Received: 13 June 2018 | Revised: 21 September 2018 | Accepted: 18 October 2018

DOI: 10.1111/jfpp.13842

SPECIAL ISSUE

WILEY Journal of Food Processing and Preservation Institute of Food Science + Technology ifst

Ultraviolet (UV-C) radiation as a practical alternative to decontaminate thyme (*Thymus vulgaris* L.)

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Funding information
Istanbul Technical University Research Fund, Grant/Award Number: 36019

Abstract

Alternative and cost-effective decontamination methods for dehydrated herbs and spices are subject of interest in industry. In this work, a fluidized bed ultraviolet (UV-C) system was tested for decontamination of dehydrated thyme. The samples were exposed to UV-C radiation at 254 nm at 25.7, 51.4, 102.8, and 205.6 J/cm^2 delivered at an intensity of 26.7 mW/cm^2. UV-C at 205.6 J/cm^2 resulted in 1.8, 1.3, and 0.3 log cfu/g reductions in total aerobic mesophilic bacteria, total yeast/mold, and *Bacillus cereus*, respectively. Total phenolic content, total antioxidant activity, moisture content, and the sensory attributes were not affected by the UV-C treatments. UV-C caused a small increase in L^* and a^* values but these changes were not detected in sensory evaluation. In conclusion, UV-C treatment up to 205.6 J/cm^2 applied in a fluidized bed setting can potentially be used in decontamination of thyme without adverse effects on quality.

Practical applications

UV-C radiation is a widely used effective technology to reduce the microbial load on various surfaces, liquids, and air environments. In this study, the potential of a fluidized bed UV system was explored to reduce natural microbial load of thyme. The results indicated that UV-C application may be an effective technology for decreasing the microbial load of thyme without inducing significant changes to the physical, chemical, and sensorial quality, therefore it has a potential as an alternative method for decontamination of thyme and similar herbs and spices industrially.

1 | INTRODUCTION

Herbs and spices are added to food to enhance taste and flavor since ancient times. Thyme (*Thymus vulgaris* L.) is one of the most widely used herbs in Turkey and many other regions of the world. The main problem associated with herbs and spices is the microbial contamination which can cause health problems for consumers (McKee, 1995). Herbs and spices are very susceptible to microbial contamination due to their plant origin, growing conditions, harvesting methods, storage conditions, and post-harvest processing steps such as drying, size reduction, packaging, and storage practices (Schweiggert, Carle, & Schieber, 2007). Pathogenic bacteria, such as *Bacillus cereus*, *Salmonella*, *Escherichia coli*, and *Clostridium perfringens*, might be present in the herbs and spices, and the presence of such microorganisms creates a potential public health risk (Banerjee & Sarkar, 2003; Sagoo et al., 2009). The microbial load of the herbs and spices can reach up to 6–8 log cfu/g which may also lead to problems for food manufacturers in export (Tainter & Grenis, 2001). Consequently, herbs and spices should be decontaminated in order to maintain safety and quality.

The most commonly known methods to reduce microbial load of herbs and spices are fumigation with ethylene oxide, thermal treatment with steam, and irradiation (Schweiggert et al., 2007; Tainter & Grenis, 2001). However, use of ethylene oxide in foods is banned in many countries due to its toxicity. The use of steam treatment was associated with color and aroma alterations. Additionally, mold development

may occur on the surface of herbs and spices if the moisture is not removed after application (Schweiggert et al., 2007). Irradiation is the most used decontamination technique, which is very effective in microbial inactivation, but it has disadvantages such as oxidation of aromatic components, poor consumer acceptance, and requirement for special facility with high cost (Sadecka, 2007; Variyar, Gholap, & Thomas, 1997). Because of these limitations, many researchers have studied alternative methods such as pulsed electric field (Keith, Harris, Hudson, & Griffiths, 1997), infrared heating (Eliasson, Libander, Lövenklev, Isaksson, & Ahrné, 2014; Staack, Ahrné, Ahrné, Borch, & Knorr, 2008), remote plasma (Hertwig et al., 2015), pulsed UV light (Fine & Gervais, 2004; Nicorescu et al., 2013; Sharma & Demirci, 2003), cold plasma (Kim, Lee, & Min, 2014), and combination of far infrared and ultraviolet (UV-C) radiation (Erdoğdu & Ekiz, 2011, 2013), gamma irradiation under modified atmosphere packaging (Kirkin, Mitrevski, Gunes, & Marriott, 2014) and combination of UV-C radiation and mild heat treatment (Cheon, Shin, Park, Chung, & Kang, 2015).

UV-C radiation is an effective nonthermal technology that has been used to reduce the microbial load on various surfaces, liquids, and air environments (Butz & Tauscher, 2002). UV-C light have destructive effects on microorganisms by forming pyrimidine dimers that disrupt the normal configuration of DNA and inhibit its replication and transcription (Gómez-López, Koutchma, & Linden, 2012; Koutchma, Forney, & Moraru, 2009). However, this technology has low penetration depth, so it only inactivates microorganisms on the surface and suitable only for surface treatment of food products (Guerrero-Beltrán & Barbosa-Cánovas, 2004). UV-C light may have a potential in decontaminating microorganisms on the surface of herbs and spices, because, the inner part of the spices usually does not contain microorganisms, especially number of microorganisms is high on the outer surface (Gómez-López et al., 2012; Nicorescu et al., 2013). However, total and effective exposure of the surface of these products to UV-C light can be a challenge due to their small size and irregular shape. In order to deal with this challenge, herbs and spices can be exposed to UV-C light in a fluidized bed system. We have designed and built a model fluidized bed UV reactor for powdered food (Dogu-Baykut, Gunes, & Decker, 2014). As the powders flow through the bed (tube) they can be exposed to UV-C more efficiently due to individual powders movement in three dimension in the exposure region. Moreover, the fluidized bed UV-C decontamination system can provide continuous treatment which can be integrated with a pneumatic conveying system for the powders.

Therefore, this study aimed to investigate the decontamination potential of fluidized bed UV-C system for thyme. Effect of UV-C dose on natural microbial load, chemical, and sensorial quality of thyme was determined.

2 | MATERIALS AND METHODS

2.1 | Materials

Thyme samples were obtained in dried and ground form from a manufacturer (Kadioglu Spice Food Agricultural Co Inc., Mersin, Turkey). No further size reduction was applied to samples before any treatment. Samples were purchased in 5 kg packages from the manufacturer. The packages were stored at ambient temperature until the day of treatments.

Peptone was purchased from Oxoid (Basingstoke, Hampshire, UK). Sodium chloride was obtained from Riedel-de Haen (Seelze, Germany). Plate count agar (PCA), dichloran rose bengal chloramphenicol (DRBC) agar, mannitol egg yolk polymyxin (MYP) agar, and *B. cereus* selective supplement were purchased from Merck (Darmstadt, Germany).

Methanol, Folin–Ciocalteu reagent (FCR), sodium carbonate (anhydrous Na_2CO_3), gallic acid, 2,2-diphenyl-1-picrylhydrazil (DPPH), 6-Hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), sodium phosphate (monobasic and dibasic), trichloroacetic acid (TCA), potasyum ferrisiyanit ($K_3[Fe(CN)_6]$) and ferric chloride ($FeCl_3$) were purchased from Sigma (St. Louis, MO, USA).

2.2 | UV-C treatment of thyme

The system we used in this study was the modification of the our previous UV-C system (Dogu-Baykut et al., 2014). The schematic diagram of the experimental UV reactor system is shown in Figure 1. The UV-C radiation equipment consisted of a quartz cylindrical tube (100 cm length × 10 cm diameter) and eight Ster-L-Ray germicidal UV lamps with a working wavelength of 254 nm (Ster-L-Ray Germicidal Lamp, Model GHO36T5L/4P, Atlantic Ultraviolet Inc., Hauppauge, NY, USA) positioned around the quartz tube. This assembly was covered with a stainless steel cylindrical outer body, and placed vertically onto a laboratory fluid bed dryer (Model FT31, Armfield Ltd., Ringwood Hampshire, UK). Prior to the treatment of the samples, the UV-C lamps were switched on for 15 min to stabilize the intensity.

For each UV-C exposure, 10 g of sample was placed in the quartz glass tube and the top covered with a filter. The fluidized bed was run 20 s (4 s at speed 1, 2, 3, 4, and 5) per cycle. The speed of the fluidized bed varied between 1.80 and 2.25 m/s (between speed 1 and 5). UV-C radiation was applied to samples for 16, 32, 64, and 128 min in the system. Control groups were treated in the same manner with the UV-C lamps off.

The measurement of UV-C intensity was made at a 254 nm wavelength, using a portable digital radiometer fitted with a UVX-25 sensor (UVP Inc., Upland, CA, USA). UV-C intensity was measured at different distances from the light source within the quartz glass tube and the average value was determined as 26.87 mW/cm^2. The applied UV-C doses were 25.7, 51.4, 102.8, 205.6 J/cm^2 achieved by 16, 32, 64, and 128 min exposures, respectively. Each treatment was replicated three times.

2.3 | Microbial analysis

Microbial analyses were made using pour plate and spread plate technique according to the International Commission on Microbiological Specifications for Foods (ICMSF, 1978). UV-C treated and untreated samples (10 g each) were homogenized in 90 ml of peptone water

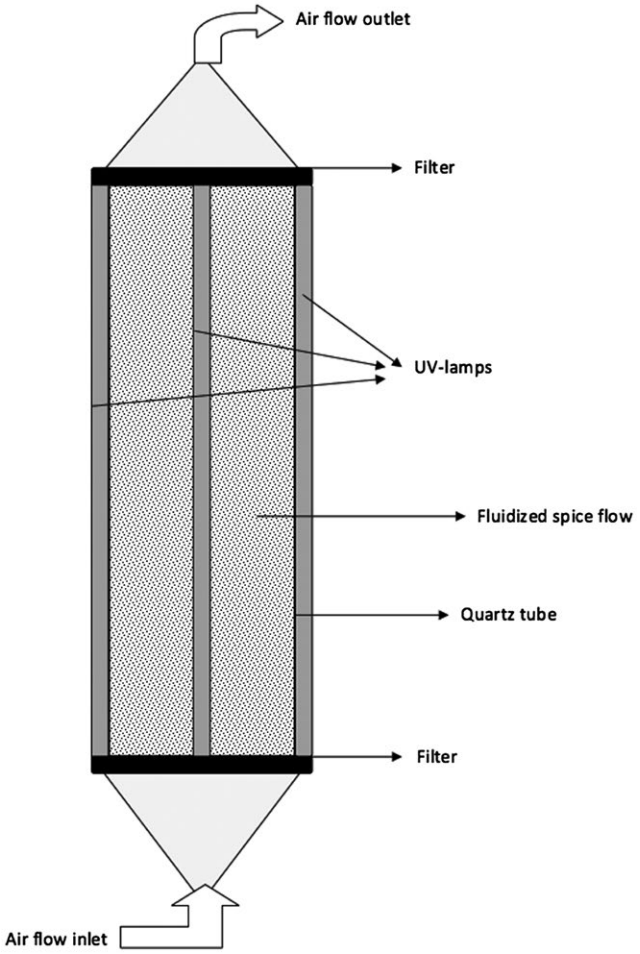

FIGURE 1 Schematic diagram of the UV-C system

(0.1%) using a stomacher (AESAP1068-Easymix, AES Chemunex, Combourg, France) at medium speed for 2 min. Further serial dilutions were made in peptone water. The total aerobic mesophilic bacteria (TAMB) was determined by pour plate technique using PCA while yeast and mold were determined by spread plate technique using DRBC. The *B. cereus* was determined by spread plate technique using MYP supplemented with *B. cereus* selective supplement and egg yolk emulsion. The PCA plates were incubated at 37°C for 48 hr, DRBC plates were incubated at 25°C for 3–5 days, and MYP plates were incubated at 30°C for 18–24 hr. The colonies on agar plates were counted after incubation and the results were expressed as log (cfu)/g sample.

2.4 | Preparation of thyme extract

Thyme samples were ground to fine powder using a grinder machine (PRG 259, Premier) for 1 min. Powdered samples (1 g) were weighed into falcon tubes and 15 ml of methanol/water (80:20 v/v) was added to each tube. The tubes were vortexed for 30 s and then placed into an ultrasonic bath (Azakli, Turkey) for 1 hr at room temperature. After sonification, samples were centrifuged (Hettich Zentrifugen Universal 32R, Tuttlingen, Germany) for 10 min at 2,700 g, and the clear supernatant was collected. Ten milliliter of methanol/water (80:20 v/v) was added to falcon tube and this extraction procedure was repeated again, and then the two supernatants were combined and stored at −18°C until analysis.

2.5 | Total phenolic analysis

The amount of total phenolics in extracts was determined spectrophotometrically according to the Folin–Ciocalteu method (Singleton, Orthofer, & Lamuela-Raventós, 1999; Viuda-Martos, Navajas, Zapata, Fernández-López, & Pérez-Álvarez, 2010). The thyme extracts (300 µl) were mixed with 2.5 ml of FCR (previously diluted 10-fold with distilled water). After 1 min, 2 ml of 7.5% (w/v) sodium carbonate solution was added. The tubes were vortexed and incubated in water bath at room temperature for 5 min. The absorbance was measured at 760 nm with a UV/VIS spectrophotometer (T80-UV/VIS, PG Instruments, Leicestershire, UK). The amount of total phenolics is expressed as mg gallic acid equivalents (GAE) per g) using a standard calibration curve prepared with gallic acid. Standard curve of gallic acid solution (10–200 ppm) was prepared using the similar procedure.

2.6 | DPPH radical scavenging assay

Free radical scavenging activities of methanol extracts of the samples were determined according to the previously reported procedure, using DPPH (Viuda-Martos, Gendy et al., 2010). Briefly, the DPPH solution in methanol (6×10^{-5} M) was prepared and 2 ml of this solution was mixed with 50 µl of methanolic solutions of extracts. The mixtures were shaken in a vortex for 1 min and kept at room temperature in the dark. After 1 hr of incubation in the dark at room temperature, the decrease in absorbance at 517 nm was determined by UV/VIS spectrophotometer (T80-UV/VIS, PG Instruments, Leicestershire, UK). Methanol was used as a blank solution and DPPH solution in methanol without any tested compound was used as control. A standard curve was made with Trolox solution (10–200 ppm), and the results were expressed as mg Trolox equivalents (TE) per g.

2.7 | Ferric reducing antioxidant power (FRAP) assay

The FRAP assay was carried out as described by Viuda-Martos, Gendy et al. (2010) with slight modifications. One milliliter of sample was mixed with 2.5 ml phosphate buffer (0.2 M, pH 6.6) and 2.5 ml potassium ferricyanide (1%). The mixture was vortexed and incubated in water bath at 50°C for 20 min. Then, 2.5 ml trichloroacetic acid (10%) was added to the mixture and shaken in a vortex. After mixing, an aliquot of the mixture (2.5 ml) was placed in a test tube and mixed with 2.5 ml water and 0.5 ml 1% $FeCl_3$. The absorbance was measured at 700 nm with a UV/VIS spectrophotometer (T80-UV/VIS, PG Instruments, Leicestershire, UK) after allowing the solution to stand for 30 min. A standard curve was made with Trolox solution (10–400 ppm), and the results were expressed as mg Trolox equivalents (TE) per g.

2.8 | Temperature analysis

The temperature measurements were carried out using an infrared thermometer (Quicktemp 826-T4, Testo, Lenzkirch, Germany) at a distance of 50 cm from the sample immediately after the each UV-C treatment.

2.9 | Color analysis

The color of the samples after UV-C treatment was measured with a chromameter (Model CR-400, Konica Minolta Sensing Inc., Tokyo, Japan) equipped with an 8-mm measuring head. A white calibration plate was used for calibration (Model CR-A43, Konica Minolta Sensing Inc., Tokyo, Japan). Color was expressed in L^*, a^*, and b^* parameters. The L^* represents the lightness of the samples, which vary from 0 (black) to 100 (white). The a^* indicates redness (positive values) and greenness (negative values) and b^* indicates yellowness (positive values) and blueness (negative values). Each sample was placed in a glass cell and the color values were measured at three different positions on each samples.

The differences to the control were calculated from the means of the color values: ΔL^*, Δa^*, and Δb^*. From the differences, the total color difference (ΔE) for each sample was calculated using the following equation:

$$\Delta E = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b)^2\right]^{1/2}$$

2.10 | Sensory analysis

Balanced 9-point hedonic scales were used to assess the degree of liking of the odor, color, and overall acceptability of thyme samples. After applying the UV-C treatments, samples were placed in non-aerated glass bottles and allowed to stand at ambient temperature until sensory analysis. UV-C treated and untreated samples were randomly 3 digit coded and served to a sensory panel in a specially designed sensory evaluation laboratory. Coded samples were assessed by eight panelists (students and employees of ITU Food Engineering Department). Before sensory analysis, panelists were trained for rating their degree of liking for each sample and descriptor by choosing the appropriate number that best describes his/her assessment about the sample. Panelists were instructed to evaluate odor first and then color and overall acceptability. The evaluation of the odor was made by smelling immediately after opening the cap. Each panelist evaluated three replicates of all the treatment groups on a 9-point numerical scale (1: dislike extremely, 5: neither like nor dislike, 9: like extremely) given in terms of odor, color, and overall acceptability.

2.11 | Statistical analysis

Each measurement was performed on three independently replicated samples and results expressed as mean values ± standard deviation. The data obtained were analyzed by analysis of variance (ANOVA) using SPSS version 21 (SPSS Inc., Chicago, IL, USA). The differences between mean values were compared using Duncan's multiple-range test with a level of significance of $p < 0.05$.

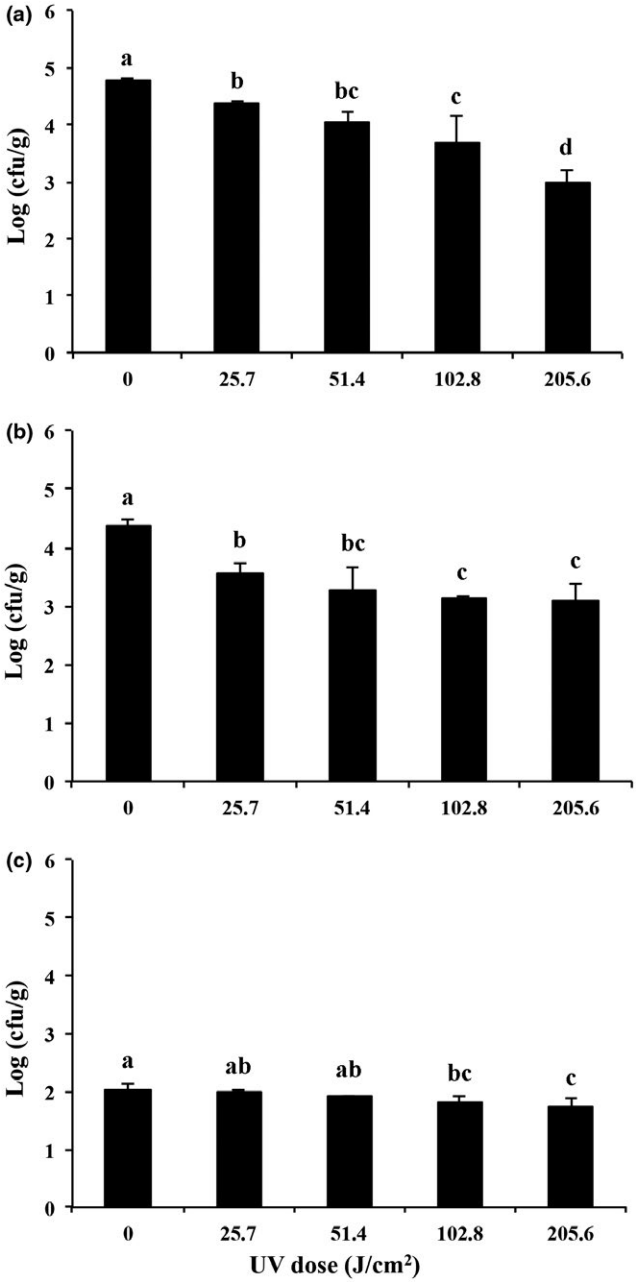

FIGURE 2 Effect of UV doses (J/cm^2) on TAMB (a), yeast and mold (b) and *B. cereus* counts of thyme. Error bars represent standard deviations of the mean (n = 3)

3 | RESULTS AND DISCUSSION

3.1 | Microbial analysis

The thyme samples used in this study were taken from the company without any decontamination process. UV-C treatments applied at all doses resulted in significant reduction in TAMB count in thyme

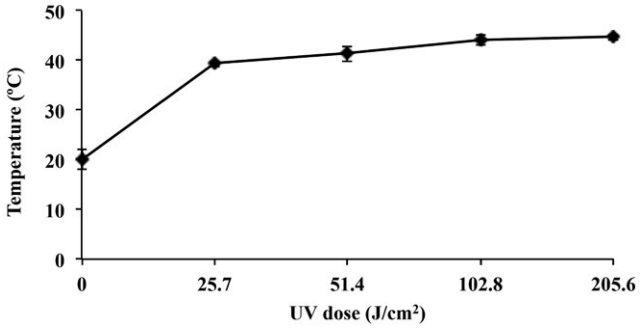

FIGURE 3 Temperature changes during UV-C light treatment for 128 min under intensity of 26.87 mW/cm^2. Error bars represent standard deviations of the mean (n = 3)

compared to the control (p < 0.05). UV-C treatment at 102.8 and 205.6 J/cm^2 decreased the TAMB count from the initial level of 4.75 log cfu/g to 3.67 and 2.98 log cfu/g, respectively. Thus, these dose levels were sufficient to decrease the TAMB count of thyme below the target value of 10^4 cfu/g suggested by ICMSF (2005).

Changes in yeast and mold counts of thyme in response to UV-C treatment were showed in Figure 2b. Initial yeast and mold counts of thyme was 4.37 log cfu/g. UV-C application of 25.7 J/cm^2 resulted in a 0.83 log reduction in total yeast and molds count (p < 0.05). However, the rapid reduction achieved at the dose of 25.7 J/cm^2 was not sustained by increasing dose. UV-C treatment at 102.8 and 205.6 J/cm^2 doses caused 1.28 and 1.32 log reduction in total yeast and mold count in thyme with the final counts decreased to 3.12 and 3.08 log cfu/g, respectively. The final levels of yeast and molds on the samples were still above the target value of 10^2 cfu/g suggested by ICMSF (2005).

The effect of UV-C doses on the *B. cereus* counts of thyme is shown in Figure 2c. UV-C treatment at 102.8 and 205.6 J/cm^2 doses decreased the *B. cereus* counts of thyme from 2.04 log cfu/g to 1.83 and 1.75 log cfu/g, respectively (p < 0.05). The UV-C treatments applied at the lower doses did not significantly affect the *B. cereus* count on the sample (p > 0.05). *B. cereus* is a spore forming bacteria and very resistant to adverse conditions and decontamination processes. For this reason, inactivation of *B. cereus* by UV-C treatment was much lower than that of TAMB and total yeast and molds. Herbs and spices can be contaminated by *B. cereus* as it is widely distributed in soils and waters. *B. cereus* produces toxins and can be a concern on foods. The target value for the number of *B. cereus* of herbs and spices in Turkish Food Codex is 3 log cfu/g (Turkish Food Codex, 2000).

Temperature during the treatment was continuously controlled to prevent temperature rise due to heat generated by the UV-C lamps. Changes in temperature with increasing UV-C doses are shown in Figure 3. With the help of a fan, the temperature of the samples after the treatments did not exceed 40°C, which would have no thermal effects on microorganisms. Thus, the microbial inactivation observed was solely due to the nonthermal effects of the UV-C treatments.

It can be seen from our microbiological results that the microbial decontamination level slowed down as the UV-C dose of the treatment increased. This behavior could be explained by the shadowing hypothesis. According to this hypothesis, UV-C light inactivates the microorganisms in the upper layers, but these microorganisms block the UV-C light passage. Little accessibility of the light to the shadowed microorganisms avoid them from destroying (Gómez-López, Ragaert, Debevere, & Devlieghere, 2007; Nicorescu et al., 2013). The fluidized bed system used in our study resulted in fairly good exposure of the surfaces of the thyme particles. However, irregular shape and size of the particles might have adversely affected the homogeneous exposure of the samples to UV-C light. Since 2011, there is no limits for TAMB and total yeast and mold counts for herbs and spices in Turkey. There are no specific microbiological limits for herbs and spices in European Union legislations either. However, lower levels of TAMB, yeast and mold on dehydrated herbs and spices is desirable as it affects quality and safety of foods in which they are added. Generally, regulation of microbial contamination for spices is based on industry guidelines. These guidelines require that spices should be free from pathogenic microorganisms at levels representing a health risk (specific requirements to be agreed between buyer and seller) and further specify that *Salmonella* spp. should be absent in at least 25 g. sample (Codex Alimentarius Commission (CAC), 1995; ESA, 2015; Muggeridge & Clay, 2001).

3.2 | Total antioxidant activity and phenolic content

Thyme is well known for its antioxidant properties. It is known that the high antioxidant activity of thyme is caused by phenolic

TABLE 1 Effects of different UV-C dose on total phenolic content and antioxidant capacity of thyme

		Antioxidant capacity	
UV-C dose (J/cm^2)	Total phenolic content (mg GAE/g)	DPPH (mg TE/g)	FRAP (mg TE/g)
0 (control*)	79.81 ± 0.9^a	121.69 ± 1.6^a	181.18 ± 7.2^a
25.7	79.64 ± 0.8^a	121.52 ± 1.3^a	179.94 ± 5.4^a
51.4	79.40 ± 2.1^a	121.02 ± 0.5^a	180.56 ± 4.0^a
102.8	78.41 ± 0.3^a	119.85 ± 0.6^a	180.56 ± 1.9^a
205.6	77.12 ± 3.1^a	120.19 ± 0.6^a	180.98 ± 3.5^a

Note. Means within a column having the same letter are not significantly different (p > 0.05).
Data represent mean values (n = 3) ± standard deviations.
*Control groups were treated in the same manner without switching the UV-C lamps on.

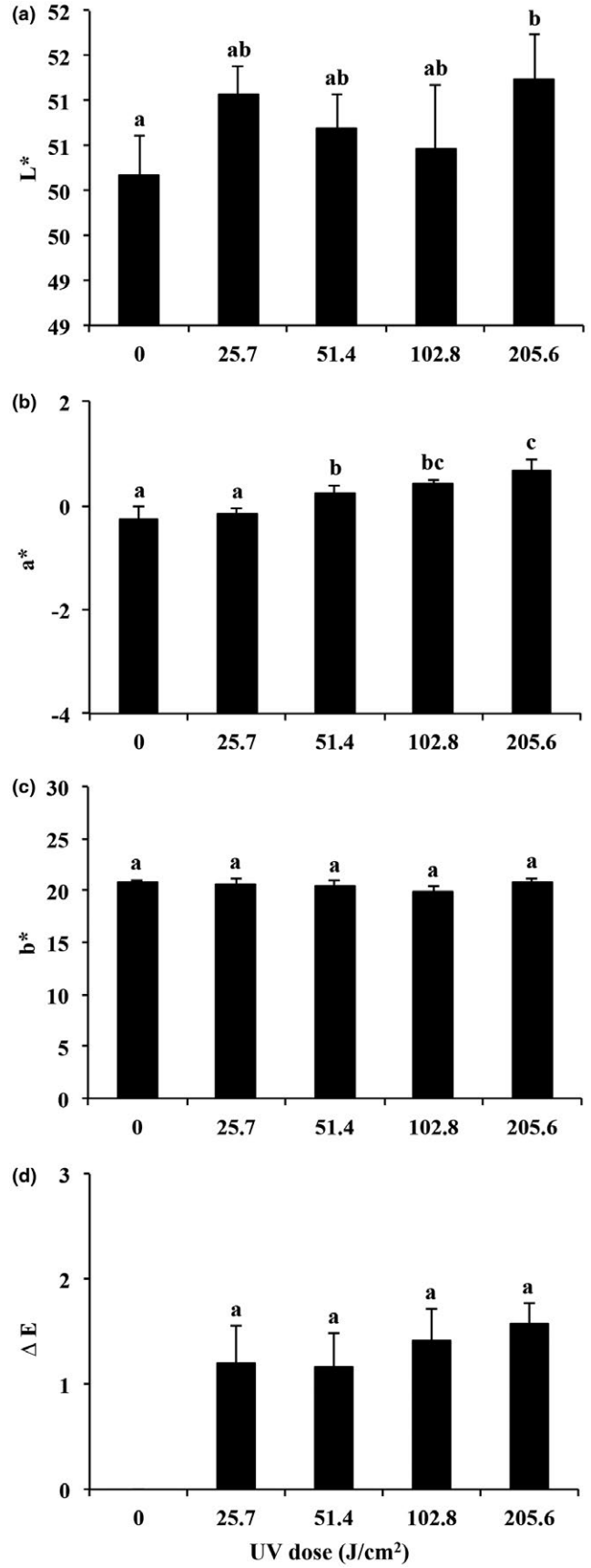

FIGURE 4 Effect of UV doses (J/cm^2) on redness (a), yellowness (b), lightness (c), and total color difference (d) of thyme. Error bars represent standard deviations of the mean (n = 3)

monoterpenes, thymol, and carvacrol, which are the major compounds found in thyme (Yanishlieva, Marinova, & Pokorný, 2006). Changes in total phenolic content and antioxidant activity of thyme are shown in Table 1. Total amount of phenolics in control thyme samples were found to be 79.81 mg GAE/g. The UV-C treatments at doses up to 205.6 J/cm^2 did not change total phenolic content of thyme samples ($p > 0.05$). The total antioxidant capacity of control thyme samples analyzed by DPPH and FRAP methods were determined as 121.69 and 181.18 mg TE/g, respectively. The UV-C treatments at doses up to 205.6 J/cm^2 did not affect the DPPH an FRAP values of the samples either ($p > 0.05$). To our knowledge, there have been no studies evaluating the effects of UV-C radiation on the total antioxidant capacity or phenolic content of thyme. There are some studies reporting the effects of gamma irradiation on the quality of thyme in literature. In accordance with our observation on the total phenolic content of thyme treated with UV-C doses up to 205.6 J/cm^2, Kirkin and Gunes (2018) reported that the total phenolic content of thyme extracts was not affected by irradiation at 14 kGy. They also reported that the DPPH of thyme was increased significantly by irradiation at 14 kGy in aerobic packaged samples compared to the non-irradiated control but not affected when irradiation was applied in modified atmosphere package. Brandstetter, Berthold, Isnardy, Solar, and Elmadfa (2009) reported similarly to our findings that the TPC of thyme extracts was not affected by irradiation at 10 kGy. Gumus, Albayrak, Sagdic, and Arici (2011) reported a decrease in the TPC of methanol extract of thyme after irradiation at 5.1 kGy, which does not agree with our results on thyme.

3.3 | Color analysis

Color is one of the most important factors by which consumers evaluate the quality of spices. The color data in terms of the L^*, a^*, and b^* values of the thyme after different doses of UV-C applications are presented in Figure 4. The initial mean L^* value of thyme was found to be 50.17. The L^* value of thyme was significantly increased after application of UV-C at a dose of 205.6 J/cm^2. b^* value of the thyme was 20.83 and not affected by any of the treatments ($p > 0.05$). a^* value of the thyme was −0.25 and had an increase in parallel with the increase in UV-C dose above 51.4 J/cm^2 ($p < 0.05$). There is a limited number of studies in the literature investigating the effect of UV-C application on the color values of herbs and spices. In a study conducted with red pepper, it was found that UV-C application at 4 J/cm^2 dose did not cause a significant change in the L^*, a^*, and b^* values of the samples (Cheon et al., 2015). In another study, Erdoğdu and Ekiz (2011) studied the combination of far infrared (200, 250, and 300°C and 4.8, 28, and 1.57 min, respectively) and UV-C application (75.6 J/cm^2) for cumin. Similar to our results, they found L^* and b^* values were not significantly affected UV-C application at a dose of 75.6 J/cm^2 while a^* value had a significant decrease.

The total color change (ΔE value) of the thyme at the dose of 25.7 J/cm^2 was only 1.19 and the slight increase with dose was not significant (Figure 4d, $p > 0.05$). ΔE values up to 2 represent a small difference in the degree to which it can be seen only by the educated

TABLE 2 Effects of different UV-C dose on sensory properties of thyme

UV-C dose (J/cm^2)	Odor	Color	Overall acceptability
0 (control*)	6.58 ± 0.4^a	6.92 ± 0.2^a	7.17 ± 0.3^a
25.7	6.33 ± 0.4^a	6.88 ± 0.3^a	6.92 ± 0.6^a
51.4	6.21 ± 0.1^a	6.88 ± 0.3^a	6.88 ± 0.4^a
102.8	6.25 ± 0.3^a	6.83 ± 0.1^a	6.96 ± 0.2^a
205.6	6.29 ± 0.4^a	6.71 ± 0.4^a	6.92 ± 0.3^a

Note. Means within a column having the same letter are not significantly different ($p > 0.05$).
Data represent mean values ($n = 3$) ± standard deviations.
*Control groups were treated in the same manner without switching the UV-C lamps on.

eye (Virtanen, Vehmas, Erho, & Smolander, 2014). In our study, we tried to eliminate the effect of temperature on color changes by keeping the temperature constant and preventing it from increasing. Because it is known that heat generally alters the aromatic components and color characteristics of herbs and spices (Pafumi, 1986).

3.4 | Sensory analysis

Like many other food products, sensorial quality is very important factor for herbs and spices that influence the consumer preferences. Sensorial analysis was performed to investigate the effect of UV-C application at different doses on sensorial quality of thyme. All samples were rated with respect to their odor, color, and general acceptability and the results are shown in Table 2. According to the results of sensory analysis, the highest odor, color, and general acceptability scores were observed in the control samples of thyme and determined as 6.58, 6.92, and 7.17, respectively. The sensory scores of the UV-C treated thyme samples were found to be close to that of control and there were no significant differences between them ($p > 0.05$).

The changes detected in the instrumental color analysis of thyme were not detected in the sensorial evaluations ($p > 0.05$). These results show that the color change in the thyme was invisible to the eye. Odor and general acceptability scores of UV-C treated thyme were also very high. Therefore, the UV-C doses used in this study did not cause any significant change in the sensorial properties of thyme.

4 | CONCLUSIONS

The results of this study indicated that UV-C treatment in a fluidized bed setting has a potential for decreasing the microbial load of thyme without any significant changes to the physical, chemical, and sensorial qualities. The UV-C treatments resulted in up to a 1.8 and 1.3 log reduction in TAMB and total yeast and mold counts, respectively. The UV-C treatments had very limited effects on *B. cereus* count on the samples. The UV-C treatments at the applied dose levels did not adversely affect the sensory and chemical quality characteristics of the samples. Further studies are needed to improve the exposure of the herb particles to UV-C by considering the variation in size, shape, and contamination level of the particles as well as varying the design parameters of the fluidized bed UV-C system. The fluidized bed UV-C system can be integrated into pneumatic conveying system for continuous treatment of thyme and other similar herbs and spices for industrial application. In this way, spice companies can decontaminate their products more economically in their own facilities.

ACKNOWLEDGMENTS

This research was partly financially supported by the grant from Istanbul Technical University Scientific Research Projects Department (ITU BAP Project No: 36019).

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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How to cite this article: Dogu-Baykut E, Gunes G. Ultraviolet (UV-C) radiation as a practical alternative to decontaminate thyme (*Thymus vulgaris* L.). *J Food Process Preserv*. 2018;e13842. https://doi.org/10.1111/jfpp.13842