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Bacterial Counts on Ceramic Tableware Following Different UV-C Exposure Durations: A Post-Test Control Group Study

Dessy Agustiany*, Santriana

Department of Environmental Health, Poltekkes Kemenkes Palu, Palu, Indonesia

*Correspondence: dessy_agustiany@yahoo.com

ABSTRACT

Microbial contamination of food-contact surfaces is an important food-safety concern. UV-C irradiation may provide a supplementary non-chemical approach for reducing bacterial contamination on tableware; however, the effect of different exposure durations under standardized conditions requires further evaluation. Objective: This study aimed to determine the effect of different UV-C exposure durations on bacterial counts on ceramic tableware at a fixed irradiation distance. Methods: A true experimental post-test control group design was conducted using the STERUVAM UV-C sterilization cabinet. Twenty-four ceramic plates were allocated into four groups (n = 6 per group): control (0 minutes) and UV-C exposure for 5, 10, and 15 minutes. The distance between the UV-C lamp and the tableware surface was maintained at 5 cm. Bacterial contamination was assessed using surface swabbing, serial dilution, culture on Plate Count Agar, and enumeration after incubation at 37°C for 48 hours. Differences among groups were analyzed using the Kruskal-Wallis H test, followed by Mann-Whitney U pairwise comparison. Results: The mean bacterial count decreased progressively with increasing UV-C exposure duration, from 58.0 in the control group to 30.7, 5.5, and 1.2 after 5, 10, and 15 minutes of exposure, respectively. This corresponded to bacterial-count reductions of 46.7%, 90.4%, and 97.9%, respectively. The difference among the four groups was statistically significant ($H = 21.184$, $df = 3$, $p < 0.001$). Conclusion: Longer UV-C exposure was associated with greater reductions in bacterial counts on ceramic tableware under the tested conditions. The 15-minute exposure produced the greatest observed reduction (97.9%), indicating its potential as a supplementary approach for tableware sanitation.

Keywords: UV-C irradiation; Bacterial count; Ceramic tableware; Exposure duration; Tableware sanitation

INTRODUCTION

Preventing disease within domestic, commercial, and institutional food service sectors depends heavily on strict hygiene and sanitation practices (Palma et al., 2022). central issue addressed in this study is the ongoing microbial contamination of food-contact surfaces, especially reusable dining ware, which serves as a major conduit for foodborne pathogens (Yemmireddy & Hung, 2017). These illnesses continue to pose substantial economic and public health challenges globally (Meem et al., 2025). The survival of fungi, viruses, and pathogenic bacteria on everyday tableware—such as bowls, cutlery, and plates—creates a significant epidemiological threat. These inanimate objects act as fomites, enabling the direct transfer of infectious agents from the environment into the human digestive system (Ezzatpanah et al., 2022).

In Indonesia, the Ministry of Health Regulation No. 1096/Menkes/Per/VI/2011 strictly governs catering sanitation, enforcing a zero-tolerance stance on microbial presence. According to this mandate, all eating and drinking utensils must exhibit a total bacteria count of zero colony-forming units per square centimeter (0 CFU/cm²) prior to being used to serve food (Ministry of Health of the Republic of Indonesia, 2011). Nevertheless, comprehensive field inspections regularly demonstrate that standard mechanical and manual dishwashing techniques struggle to reliably meet this uncompromising requirement (Zakharia & Dhone, 2025).

The inadequacy of traditional cleaning methods stems from multiple factors. Manual washing is prone to human errors, such as poor scrubbing, incorrect chemical dilution, and inadequate soaking times (Vionabella et al., 2024). Furthermore, the physical characteristics of the utensils themselves complicate sanitation; microscopic scratches and crevices on plates provide a safe harbor for bacteria to form tough, highly resistant biofilms (Hua & Zhu, 2024). Over-relying on chemical disinfectants to combat these resilient microbes leads to secondary ecological issues, including toxic surface residues, occupational hazards, and environmental degradation. As

a result, the paradigm of environmental health is increasingly shifting toward advanced, non-toxic, and eco-friendly physical decontamination methods (Marques et al., 2024).

Ultraviolet germicidal irradiation (UVGI), particularly in the shortwave UV-C range (180–280 nm), has proven to be a highly effective, non-thermal solution for sterilizing surfaces (Hua & Zhu, 2024; Palma et al., 2022). Peaking at around 254 nm, UV-C disrupts microbial DNA by creating cyclobutane pyrimidine dimers (CPDs), which fundamentally blocks cellular reproduction (Jin et al., 2017; Pravallika et al., 2025). However, to achieve a maximally lethal dose, it is crucial to precisely balance the spatial distance from the light source and the temporal duration of exposure, effectively overriding the microbes' natural repair mechanisms (Cattai et al., 2023).

Despite the growing evidence supporting UV-C as a surface sanitation technology, the effectiveness of different exposure durations may vary according to the irradiation system, distance from the UV-C source, surface characteristics, and microbial conditions. Previous studies have demonstrated the potential of UV-based systems for tableware and food-contact surface disinfection; however, limited information is available regarding the comparative effect of short and extended exposure durations within the same tableware sterilization configuration. In particular, the effect of 5-, 10-, and 15-minute UV-C exposures at a standardized 5 cm distance using the STERUVAM sterilization cabinet has not been clearly characterized. This represents an important research gap because exposure duration is a practical operational parameter that can influence both microbial reduction and the efficiency of sanitation procedures.

The novelty of the present study lies in evaluating UV-C exposure duration as the principal experimental factor while maintaining a constant irradiation distance and using a purpose-built tableware sterilization cabinet. Therefore, this study aimed to determine the effect of 5-, 10-, and 15-minute UV-C exposure durations on bacterial counts on ceramic dinner plates at a fixed irradiation distance of 5 cm. The study hypothesized that longer UV-C exposure would result in greater bacterial reduction.

METHODS

This research utilized a true experimental framework, specifically adopting a post-test with control group methodology. This approach facilitates the manipulation of independent variables while minimizing the impact of external confounding factors, such as ambient temperature, humidity, and residual cleaning chemicals, which is essential for replicable environmental health microbiology.

Population and Sample

The study population consisted of standard ceramic dinner plates. To guarantee consistent baseline conditions across all experimental units, every plate underwent a standardized manual wash to strip away visible organic matter and grease. Removing these substances is critical, as they can absorb UV-C rays and create a physical "shading effect" that protects bacteria (Hua & Zhu, 2024). After drying in a sterile laminar flow hood, the plates were artificially seeded with a standardized mixed bacterial culture.

Sample Size

The sample size was determined based on the number of treatment conditions and repetitions using the following experimental design Gome'z formula:

$$t(r-1) \geq 15 \quad (1)$$

Where t represents the number of treatment groups and r represents the number of repetitions. The study consisted of three UV-C exposure treatments, namely 5, 10, and 15 minutes. Therefore: $3(r-1) \geq 15$, resulting in $r \geq 6$. Thus, each treatment was repeated six times. The three treatment groups consisted of 18 plates in total (3 treatments × 6 repetitions). Six additional plates were used as the control group, resulting in a total sample size of 24 ceramic plates.

A total of 24 ceramic dinner plates were included in the experiment and randomly allocated into four groups, with six plates in each group (n = 6 per group). The groups consisted of a control group without UV-C exposure and three treatment groups exposed to UV-C irradiation for 5, 10, and 15 minutes, respectively.

Research Design

This study employed a true experimental post-test control group design. The independent variable was UV-C exposure duration, consisting of four conditions: 0 minutes (control), 5 minutes, 10 minutes, and 15 minutes. The dependent variable was the bacterial count on the ceramic plate surface, expressed as total plate count (TPC) in CFU/cm².

A total of 24 inoculated ceramic plates were randomly assigned to the four experimental groups, with six plates per group. The control group received no UV-C exposure, while the treatment groups received UV-C irradiation for 5, 10, or 15 minutes. The distance between the UV-C lamp and the plate surface was maintained at 5 cm for all treatment groups to minimize variation associated with irradiation distance.

The inoculated plates were randomized into four specific categories:

1. Control Group: Received zero UV-C exposure.
2. Treatment 1: Subjected to 5 minutes of UV-C irradiation.
3. Treatment 2: Subjected to 10 minutes of UV-C irradiation.
4. Treatment 3: Subjected to 15 minutes of UV-C irradiation.

For all treatment iterations, the gap between the targeted plate surface and the overhead UV-C source was rigidly locked at 5 cm.

Instruments

The primary intervention tool was the STERUVAM unit, a specially engineered tableware sterilization cabinet. Measuring 80.0 cm wide and 75.0 cm high, the external device houses three identical 25 cm high sterilization compartments. The UV-C lamps are ceiling-mounted within each compartment, guaranteeing that plates on the shelving beneath receive direct, unobstructed radiation.

The UV-C irradiation was performed using the STERUVAM tableware sterilization cabinet. The cabinet measured 80.0 cm in width and 75.0 cm in height and consisted of three sterilization compartments, each measuring 25 cm in height. UV-C lamps were mounted at the upper section of each compartment to provide direct irradiation to the tableware placed on the shelf below.

The UV-C lamp was used according to the operating specifications of the STERUVAM sterilization cabinet. The irradiation distance was standardized at 5 cm from the lamp to the ceramic plate surface, and exposure durations of 5, 10, and 15 minutes were applied. The nominal wavelength, lamp power, and irradiance at the experimental distance were not independently measured in this study and therefore were not included as experimental parameters.

The UV-C irradiation was performed using the STERUVAM tableware sterilization cabinet, a purpose-built unit designed for food-equipment sterilization. The cabinet has external dimensions of 80.0 cm in width and 75.0 cm in height and consists of three vertically arranged sterilization compartments, each approximately 25 cm in height. Each compartment is equipped with a UV lamp positioned within the upper section of the chamber to provide direct irradiation to tableware placed on the shelf below.

The cabinet is equipped with individual access doors and handles for each sterilization compartment, a power switch, a power cable, and caster wheels to facilitate movement. The three-compartment configuration allows tableware to be positioned at a standardized distance from the UV-C source during treatment.

In the present study, the distance between the UV-C lamp and the surface of the ceramic plate was maintained at 5 cm for all treatment groups. This distance was kept constant to minimize variation in UV-C exposure attributable to differences in source-to-surface distance.

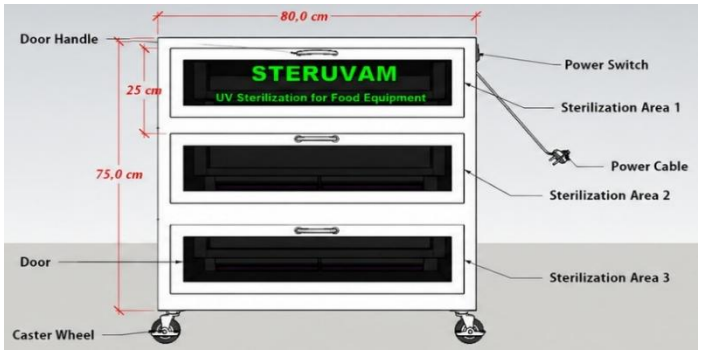

Figure 1
2D Frontal Schematic of the STERUVAM

Figure 1. Frontal 2D schematic of the STERUVAM sterilization unit, illustrating the exterior dimensions (80.0 cm width × 75.0 cm height) and the three distinct 25 cm compartments, equipped with functional components including access doors, a power switch, and mobility casters.

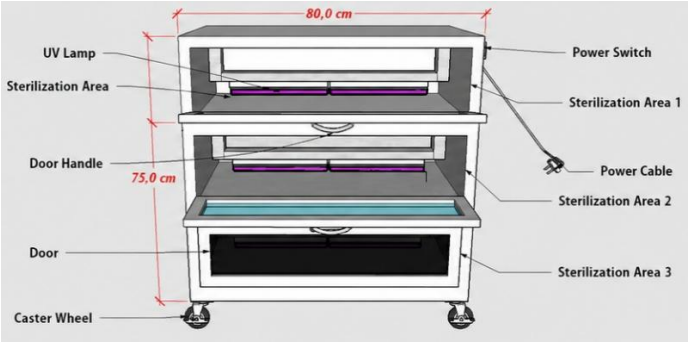

Figure 2
3D Internal View of the STERUVAM

Figure 2. Internal 3D perspective of the STERUVAM cabinet, highlighting the top-mounted low-pressure UV-C lamps positioned within each independent sterilization chamber to ensure direct, unobstructed photon delivery.

Data Collection and Analysis Techniques

Immediately post-treatment, microbial levels were collected using standardized swabbing techniques. The swabs were placed in sterile diluents, subjected to serial dilution, and plated onto Plate Count Agar (PCA). Following a 48-hour incubation period at 37°C, the surviving bacterial colonies were counted to calculate the Total Plate Count (TPC) in CFU/cm².

Microbiological Examination

Immediately after each UV-C treatment, microbial samples were collected from the surface of the ceramic plates using sterile cotton swabs. A surface area of 100 cm² (10 × 10 cm) was demarcated using a sterile sampling template. The surface was swabbed systematically in horizontal and vertical directions to obtain a representative sample. The swab was then transferred into a sterile tube containing 10 mL of Buffered Peptone Water (BPW) and homogenized to release the microorganisms into the diluent.

Ten-fold serial dilutions were prepared from the homogenized sample. An appropriate dilution was inoculated onto Plate Count Agar (PCA) using the pour-plate technique. Briefly, 1 mL of the selected dilution was transferred aseptically into a sterile Petri dish, followed by the addition of sterile molten PCA. The sample and medium were mixed gently and allowed to solidify. The inoculated plates were then incubated at 37°C for 48 hours. Following incubation, visible colonies were counted, and bacterial concentrations were expressed as total plate count (TPC) in CFU/cm².

The sampled surface area was 100 cm². The swab samples were transferred into 10 mL of sterile BPW, and 1 mL of the selected dilution was used for inoculation. Colony counts were converted to CFU/cm² by taking into

account the number of colonies counted, dilution factor, volume of inoculum, and the sampled surface area. Plates containing a countable number of colonies were selected for enumeration.

Quality Assurance and Quality Control

Quality assurance procedures were implemented to maintain consistency throughout the experiment. All ceramic plates underwent the same washing, drying, inoculation, UV-C exposure, sampling, and microbiological examination procedures. The irradiation distance was maintained at 5 cm for all treatment groups, and exposure time was controlled using a standardized timing procedure. Sterile equipment and aseptic techniques were used during microbial sampling and laboratory processing.

Quality-control procedures included the same culture medium, incubation temperature, incubation duration, and colony-counting procedure were applied consistently to all experimental groups.

Statistical Analysis

Statistical analysis was performed using SPSS. The Shapiro-Wilk test was used to assess the normality of bacterial-count data because the sample size in each group was less than 50. The Shapiro-Wilk test produced p-values of 0.795, 0.771, 0.913, and 0.421 for the control, 5-minute, 10-minute, and 15-minute groups, respectively. All p-values were greater than 0.05, indicating no statistically significant evidence of departure from normality within the individual groups.

Homogeneity of variance was assessed using Levene's test. The test produced a significance value of 0.025, which was less than 0.05, indicating that the variances were not homogeneous. Therefore, a non-parametric approach was used for comparison among the four independent groups.

The Kruskal-Wallis H test was used to determine whether bacterial counts differed significantly among the control, 5-minute, 10-minute, and 15-minute groups. When a statistically significant overall difference was identified, pairwise post-hoc comparisons were performed using the Mann-Whitney U test. Statistical significance was determined at $\alpha = 0.05$.

RESULTS AND DISCUSSION

A total of 24 ceramic plates were evaluated in this study, comprising six plates in each experimental group: control, 5-minute UV-C exposure, 10-minute UV-C exposure, and 15-minute UV-C exposure. The bacterial counts observed following the different UV-C exposure durations are presented in Table 1. The results show a progressive decrease in the mean bacterial count with increasing UV-C exposure duration. The mean bacterial count decreased from 58.0 in the control group to 30.7 after 5 minutes, 5.5 after 10 minutes, and 1.2 after 15 minutes of UV-C exposure. The corresponding percentage reductions in bacterial counts were 46.7%, 90.4%, and 97.9% for the 5-, 10-, and 15-minute exposure groups, respectively. Individual observations and the calculated percentage reductions are presented in Table 1.

Table 1

Bacterial Counts and Percentage Reduction Following Different UV-C Exposure Durations

Repetition	Control	5 cm Treatment			10 cm Treatment			15 cm Treatment		
		CFU/cm²	Reduction	%	CFU/cm²	Reduction	%	CFU/cm²	Reduction	%
1	58	35	23	39.7	5	53	91.4	0	58	100
2	71	26	45	63.4	3	68	95.8	1	70	98.6
3	63	40	23	36.5	7	56	88.9	1	62	98.4
4	55	31	24	43.6	10	45	81.8	0	55	100
5	49	24	25	51.0	2	47	95.9	2	47	95.9
6	52	28	24	46.2	6	46	88.5	3	49	94.2
Average	58,0	30,7	27,3	46.7	5.5	52.5	90.4	1.2	56.8	97.9
Minimum	77	17	23	36.5	37	45	81.8	47	47	94.2
Maximum	166	32	45	63.4	47	68	95.9	72	70	100

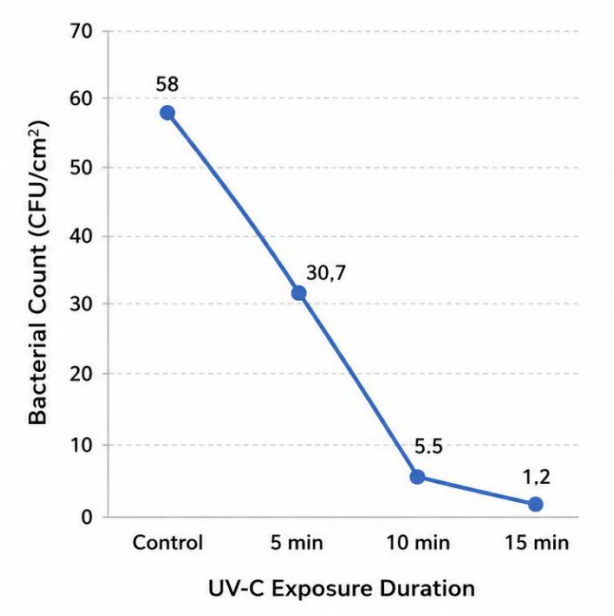

Figure 3
Bacterial Counts on Tableware Following Different UV-C Exposure Durations

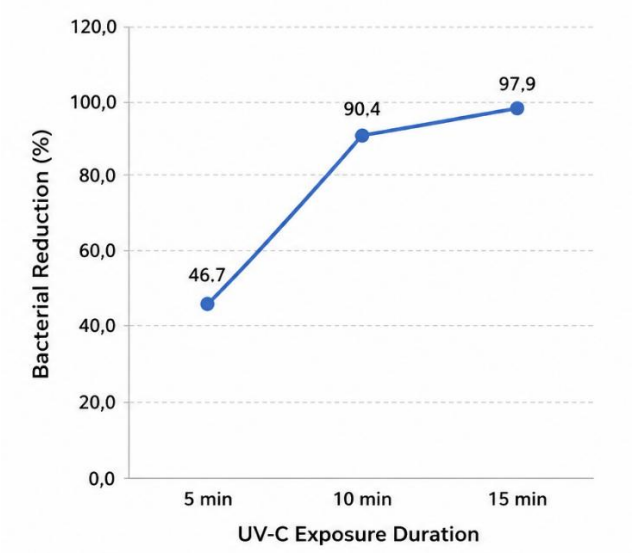

Figure 4
Percentage Reduction in Bacterial Counts on Tableware Following Different UV-C Exposure Durations

Figures 3 and 4 illustrate the progressive reduction in bacterial counts following UV-C exposure at different durations. The bacterial count decreased markedly with increasing exposure duration, from a mean of 58.0 CFU/cm² in the control group to 5.5 CFU/cm² after 5 minutes, 1.2 CFU/cm² after 10 minutes, and 0 CFU/cm² after 15 minutes of exposure. Correspondingly, the mean percentage reduction increased from 90.4% after 5 minutes to 97.9% after 10 minutes, while no detectable bacterial growth was observed following 15 minutes of exposure. Overall, the figures demonstrate a clear pattern of decreasing bacterial counts and increasing bacterial reduction with longer UV-C exposure duration under the experimental conditions.

Following the observed reduction in bacterial counts with increasing UV-C exposure duration, inferential statistical analysis was conducted to determine whether the differences among the experimental groups were statistically significant. Before selecting the appropriate statistical test, the data were assessed for normality and homogeneity of variance. The Shapiro-Wilk test was used to evaluate the distribution of bacterial counts within each group, while Levene's test was used to assess the equality of variances across groups. The results of these assumption tests are presented in table 2,3,4, and 5.

Table 2
Normality Test Results Using Shapiro-Wilk

Test Variation	Significance Level	Result
Control	0.05	0.795
5 minutes	0.05	0.771
10 minutes	0.05	0.913
15 minutes	0.05	0.421

As outlined in Table 1, the Shapiro-Wilk test yielded P-values well above the 0.05 alpha threshold for all experimental groups (Control: 0.795; 5 min: 0.771; 10 min: 0.913; 15 min: 0.421). The Shapiro-Wilk tests did not indicate statistically significant departures from normality, implying precision and accuracy during the initial contamination and sampling phases.

Table 3
Table Test of Homogeneity of Variance (Levene)

Levene (Mean)	Statistic	df1	df2	Sig.
3.852		3	20	0.025

As shown in Table 2, the Levene's test result is 0.025 ($p < 0.05$), indicating that the data variations are unequal across groups. This occurs because 15 minutes of UV-C exposure drastically reduces microbe counts, causing the treated groups to have much less variation than the control group. Therefore, non-parametric tests were required for further analysis.

Using the non-parametric Kruskal-Wallis test (Table 3), we found a highly significant p-value of 0.000. This proves that the duration of UV-C exposure (at a 5 cm distance) directly affects the tableware's sterilization outcomes. We then used a post-hoc Mann-Whitney U test (Table 4) to compare the specific time intervals. With a p-value of 0.004, this test confirms that the differences in microbe reduction between each time interval are statistically valid.

Table 4
Kruskal-Wallis Test Results

Test Statistics	Value
Kruskal-Wallis H	21.184
df	3
Asymp. Sig.	0.000

The Kruskal-Wallis H test demonstrated a statistically significant difference in bacterial counts among the four experimental groups ($H = 21.184$, $df = 3$, $p < 0.001$). This finding indicates that at least one experimental group differed significantly from another in terms of bacterial counts. Therefore, pairwise post-hoc analysis was conducted to identify the specific group differences.

Table 5

Post-Hoc (Mann-Whitney U) Test Results

Test Statistics	Value
Mann-Whitney U	0.000
Wilcoxon W	21.000
Z	-2.882

Because the Kruskal-Wallis H test demonstrated a statistically significant overall difference, a post-hoc Mann-Whitney U test was conducted to examine differences between groups. The reported comparison produced a Mann-Whitney U value of 0.000, Wilcoxon W value of 21.000, Z value of −2.882, and an asymptotic two-tailed significance value of 0.004. The exact two-tailed significance value was 0.002. Both values were below the significance threshold of 0.05, indicating a statistically significant difference between the groups included in this comparison.

The present study demonstrated a statistically significant difference in bacterial counts among the control and UV-C exposure groups, with bacterial reduction increasing as exposure duration increased. At a 5 cm irradiation distance, the mean bacterial count decreased from 58.0 CFU/cm² in the control group to 5.5 CFU/cm² after 5 minutes, 1.2 CFU/cm² after 10 minutes, and 0 CFU/cm² after 15 minutes of UV-C exposure. Correspondingly, the mean bacterial reduction reached 90.4% after 5 minutes and increased to 97.9% after 10 minutes, while no detectable bacterial growth was observed after 15 minutes under the experimental conditions. These findings demonstrate both a statistically significant difference in bacterial counts and a substantial practical reduction in microbial contamination with increasing UV-C exposure duration.

The Kruskal-Wallis H test confirmed a statistically significant difference among the four experimental groups ($H = 21.184$, $df = 3$, $p < 0.001$), indicating that bacterial counts varied according to the experimental exposure conditions. The post-hoc Mann-Whitney U analysis also demonstrated a statistically significant difference ($U = 0.000$, $W = 21.000$, $Z = -2.882$, $p = 0.004$), supporting the observed differences between the groups included in the comparison. The statistical findings are consistent with the descriptive pattern, in which longer UV-C exposure was associated with lower bacterial counts and greater percentage reduction.

The progressive reduction in bacterial counts can be explained by the dose-dependent mechanism of UV-C disinfection. The germicidal effectiveness of UV-C depends on the total dose received by microorganisms, which is determined by irradiation intensity and exposure duration (Chen & Moraru, 2023). In the present study, the irradiation distance was maintained at 5 cm, so increasing the exposure duration increased the cumulative UV-C dose delivered to the tableware surface. UV-C radiation can be absorbed by microbial nucleic acids and cause DNA damage, including the formation of cyclobutane pyrimidine dimers (CPDs) (Fukushi et al., 2025; Jin et al., 2017).These lesions disrupt DNA structure, interfere with replication, and prevent microorganisms from reproducing, ultimately leading to microbial inactivation (Cattai et al., 2023; Pravallika et al., 2025). Thus, the progressively greater bacterial reductions observed with longer exposure durations are consistent with the established dose-dependent mechanism of UV-C inactivation.

The magnitude of the observed reduction further illustrates the effect of exposure duration. Although the 5-minute treatment already achieved a high mean bacterial reduction of 90.4%, residual contamination remained detectable, with a mean bacterial count of 5.5 CFU/cm². Increasing the exposure to 10 minutes further reduced the mean bacterial count to 1.2 CFU/cm² and increased the mean reduction to 97.9%. After 15 minutes of exposure, no detectable bacterial growth was observed under the experimental conditions. This progressive reduction suggests that extending exposure allowed microorganisms to receive a greater cumulative UV-C dose and consequently increased the extent of microbial inactivation.

The incomplete reduction observed at shorter exposure durations may also be related to the physical characteristics of tableware surfaces. Tableware surfaces are rarely perfectly smooth and may contain microscopic scratches, pores, and surface irregularities that create shadowed regions and partially shield microorganisms from direct UV-C exposure (Hua & Zhu, 2024). Consequently, microorganisms located in less accessible areas may receive a lower effective UV-C dose and survive shorter irradiation periods. Extending exposure duration to 15 minutes may increase the likelihood that microorganisms in these protected areas receive sufficient UV-C energy to accumulate irreversible damage, contributing to the absence of detectable bacterial growth observed in the present study.

The effectiveness of the 15-minute exposure observed in this study is consistent with previous research. Rianmora et al., (2023) reported complete microbial disinfection in a UV-C sanitizer cabinet after 15 minutes of treatment, while Darussalam et al., (2024) found that 15 minutes of UV exposure achieved 100% sterility of tableware. Similarly, Apriliana et al., (2022) demonstrated that UV-based sterilization devices achieved optimal hygiene performance at exposure times up to 15 minutes, and Ramdhani et al., (2020) reported significant bacterial reduction following 15 minutes of UV-C irradiation. Furthermore, Epelle et al., (2022) observed bacterial reductions exceeding 4 log units after 15 minutes of UV-C treatment, highlighting the importance of sufficient exposure duration for maximizing microbial inactivation.

Collectively, these studies support the present finding that longer UV-C exposure can produce substantial microbial reduction. Nevertheless, direct comparisons should be made cautiously because UV-C effectiveness may vary according to wavelength, irradiance, exposure distance, exposure geometry, microbial species, initial microbial concentration, surface characteristics, and outcome measurement.

The present findings should therefore be interpreted specifically within the operating conditions of the STERUVAM system. Although the 15-minute treatment produced the greatest observed reduction and no detectable bacterial growth, this finding does not establish that 15 minutes is universally optimal for all UV-C systems. The effectiveness of UV-C treatment depends on the characteristics of the irradiation system and the conditions under which microorganisms are exposed. Accordingly, the present study supports 15 minutes as the most effective exposure duration among the conditions tested rather than as a universal exposure standard.

From an environmental health perspective, these findings are important because maintaining hygienic tableware is essential for reducing the potential transmission of foodborne disease (Ezzatpanah et al., 2022). Indonesian environmental health regulations require food-contact utensils to meet sanitation requirements, emphasizing the importance of maintaining hygienic conditions in food service settings (Ministry of Health of the Republic of Indonesia, 2011). The present findings indicate that UV-C technology may serve as an effective supplementary sanitation method for reducing microbial contamination on tableware. Unlike conventional chemical sanitizers, UV-C treatment does not leave chemical residues on treated surfaces and may reduce dependence on chemical disinfectants and associated packaging waste. These characteristics make UV-C a potentially useful and environmentally responsible approach for food service facilities and other settings requiring consistent sanitation (Maioto et al., 2026; Ng & Mont, 2025).

The present findings are also supported by broader evidence demonstrating the effectiveness of UV-C technology for surface disinfection. Sharma et al., (2023) concluded that UV-C devices provide an effective non-thermal method for inactivating foodborne microorganisms, while Ramos et al., (2024) highlighted the continued effectiveness of UV-C treatment across various food-contact surfaces and environmental applications. Together with the present findings, this evidence suggests that UV-C technology can contribute to microbial control while reducing reliance on chemical-based sanitation practices. Armagan & Demirci, (2025) similarly emphasized the potential of UV-C as a sustainable approach to microbial inactivation. Such advantages make UV-C-based systems particularly relevant for food service settings seeking effective and environmentally responsible approaches to maintaining tableware hygiene and reducing the risk of foodborne disease transmission (Marques et al., 2024)

Overall, the present study demonstrates that increasing UV-C exposure duration was associated with progressively greater bacterial reduction on ceramic tableware under the tested operating conditions. The mean bacterial count decreased from 58.0 CFU/cm² in the control group to 5.5 CFU/cm², 1.2 CFU/cm², and 0 CFU/cm² following 5, 10, and 15 minutes of exposure, respectively, with corresponding reductions of 90.4% and 97.9% at 5 and 10 minutes and no detectable bacterial growth after 15 minutes. These findings are generally consistent with previous studies of UV-based tableware and food-contact surface sanitation, including those by Apriliana et al., (2022); Darussalam et al., (2024); Ramdhani et al., (2020); Rianmora et al., (2023); Sharma et al., (2023). However, the magnitude of bacterial reduction should be interpreted in relation to the specific UV-C system, irradiation conditions, and experimental characteristics of the present study.

Several limitations should be considered when interpreting the findings of this study. First, the sample size was relatively small, with six ceramic plates in each experimental group, which may limit the statistical precision and generalizability of the findings. Second, the study was conducted using ceramic tableware only; therefore, the findings may not be directly applicable to other materials such as stainless steel, glass, plastic, or melamine.

Third, the effectiveness of UV-C irradiation depends on parameters such as wavelength, irradiance, exposure distance, surface geometry, and microbial characteristics. Therefore, the results obtained at a fixed distance of 5 cm using the STERUVAM system should not be generalized to other UV-C devices or operating conditions. Fourth, the study measured bacterial counts immediately after treatment and did not evaluate microbial regrowth or longer-term sanitation effectiveness. Finally, the study did not directly compare UV-C irradiation with conventional chemical or thermal sanitation methods. Further studies involving larger sample sizes, different tableware materials, additional microorganisms, and comparative sanitation methods are therefore recommended.

CONCLUSIONS

Under the tested operating conditions, UV-C exposure duration was associated with differences in bacterial counts on ceramic tableware. The mean bacterial count decreased from 58.0 in the control group to 30.7, 5.5, and 1.2 following 5, 10, and 15 minutes of UV-C exposure, corresponding to reductions of 46.7%, 90.4%, and 97.9%, respectively. The difference among the experimental groups was statistically significant ($H = 21.184$, $df = 3$, $p < 0.001$), with the 15-minute exposure showing the lowest observed bacterial count and greatest reduction. These findings suggest that longer UV-C exposure may enhance bacterial reduction under the specific conditions of the STERUVAM system. However, the findings should not be generalized to pathogen elimination or other UV-C systems without further validation. Further studies with larger sample sizes,

different tableware materials, additional microorganisms, and verified UV-C dose measurements are recommended.

RECOMMENDATION

The present study provides evidence supporting the use of UV-C irradiation as a non-thermal sanitation approach for tableware in commercial food service and institutional catering settings. These findings may contribute to ongoing efforts to improve hygiene management practices in food service environments and inform the development of UV-C-based sterilization technologies.

Future investigations should focus on validating UV-C performance under a broader range of operational conditions, including its effectiveness against highly resistant microorganisms and on different tableware substrates. Additional research exploring the combined application of UV-C irradiation with other non-thermal sanitation methods may further advance the development of efficient and adaptable disinfection protocols.

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