spectra, and Mechanisms. *Environ Sci Technol.* 2023;57(29):10891-10900.
23. Jaiaue P, Piluk J, Sawattrakool K, et al. Mathematical Modeling for Evaluating Inherent Parameters Affecting UVC Decontamination of Indicator Bacteria. *Appl Environ Microbiol.* 2022;88(7):e0214821.
24. Ishida K, Matsubara M, Nagahashi M, et al. Efficacy of ultraviolet-light emitting diodes in bacterial inactivation and DNA damage via sensitivity evaluation using multiple wavelengths and bacterial strains. *Arch Microbiol.* 2025;207(6):130.
25. Gayán E, Serrano MJ, Pagán R, Álvarez I, Condón S. *Listeria monocytogenes*'in UV-C direncini etkileyen çevresel ve biyolojik faktörler. *Food Microbiol.* 2015;46:246-253.
26. Gabriel AA, Tongco AMP, Barnes AA. Utility of UV-C radiation as anti-*Salmonella* decontamination treatment for desiccated coconut flakes. *Food Control.* 2017;71:117-123.
27. Atik A, Gumus T. The effect of different doses of UV-C treatment on microbiological quality of bovine milk. *Lwt.* 2021;136:110322.
28. Hassan AB, Al Maiman SA, Sir Elkhatim KA, et al. Effect of UV-C radiation treatment on microbial load and antioxidant capacity in hot pepper, fennel and coriander. *Lwt.* 2020;134:109946.