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Research Article

The Effect of Pulsed UV Light on Biochemical Changes: Quail Egg Model for *Salmonella* Typhimurium Inactivation

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Abstract

Foodborne Salmonella infections pose a critical threat to public health and the disinfection potential of non-thermal technologies such as pulsed UV light is becoming increasingly important. The aim of this study was to determine the biochemical changes in quail eggs at varying process parameters in the model application of pulsed UV light for *Salmonella* Typhimurium inactivation. In this context, pulsed UV light was applied to quail eggs at distances of 5, 8, and 13 cm and durations of 20, 40, and 60 s. Salmonella Typhimurium inactivation was observed in all quail eggs depending on the treatment distance and duration and biochemical changes in quail eggs were evaluated in terms of thiobarbituric acid, phenolic and antioxidant content, fatty acid composition and color change. Salmonella inactivation was observed in all treatments. However, phenolic and antioxidant contents decreased for the longest time and at the closest distance in the application processes, while thiobarbituric acid and linoleic acid content (control:13.35%→5D60S:25.51%) increased. The increase in the amount of linoleic acid in 5D60S and 5D40S was higher than that in other samples. Although pulsed UV light is effective in Salmonella inactivation, long duration/close distance applications may adversely affect product quality. These findings emphasize the importance of parameter optimization in the food industry and reveal the need to develop protocols that are safe but minimize quality loss.

Keywords: Pulsed UV light, Quail eggs, *Salmonella* Typhimurium, Biochemical change, Fatty acid

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Introduction

Non-thermal methods have recently been studied as thermal disinfection methods for preserving the color, texture, and nutritional properties of foods [1]. Non-thermal technologies such as high-voltage processes, pulsed electric fields, ultrasound, cold plasma, high-pressure processes, ionizing radiation, ultraviolet (UV) light and pulsed light typically generate minimal heat during the food processing process [2]. Pulsed light effectively kills microorganisms on food surfaces, offering both advantages and disadvantages [3]. It effectively decontaminates surfaces by inactivating spores and vegetative cells of various bacteria, and a higher inactivation is achieved at higher input voltages [4]. Pulsed light also effectively decontaminates solid foods and food contact materials, prevents recontamination, and improves product quality and safety [5]. On the other hand, pulsed light applications can improve food safety and extend shelf life, but appropriate application conditions should be evaluated for each food and microorganism to minimize adverse effects on photosensitive compounds and sensory properties [6].

Quail eggs, which are frequently found in people's tables, are rich in vitamins, minerals (calcium, phosphorus), and antioxidants, and can serve as a dietary supplement to enhance bone healing [7]. Quail eggs are a useful source of nutrients that provide high-quality proteins and a variety of nutrients that support growth and development [8]. Studies on changes in the nutritional value of quail eggs

are generally based on quail nutrition. In a study on chemical changes in quail eggs, microalgae added to quail diets were found to improve egg quality and consumer health by reducing saturated fatty acids, increasing monounsaturated fatty acids, and increasing antioxidant [9]. In another study, curcumin nanocapsules added to quail feed enhanced the antioxidant effect and increased unsaturated fatty acid levels [10].

Salmonella Typhimurium is a well-recognized foodborne pathogen responsible for significant illness in both humans and animals globally. It ranks among the most prevalent causing foodborne disease, typically leading to gastroenteritis and, in severe cases, progressing to systemic infections. Its widespread occurrence and notable antibiotic resistance render it a critical concern for both food safety and public health. *S.* Typhimurium is frequently identified in a diverse array of food products, particularly raw and undercooked animal-derived items, including meat and poultry. It stands as a primary contributor to foodborne outbreaks worldwide, with high detection rates observed in retail and ready-to-eat foods. In certain regions, it represents the dominant serotype found in human infections and is closely linked to considerable morbidity and mortality [11,12].

Egg varieties are important sources of pathogenic microorganisms and nutritionally valuable. Therefore, it is important to develop methods for microbial decontamination of shell surfaces. Thermal and non-thermal decontamination methods can extend the shelf life of eggs and reduce consumer risk from foodborne pathogens [13]. In this context, research has been conducted using different techniques. Pulsed UV light treatment is an effective method for reducing microbial pathogens on the surface of egg shells. The study showed that higher energy levels resulted in greater reductions in microbial load. In particular, treatments with energy levels of 1.0, 2.4, 3.1 and 4.9 J/cm² resulted in a significant reduction of *Escherichia coli* and *Enterococcus faecium* bacteria on the egg surface [14]. Another study, using new technologies, investigated the effectiveness of pulsed UV light for the inactivation of *E. coli* K12 in hard-cooked eggs. In a study where distance and time were examined as variables, temperature increase, color, and texture of eggs were investigated in addition to microbial inactivation. In a study in which microbial inactivation was found to be important, no significant changes were observed in other parameters [15]. In a study in which pulsed light was applied to egg whites, the chemical and physical properties of the product were examined. Pulsed light caused deterioration in the protein structure and an increase in brown color formation, but did not change the viscosity. On the other hand, egg white foam obtained as a result of this process is more stable [16]. Pulsed UV light application on eggshells is an effective method for inactivating pathogens on eggshell surfaces, and no change in albumen height and eggshell strength has been observed [17]. In this study, it's hypothesized that the applied pulsed UV light will effectively inactivate *S.* Typhimurium contamination on the quail egg surface, and this application will lead to acceptable levels of changes in the egg's biochemical properties (e.g., fatty acid composition, TBARS, phenolic and antioxidant contents, and color values).

The aim of this study was to determine how pulsed UV light application affects the biochemical properties of quail eggs, which are small in size and generally used as a supplement in pediatric nutrition. In this context, *S.* Typhimurium inactivation was selected as a model application, and pulsed UV light was applied to quail eggs by changing the application parameters. All samples were examined for microbial decontamination and biochemical analysis of fatty acid composition, TBARS, phenolic and antioxidant contents, and color values.

Material and Methods

Ethical Statement

This study does not require ethical approval.

Material

Quail eggs were obtained from a local producer using the same batch of eggs for each replicate, using the same group of quails. Fresh quail eggs with an average weight of 10-10.5 g were used in this study. Eggs were transported to the laboratory in a cold chain and stored at +4°C. On the day of the experiment, the eggs were removed from the cold chain and transferred to the laboratory at an ambient temperature of approximately 20°C.

Activation and Inoculation of *Salmonella* Typhimurium

The target microorganism for the model inactivation media trial was determined to be *Salmonella* Typhimurium. In this context, lyophilized *Salmonella* Typhimurium strain (RSKK 11020-Türkiye) was activated. In the first step of the activation process, cells were incubated in Tryptic Soy Broth (Merck, 105459) agar at 37°C for 18-24 h. After the completion of this period, the strain was again transferred to a medium containing Tryptic Soy Broth and incubated at 37°C for 18-24 h. After 24 h, the medium prepared with Tryptic Soy Agar (TSA) (Merck, 105458) was inoculated by the smear method and incubated at 37°C for 18-24 h. Single colonies from the Petri dishes were transferred to tubes containing Tryptic Soy Broth and incubated at 37°C for 18-24 h. After incubation, the tubes were removed at +4°C. To the glass tubes, 5 mL of Tryptic Soy Broth and 300 µL of cultures in which growth was observed were added and incubated. Then, 300 µL of the previous

culture was added to tubes containing 10 mL of Tryptic Soy Broth and incubated. The tube with the most intense incubation was taken, the optical density was measured using a spectrophotometer, and it was determined that the measurement result was within the reference range [1]. Eight tubes were diluted to 10^{-8} with peptone water and inoculated on Tryptic Soy Agar, and at the end of incubation, uniform growth was observed [18].

Before starting the study, each egg was kept in 10 mL 68% ethyl alcohol for 10 min, and the egg surface was washed. *Salmonella* Typhimurium inoculation liquid was prepared at 10^5 CFU/mL, and quail eggs were kept in this liquid for 20 min. Samples removed from the inoculation liquid under aseptic conditions were kept for an average of 30 min (until dry), and after reaching room temperature, they were prepared for pulsed UV application.

Pulsed UV Light Application

The inactivation process was carried out using the Steri-Pulse XL 3000 Pulsed UV-Light Sterilization System (Xenon Corporation, MA, USA). This system comprised a stainless-steel sterilization chamber, a control unit, a lamp assembly, and a cooling system. The xenon lamp emitted light energy of 1.27 J/cm² at a distance of 1.5 cm below the lamp surface, operating with 3800 V energy at a frequency of 3 Hz, and a pulse duration of 360 µs (pulse time). The UV lamp produced 3 pulses per second. Samples were placed inside a chamber (measuring 0.64 m x 0.15 m x 0.19 m) and exposed at three different shelf distances (5, 8, and 13 cm) and three different exposure durations (20, 40, and 60 sec). Pulsed UV light treatment was applied to both the control group quails and those inoculated with *S.* Typhimurium according to the experimental conditions.

Salmonella Typhimurium Count Analysis

The eggshell surface in each bag was rubbed with the maximum recovery diluent for two minutes. After the scrubbing process, a five-minute break was taken, and the scrubbing process was repeated for the same duration. Therefore, the microbial load around and above the shell was completely transferred to the added liquid. After this process, the dilution liquids to be used in the study from 10^{-1} to 10^{-8} were prepared by consecutively transferring 1 mL each consecutively from the first dilution (10^{-1}) of the microbial-loaded washing water obtained from the first dilution (10^{-1}) culture liquid to tubes containing 9 mL of ringer solution. Salmonella counts were obtained from the samples. For *S.* Typhimurium enumeration in experimental samples, Xylose Lysine Deoxycholate (Merck, 105287) agar was inoculated and counts were performed after incubation at 35°C for 24-48 h [18].

Temperature and Energy Measurements in Pulsed UV Light Application

The definitions of "severe," "moderate" and "mild" for the pulse UV light applications planned within the scope of the study were determined as 60 sec at a distance of 5 cm, 40 sec at a distance of 8 cm and 20 sec at a distance of 13 cm, respectively. The surface temperature of the quail eggs was measured before and after treatment with an infrared thermometer (Extech Instrument, USA) adapted to the device under these working conditions.

The amount of energy released during the pulses was measured using an energy measurement sensor (PE50-DIF-C, Ophir Optronics, Israel) placed on the quail eggs at different treatment distances (5, 8, and 13 cm) with a reader (Nova II, Ophir Optronics, Israel) [17].

Color Values

The brightness L^*, redness-greenness a^*, and yellowness-blueness b^* color values of quail egg whites were measured using a color analyzer (Minolta Co., Osaka, Japan).

Thiobarbituric Acid Number

Thiobarbituric acid (TBA) count values of pulsed UV-treated quail egg samples were determined by modifying the spectroscopic method [19,20]. After the quail eggs were beaten, 10 g of sample was taken, and 10 mL of 15% trichloroacetic acid and 50 mL of distilled water were added and homogenized for 60 sec. After mixing, 8 mL of the sample was filtered through a filter paper and placed in a test tube. Two mL of 0.06 N TBA was added to the tube and kept in a water bath at 80°C for 90 min. When the time was increased, the samples in the tubes were quickly cooled to room temperature and analyzed against the control sample using a spectrophotometer (Genesys 10S) at 520 nm absorbance. The results obtained were multiplied by 7.8 and the TBA values of quail eggs were determined

Total Phenolic and Antioxidant Content

The antioxidant activity value for determining the physicochemical changes in quail eggs caused by the applied pulsed UV light process and changing operating parameters was determined by DPPH radical scavenging activity analysis. Eggs were extracted with 80% methanol. 0.1 mL of extract taken from the sample obtained after extraction was mixed with 3.9 mL of DPPH solution, vortexed, and kept in the dark for 30 min. Analysis was performed using a spectrophotometer (Genesys 10S) at 517 nm. Methanol was used as a control during the analysis, and the spectrophotometer was zeroed. The results were expressed as % inhibition [21].

The total phenolic content of quail eggs was determined using the Folin-Ciocalteu method. The prepared 0.5 mL sample solution was mixed with 0.5 mL of Folin-Ciocalteu reagent diluted three times. After adding 1 mL of supersaturated 35% sodium carbonate solution

(prepared the night before), 1 mL of pure water was added and the mixture was kept in the dark for 30 min. After this period, the absorbance at 760 nm was measured using a spectrophotometer. Pure water was used instead of the control sample and the total amount of phenolic substances was expressed as gallic acid equivalents [22].

Fatty Acid Composition Content

To analyze the fatty acid profile of quail eggs, both the eggs treated with Pulsed UV light and the control group were degreased using hexane. The fatty acid composition was evaluated using a gas chromatograph (Agilent 7890 GC/FID, USA) fitted with a flame ionization detector and a silica capillary column. The initial oven temperature was set to 165°C for 15 min, followed by an increase to 200°C at a rate of 5°C/min. Both the injector and detector temperatures were maintained at 250°C. A 1 µL sample volume was used for the injection. The fatty acid composition was expressed as the percentage of total fatty acids [23].

Statistical Analysis

At the end of the study, one-way variance analysis (ANOVA) and Tukey test were performed using SPSS Statistics 17.0, with the support of the advisor to evaluate the data.

Results

Microbiological Analysis

Quail eggs contaminated with *S.* Typhimurium were formed into 10 different experimental groups by taking into account the pulse duration and intensity applied. No pulsed light was applied to the control group samples. The number of microorganisms in the control group samples was determined as 4.13 $\log_{10}$ CFU/g. The most effective results were obtained with 40 and 60 s application at 5 cm distance and 60 s application at 8 cm distance *(Table 1)*.

Temperature and Energy Levels Occurring in Pulsed UV Light Application

The temperature increase and changes in energy levels of quail eggs resulting from pulsed UV light application are given in *Table 2*. The initial temperatures of quail eggs are 20.5±0.4°C. Measurements were made in 3 working parameters selected as the model for temperature increase. The temperature increase in 13D20S (mild), 8D40S (medium) and 5D60S (severe) samples was determined as 0.33, 14.25 and 25.11°C, respectively.

The energy amounts released in 1 sec during the pulsed UV light treatment applied to quail eggs at different distances were calculated as 1.57, 1.13 and 0.79 $J.cm^{-2}.s^{-1}$ for the application parameters of 5, 8, and 13 cm, respectively.

Color Values

The color changes in egg white as a result of the application of pulsed light at different distances and times to quail egg samples are given in *Table 3*. The images of quail eggs after pulsed UV light application were given in *Fig. 1*. The L^*, a^* and b^* color values were 57.65, 7.88 and 19.32, respectively, in the control sample without pulsed light. While the brightness value expressed by L^* color value decreased in all quail eggs analyzed, a^* and b^* values increased with the effect of the light. The highest decrease and increase in these values were observed in the sample coded 5D60S and it was determined that the color values changed as the distance of the applied beam decreased. In general, effective color changes were detected in the 5D sample groups compared to other distance trials. Again, the effect of the increase in the application time in the 5D group, especially in the L^* value, is clearly seen.

Thiobarbituric Acid Number

As a result of pulsed light treatment of quail eggs at different distances (5, 8, and 13 cm) and durations (20, 40 and 60 s), TBA values of eggs varied between 0.79-3.41 mg malondialdehyde/kg eggs *(Fig. 2)*. The lowest TBA value of 0.79 mg malondialdehyde/kg egg was determined in the control sample without pulsed UV light.

Table 1. *S. Typhimurium count on the surface of quail eggs ($\log_{10}$ cfu/g)*

Samples	Control	5D20S	5D40S	5D60S	8D20S	8D40S	8D60S	13D20S	13D40S	13D60S
S. Typhimurium ($\log_{10}$ cfu/g)	4.13^a	1.92^c	<10	<10	1.57^c	0.38^d	<10	3.01^b	1.15^c	0.36^d

Different letters in the same row indicate statistically significant differences in the results (P<0.05)

Table 2. *Temperature and energy levels in pulsed UV light application*

Energy Level ($J.cm^{-2}.s^{-1}$)		Temperature Increase (ΔC°)	
Distance (cm)	Value	Sample Code	Value
5	1.57±0.04^a	13D20S	0.33±1.19^c
8	1.13±0.03^b	8D40S	14.25±1.16^b
13	0.79±0.02^c	5D60S	25.11±1.31^a

Different letters in the same column indicate statistically significant differences in the results (P<0.05)

Table 3. Color values in quail eggs after pulsed UV light treatment

Samples	*L**	*a**	*b**
Control	57.65±1.67^{a}	7.88±1.38^{d}	19.32±0.94^{c}
5D20S	51.20±0.13^{b}	14.45±0.62^{bc}	30.02±0.40^{a}
5D40S	49.10±0.76^{c}	14.05±0.41^{c}	27.87±2.72^{ab}
5D60S	46.18±0.68^{d}	13.78±0.94^{c}	23.56±0.85^{bc}
8D20S	50.01±0.09^{c}	15.51±0.62^{b}	29.69±0.18^{a}
8D40S	49.46±0.76^{bc}	14.75±0.45^{bc}	27.97±1.38^{ab}
8D60S	50.97±2.18^{bc}	15.49±0.58^{b}	27.88±2.14^{ab}
13D20S	51.70±0.12^{bc}	16.11±0.56^{a}	30.51±0.36^{a}
13D40S	49.12±0.19^{c}	14.33±0.11^{bc}	28.16±0.12^{ab}
13D60S	50.91±0.08^{bc}	16.68±0.28^{a}	31.22±0.29^{a}

Different letters in the same column indicate statistically significant differences in the results (P<0.05)

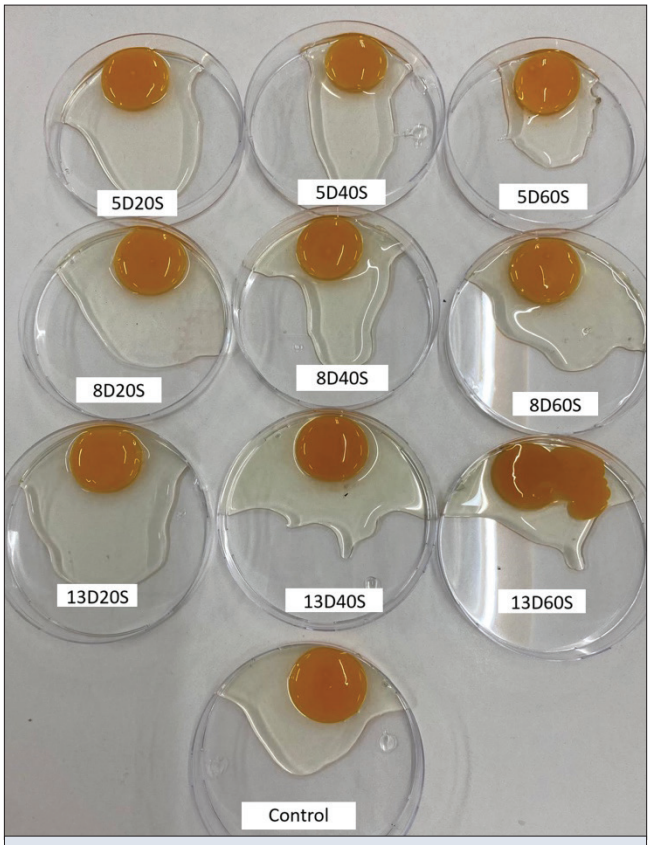

Fig 1. Images of quail eggs after pulsed UV light treatment

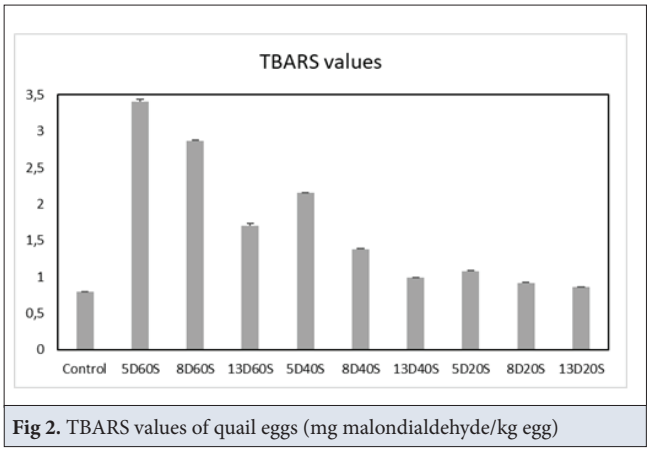

Fig 2. TBARS values of quail eggs (mg malondialdehyde/kg egg)

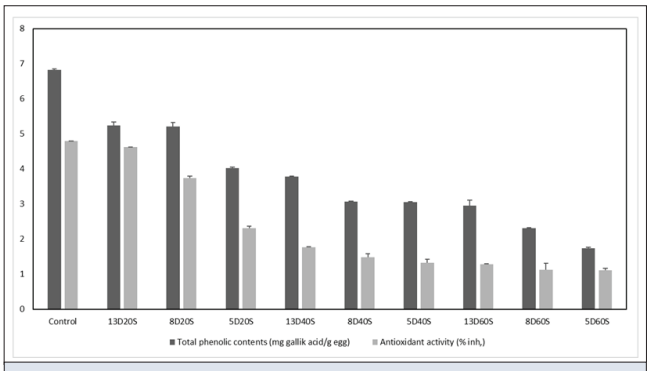

Fig 3. Total phenolic content and antioxidant activity level of quail eggs

Total Phenolic Content and Antioxidant Activity Level

The total phenolic content and antioxidant activity values of quail eggs exposed to pulsed UV light at different distances and times are shown in *Fig. 3*. The total phenolic content and antioxidant activity of the control sample without pulsed light were 6.822 mg gallic acid/g egg and 4.793%, respectively. The total phenolic matter content and antioxidant activity of quail egg samples decreased with the application of scattered light. While the highest decrease in total phenolic matter and antioxidant activity value was observed in the sample coded 5D60S, the lowest decrease was observed in sample 13D20S. This decrease is thought to be due to the breakdown of phenolic compounds in the egg because of the increase in temperature as a result of the applied beam being closer and the applied time being longer.

Fatty Acid Composition of Quail Eggs

Table 4 shows the fatty acid composition of quail egg samples irradiated with pulsed UV at different distances

Table 4. *Fatty acid composition values of quail eggs*

Samples	Fatty Acid Composition					
	Palmitic (C16:0)	Palmitoleic (C16:1)	Stearic (C18:0)	Cis-Oleic (C18:1)	Trans-Oleic (C18:1)	Linoleic (C18:2)
Control	28.92	1.11	18.00	41.87	2.34	13.35
5D20S	24.31	1.45	12.37	32.34	1.38	21.55
5D40S	23.23	1.43	11.95	30.21	1.36	25.35
5D60S	22.14	1.64	10.68	25.19	1.26	25.51
8D20S	26.56	1.25	14.41	34.62	1.53	17.59
8D40S	26.09	1.37	14.00	32.82	1.42	18.84
8D60S	24.44	1.34	13.87	31.35	1.30	20.07
13D20S	27.87	1.15	16.85	40.63	1.74	14.45
13D40S	27.31	1.18	15.97	40.10	1.69	15.25
13D60S	26.87	1.20	15.10	38.41	1.48	16.32

and times. The predominant fatty acids in the unirradiated control samples were palmitic acid (C16:0), palmitoleic acid (C16:1), stearic acid (C18:0), cis-oleic acid (C18:1), trans-oleic acid (C18:1), and linoleic acid (C18:2), which were determined as 28.92%, 18%, 41.87%, 2.34% and 13.35%, respectively. As the amount and proximity of irradiation increased, the amounts of cis-oleic and trans-oleic acids decreased, and the amount of linoleic acid increased. The increase in the amount of linoleic acid in 5D60S and 5D40S quail eggs was higher than that in the other samples. This increase is thought to be due to the breakage of carbonyl groups and double bonds in unsaturated fatty acids under UV light.

Discussion

Surface decontamination treatments, particularly non-thermal treatments, have been widely researched and used for microbial inactivation. However, while microbial inactivation has been evaluated in products after surface inactivation, other product properties, especially changes in biochemical structures, have not been examined. In this context, our study is considered to be very innovative in terms of its application and contains very effective results. Pulsed UV light application for surface decontamination of quail eggs, which are small in size, was studied using different distance and light intensity variables. A concentration of 4.13 $\log_{10}$ CFU/g of *S.* Typhimurium was observed in control eggs. Conversely, the application of pulsed UV light resulted in a reduction in microorganism counts in all samples. The most favorable application conditions were identified when the applied time was extended and the distance was minimized. *Salmonella* Typhimurium inactivation was targeted for surface decontamination, and inactivation was successfully achieved in each model. In a study; It was reported that there was a 7.9 log decrease in eggs contaminated with *Salmonella* Enteritidis with 4 J/cm^2 pulsed light application [24]. In a study in which 2.1 J/cm^2 pulsed light was applied to eggs contaminated with *S.* Typhimurium, a 5 log decrease was reported and no significant temperature increase was reported in the eggs [25]. On the other hand, in the study in which it was stated that *Salmonella* Enteritidis was inactivated by Pulse UV light application on the egg surface, no visual change was observed on the egg surface [17].

Energy is generated during pulsed UV light application, and this energy is absorbed by the egg shell, causing a temperature increase on the surface. The mentioned temperature increase is affected by the application parameters of time and distance [26]. The temperature increase increases more as the proximity to the lamp and the application time increase. For example, a 30-sec application at a distance of 9.5 cm from the lamp resulted in a temperature increase of up to 16.3°C [17]. The energy density released decreases as the distance from the light source increases due to the inverse square law [27]. In accordance with the literatures, an increase in temperature was observed as the application time increased and the distance decreased from the pulsed UV light process parameters. On the other hand, the energy levels decreased as the pulsed UV light application distance increased.

In most of the studies in which pulsed UV light application was performed on eggs, color changes were observed in egg white. It is stated that these changes are related to the process parameters and intensity [28,29]. The degree of color changes that occur in pulsed UV light applications is related to the intensity and duration of application. Higher energy doses and longer exposure times are more likely to cause noticeable changes in color [30]. On the other hand, this change is thought to be caused by enzymatic browning of the egg white due to the heat generated by the

effect of light [31,32]. In pulsed UV light application, color changes were observed in egg white, although the color changes varied according to the process conditions. These changes should be taken into consideration when making applications for food safety purposes.

TBARS are indicative of malondialdehyde levels and provide insight into the degree of lipid oxidation. In eggs, oxidative damage to cholesterol and unsaturated fatty acids significantly contributes to lipid peroxidation, leading to quality degradation [31,33]. The TBA value increased as the distance of the applied beam became closer and the applied time increased. This increase is thought to be due to the breakdown of unsaturated fatty acids in the egg. In a similar study conducted by Quyang et al.[30], it was determined that the TBA value increased as the distance decreased in pulsed light application applied to commercial and fresh liquid egg whites. In a study conducted on bacon, it was observed that TBARS and lipid oxidation values increased as the distance and application time increased [34]. High temperature is known to accelerate many chemical reactions, including lipid oxidation. The increase in lipid oxidation also affects TBARS formation [35]. In addition, it can also be explained by the decrease in the antioxidative effects in the egg with increasing temperature and the inability to resist lipid oxidation, which also increases with increasing temperature [36].

The total phenolic content and antioxidant activity of quail egg samples decreased with the application of scattered light. In a study conducted by Manzocco et al.[32], it was reported that antioxidant activity decreased as a result of egg paste irradiation. The high energy levels created by light pulses in pulse light applications may cause degradation by breaking down phenolic components and reducing the amount of phenolic substances and antioxidant effects. The decrease in the amount of phenolic substances and structural damage to phenolic components affect the antioxidant activity values of the products because of the antioxidative properties of phenolic components [37]. However, it has been stated that the decrease in the amount of phenolic and antioxidant substances caused by pulsed UV light application can be explained by the disruption of the secondary tertiary structures of enzymes in the metabolism of phenolic components by the intense energy generated during the process [38].

Changes in the fatty acid composition are important because of their significant impact on health, disease risk, and biological processes. These changes can affect obesity, cancer, metabolic health, and the quality of food sources [39,40]. Pulsed UV treatment caused changes in fatty acid composition were observed. Fragmentation of chain structures in saturated fatty acids changes the fatty acid composition and causes the formation of radicals, accelerating lipid oxidation. Soro et al.[41] examined the effects of two different UV sources, conventional UV lamp and UV-LED, on fresh chicken breast meat. At the end of the study, it was reported that lipid oxidation was the most affected quality characteristic in meat treated with UV lamp. Wang et al.[1] found in a different study that UV light exposure can trigger lipid oxidation by breaking carbonyl groups and double bonds in unsaturated fatty acids, leading to the formation of free radicals that promote further lipid oxidation through auto-oxidative chain reactions. Meanwhile, a study investigating the impact of pulsed UV light on microalgal growth revealed an increase in saturated and monounsaturated fatty acids, alongside a reduction in polyunsaturated fatty acids following treatment [42].

Among the pulsed UV light application parameters, the small application distance and prolonged application time affected and increased all biochemical transformations. Our results revealed the necessity of evaluating such applications preferred for microbial safety in terms of biochemical changes. In light of these findings, it's clear that while pulsed UV light application effectively ensures microbial safety for surface decontamination of quail eggs, it can also lead to significant alterations in the product's biochemical properties. Crucially, parameters such as application distance and duration directly impact critical biochemical metrics including temperature increase, color changes, lipid oxidation (TBARS), and phenolic content/antioxidant activity. Furthermore, observed changes in fatty acid composition indicate that such non-thermal treatments have the potential to profoundly affect not only microbial load but also the nutritional value and overall quality of the product. These results lay an important foundation for future studies aiming to determine optimized application conditions and develop balanced solutions that preserve both microbial safety and nutritional quality in food products.

Declarations

Availability of Data and Materials: The data that findings of this study are available from the corresponding author (MGS) upon reasonable request.

Conflict of interest: The authors declare that they do not have any conflict of interest.

Financial Support: There is no funding source.

Ethical Statement: This study does not require ethical permission.

Generative Artificial Intelligence (AI): It is hereby stated by the authors that the content, figures, and tables within this article were entirely developed without the involvement of AI or AI-powered assistance.

Author Contributions: MGS: Conceptualization; writing-original draft; validation; supervision; resources. TD: Conceptualization; writing-original draft; validation; supervision; resources. OPC:

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