MISR JOURNAL OF AGRICULTURAL ENGINEERING
https://mjae.journals.ekb.eg/
ISSN-Print: 1687-384X
ISSN-Online: 2636-3062
Misr J. Ag. Eng., 41 (3): 243 – 262 **DOI:** 10.21608/mjae.2024.297676.1138

APPLYING GERMICIDAL ULTRAVIOLET IN CHICKEN MANURE DISINFECTION FOR PROMOTING AGRICULTURAL SUSTAINABILITY

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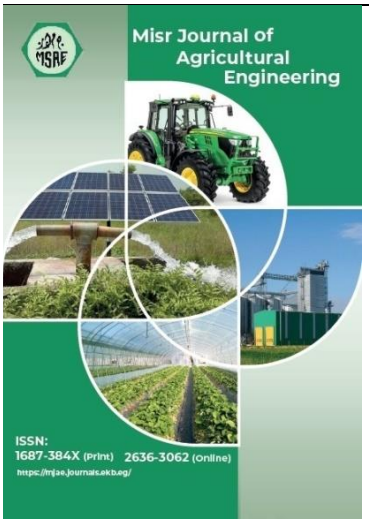

Keywords:
Germicidal ultraviolet; Chicken manure; Disinfection; Radiation intensity; Microbial count.

ABSTRACT

Chicken manure is a valuable resource when properly managed, while mismanagement of manure often results in serious challenges and public health worries. The environmentally friendly management of chicken manure is critical for agricultural sustainability. One of the strategies for promoting sustainable management of chicken manure is the application of the UV technique. The present research was carried out to apply and evaluate the performance of a germicidal ultraviolet (UV-C) disinfection system as a sustainable technology for disinfecting chicken manure. The performance of a UV-C disinfection system was studied as a function of changes in UV-C intensity (980, 1470, and 1960 µW/cm^2) and exposure time to UV-C (5, 10, 15, 30, 60, and 90 min). Performance evaluation of the UV-C system was carried out in terms of microbial count, disinfection efficiency, specific energy, and disinfection cost. Experimental results revealed that the optimal limits for reducing TBC, coliform, and E. coli count (1.5, 2.8, and 1.8 log CFU g^{-1}), disinfection efficiency (96.58, 99.84, and 98.40%), specific energy (0.33, 2.93, and 0.16 kW.h/kg), and disinfection cost (0.024, 0.218, and 0.012 USD/kg) were achieved at a UV-C intensity of 1960 µW/cm^2 and exposure times of 10, 90, and 5 minutes, respectively. According to this study, UV-C disinfection provides an eco-sustainable alternative to chemical composites for controlling microbiological contamination in chicken manure.

INTRODUCTION

In order to satisfy the requirements of a growing population, the increased production of poultry products has led to massive poultry operations producing huge quantities of manure, causing health and environmental concern because of the storage and disposal of it **(Hu *et al.*, 2017)**. Inappropriate manure treatment and disposal can pollute the soil, water, and air, eliminate biodiversity, cause habitat degradation, and spread animal pathogens **(Singh *et al.*, 2018)**. Nevertheless, the disposal of such wastes remains challenging in terms of

biosecurity, cost, and environmental conservation **(Rahman *et al.*, 2022)**. The effect of intensive poultry production on human wellness and the environment, industry challenges, and a perspective on the most effective strategies for a sustainable future were all presented by **(Gržinić *et al.*, 2023)**. Untreated chicken waste releases a bad odor, which attracts rodents and vermin, transmits infections, and provides a serious menace to the wellness of humans **(Tawfik *et al.*, 2023)**. The odor of manure is due to microorganisms' activity in the manure **(Hidalgo *et al.*, 2022)**. Livestock manure ought to be managed correctly in order to get advantages without affecting the environment **(Zayadi, 2021)**. Therefore, economically feasible strategies for chicken manure management must be examined **(Duan *et al.*, 2019)**.

Poultry manure is a high-macronutrient source of organic matter, phosphorus, nitrogen, and potassium because it enhances the fertility of the soil, agricultural product quality, and crop productivity **(Rasool *et al.*, 2023)**. Poultry manure represents one of the most important fertilizers used to improve soil fertility and increase agricultural crop yields **(Ravindran *et al.*, 2017)**. Poultry manure is utilized as a nutritious organic fertilizer in the province's agriculture fields to improve crop productivity **(Muhammad *et al.*, 2020)**. It is recommended that organic livestock wastes be used as substitutes for costly components in organic fish feed production. Poultry waste could substitute for 30% of soybean meal in Nile tilapia practical diets without affecting growth **(George *et al.*, 2018)**. Poultry manure has the potential to be used as a feed or supplement to conventional fish diets for increasing growth rates **(Usman *et al.*, 2019)**. In the diets of African catfish C. gariepinus, dried poultry manure meal can substitute for up to 60% of the soybean meal **(Obasa *et al.*, 2009)**. Along with the common microflora of animal intestines, microbiological analyses of manure indicated the existence of several pathogenic microorganisms. Among the most essential variables in infection transmission is pathogen persistence in manures. According to manure type, oxygen level, temperature, ammonia concentration, and pH, zoonotic pathogens can survive in these environments for up to 4 months **(Guan and Holley, 2003)**. Poultry litter has been shown to be a reservoir for human enteric pathogens such as Salmonella enterica **(Dunn *et al.*, 2022)**, Campylobacter jejuni **(Bailey *et al.*, 2022)**, and Escherichia coli **(Ramos *et al.*, 2021)** that, when applied to agricultural land, can pollute produce if not treated correctly **(Semenov *et al.*, 2021)**. Salmonella is a main foodborne pathogen related to poultry products, as well as one of the principal causes of human salmonellosis **(Wang *et al.*, 2023)**. In poultry excreta, microbial concentrations can exceed 10^{10} CFU g^{-1}, and gram-positive bacteria forming nearly 90% of the microbial diversity **(Bolan *et al.*, 2010)**. In the management system of poultry waste, pathogen control may necessitate various control interventions in order to attain significant pathogen reduction. As a result, some biological, chemical, and physical methods as alternative disinfection techniques have been evolved for animal waste treatment **(Chen and Jiang, 2014)**. They also added that disinfection by UV may be an effectual treatment for lowering the concentrations of pathogens in animal waste. Because of its ease of use and ability to kill most foodborne pathogens, ultraviolet (UV) radiation processing represents one of the most promising non-thermal techniques that have evolved most recently **(Bhattacharjee *et al.*, 2019)**.

UV irradiation disinfection is a physical method in which energy serves as the germicidal medium **(Bolton, 2010)**. UV-C, as opposed to chemical biocides, does not let in toxins to the

process and does not change the product's chemical composition **(McKeen, 2012)**. UV radiation has been noticed to be an effective bacterial control disinfectant in cattle manure. The UV light source intensity, the exposure duration to the radiation, the microbes' type, and the amount of suspended solid materials in the manure samples all influence its efficiency **(Manyi-Loh *et al.*, 2016)**. The efficacy of UV light is affected by a number of factors, including operating and measuring conditions, UV sources, UV devices, and target microorganisms **(Koca *et al.*, 2018)**. UV radiation encompasses the region of the electromagnetic spectrum between visible light and X-rays (100–400 nm) **(Delorme *et al.*, 2020)**. According to the wavelengths and energy intensity, the UV region is divided into three sub-regions: UV-A (315–400 nm), UV-B (280–315 nm), and UV-C (200–280 nm) **(Björn, 2015)**. Ultraviolet germicidal irradiation (UV-C) is an efficient pathogen disinfection method that uses short-wave ultraviolet energy to inactivate fungal, bacterial, and viral organisms by creating photo-dimers in nucleic acids (DNA and RNA), inhibiting either transcription or replication **(Beck *et al.*, 2016)**. A wavelength of UV-C irradiation of about 254 nm has been proven to be efficient at destroying cells, with the highest DNA absorption indicating UV-C as the most germicidal region **(Kowalski, 2009)**. solely type UV-C can destroy microbial DNA by cleaving the hydrogen bond **(Dai *et al.*, 2012)**. The product transmissivity, reactor geometric configurations, power, wavelength and physical arrangement of the UV-C sources, product profile, and radiation path length are all crucial variables influencing the efficiency of UV-C treatment **(Koutchma *et al.*, 2009)**. **Li *et al.* (2024)** offered a scientific foundation for the selection of novel light sources in the field of ultraviolet disinfection and new insights into the properties of multiple-wavelength ultraviolet. The impact of UV light on the inactivation of airborne *E. coli* carried by poultry dust particles showed a significant decrease in the inactivation rates from around 99.87% and 99.95% at a contact time of 5.62 s with irradiance levels of 1707 μW cm^{-2} and 3422 μW cm^{-2} to 72.90% and 86.60% at a contact time of 0.23 s with irradiance levels of 1707 μW cm^{-2} and 3422 μW cm^{-2} **(Nguyen *et al.*, 2022)**. A thin layer of salmonella cells exposed to UV radiation showed a 5-log decrease within 80 min, compared to a 1.5-log decrease in a thin layer of turkey manure **(Oni *et al.*, 2013)**. Disinfection using UV-C radiation technology is an environmentally friendly and physical process that is remarkably effective against nearly all pathogenic microorganisms prevalent in the environment. Therefore, it's important to examine the impact of some influencing parameters on the pathogenic microorganism's inactivation in chicken manure using UV-C disinfection. The objectives of the present study are to: (1) Apply a UV-C disinfection system as a sustainable technology for disinfecting chicken manure; (2) Optimize some operating parameters affecting the performance of the UV-C disinfection system (UV-C intensity and exposure time to UV-C); and (3) Evaluate the applied UV-C disinfection system from an economic point of view.

MATERIALS AND METHODS

The current study was conducted at the Department of Agricultural and Biosystems Engineering, Faculty of Agriculture, Alexandria University, Egypt, over the period from May to July 2022.

UV-C disinfection system

For broiler chicken manure disinfecting, a UV-C radiation disinfection system was

manufactured from a light-impermeable acrylic chamber. The dimensions of the chamber are 710 x 510 x 355 mm for length, width, and height, respectively, as shown in Fig. 1. The UV-C radiation device was equipped inside with Philips germicidal lamps of lamp wattage 83W (LTC80T5/4 UV-C Germicidal Lamp), lamp current 800 mA, lamp voltage at high frequency 103 V, with UV-C radiation output of 27 W and a peak emission wavelength of 253.7 nm (100 hr), intensity 245 μw/cm^2, and rated average life 9000 hrs. Ultraviolet lamps are fluorescent tubes with dimensions of 600 mm total length, 593 mm base face to base face length, and 15.7 mm diameter (4 pin single ended) base.

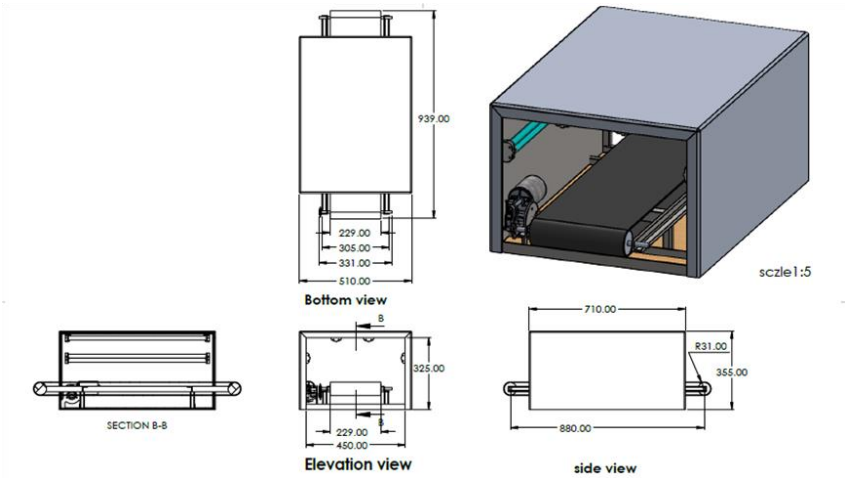

Fig. (1): Schematic views of the UV-C disinfection system.

As illustrated in Fig. 2, for a better distribution of radiation, four germicidal lamps were located at the upper part of the UV-C device at regular distances between each other of 2 cm and a vertical distance of 15 cm from the surface of the manure sample. As well as one lamp located at each side part of the device with a distance of 30 cm between each other and two lamps located at the lower part of the device with a distance of 10 cm between each other. The manure is placed in Petri dishes carried on a conveyor belt with dimensions of 600 x 400 mm in length and width, which is sufficient to hold six Petri dishes.

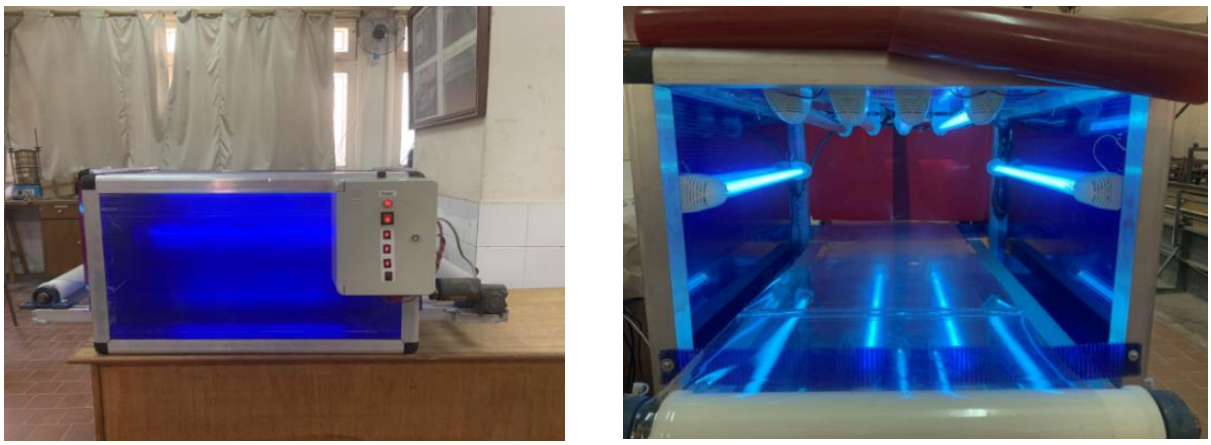

Fig. (2): Photographic views of the UV-C disinfection system.

Broiler chicken manure

The manure used in the present work was broiler chicken manure at 35 days of age and was

obtained from the farm of the Poultry Production Department, Faculty of Agriculture, Alexandria University. Manure was freshly collected, was not subjected to any treatment on the farm, and was sampled with weights of 250 g. Samples were transferred in sterile and clean plastic bags, and then all samples were transferred to the scientific lab in an icebox where it was stored at -18°C. Chemical and biological analysis of fresh manure samples was performed within approximately 30 min of sample collection, then each group was divided into ten homogenized replicates with an average weight of 25 grams, prepared, and placed in glass petri dishes (Nunclon^{TM}, Nunc; diameter 15.0 cm), which made the height of the manure approximately 1.0 cm to analyse the chemical composition of manure (5 samples) and the enumerate bacteria (5 samples), as well as to determine the presence of total bacteria count (TBC), Coliform, and *Escherichia coli* (*E. coli*) spp.

Chemical analysis of manure

The chemical analysis was carried out for five manure samples for each group, whether fresh manure (the control group) or groups that will be treated with UV-C. Samples were dried in a forced-air oven at 70 °C for 48 h in order to analyze the dry matter content based on **AOAC (2005)** assays for moisture and dry matter (DM; ID number 930.15), organic matter (OM; ID number 942.05), pH, crude protein (CP; as 6.25 below N; ID number 954.01), ether extract (EE; ID number 920.39), crude fiber (CF; ID number 920.85), total carbohydrate (micro-kjeldahl), and ash in manure (Ash; ID number 942.05) that were determined according to **AOAC (1990)**. Manure samples were digested in nitric perchloric and hydrofluoric acid and subsequently analyzed for calcium, phosphorus, and potassium by flame atomic absorption spectroscopy.

Microbiological analyses

Ten grams of manure samples were put into a sterilized flask containing 90 mL of sterilized isotonic sodium chloride solution (0.85% NaCl) and shaken for 3 min. Next, 1 mL of suspension diluted for suitable magnification was applied uniformly on an agar culture medium with a Conrad stick. Five Petri dishes each with 20 mL of agar culture media were prepared for every experiment stage. The aerobic plate count was put into a 30 ºC incubator, and the number of colonies was counted after 72 h. The average values of Petri dishes were converted into the number of microorganisms per gram of sample, and this value is represented as a colony-forming unit (CFU g^{-1}). The genus of the bacteria was distinguished using Gram staining reagent, and the genus of the mold was distinguished by observing a SEM image (SHIMADZU SUPERSCAN model 220).

The total number of bacteria counted in broiler chickens' manure was carried out according to **APHA (1992)**. Also, total coliform samples were enumerated by procedure of **APHA (2005)**, and Escherichia coli (*E. coli*) were examined according to **Okrend *et al.* (1990)** by means of the liquid-medium culture technique of colony-forming unit (CFU g^{-1}) and calculation of the most probable number after incubation at 37°C, then at 44°C for 48 hours.

Experimental conditions and measurements

Nineteen groups of manure were divided into ninety-five homogenized samples (5 replicates per group) in petri dishes with covers. The microbial count of the first group was tested as a control group, while other groups (from the second to the nineteenth group) were exposed to

different UV-C irradiation intensities (980, 1470, and 1960 µW/cm^2) at different exposure times (5, 10, 15, 30, 60, and 90 min), then microbial count analysis of these groups was performed. Performance evaluation of the UV-C disinfection system was based on the following indicators:

Log reduction

The relative number of living microbes eliminated by disinfection is expressed mathematically as a log reduction. The following formula was used to calculate the $\log_{10}$ reduction based on the measurement of colony-forming units (CFU):

$$Log\ reduction = log_{10}(\frac{N_O}{N})$$

Disinfection efficiency

Disinfection efficiency is a term used to express the percentage of bacterial growth inhibition (UV treatment's effectiveness). Disinfection efficiency was calculated according to **Shinde *et al.* (2021)** using the following equation:

$$Disinfection\ efficiency\ (\%) = \frac{N_O - N}{N_O} \times 100$$

Where:

N_O = CFU of microorganisms prior to UV radiation exposure.
N = CFU of microorganisms after UV radiation exposure.

Specific energy

The specific energy for the UV-C disinfection system can be calculated as follows:

$$SE = \frac{P_l \times T \times A_d \times N_l}{A_b \times Q_m}$$

Where:
SE = Specific energy, kW.h/kg;
P_l = Lamp power, kW;
T = Exposure time, h;
A_d = Petri dish area, cm^2;
N_l = Number of lamps;
A_b = Belt conveyor area, cm^2.
Q_m = Amount of manure, kg.

Disinfection cost

The disinfection cost of the UV-C disinfection system can be calculated as follows:

$$Disinfection\ cost\ (USD\ /\ kg) = SE \times 0.074$$

0.047 Electricity price, USD/kW.h.

The price of a kilowatt-hour of electricity by dollar was determined according to the official price of the dollar in the local market, which is estimated at one dollar equivalent to 18.83 Egyptian pounds at the time of the experiment period.

Statistical analysis

The statistical analyses were carried out using two methods. The first analysis method, using a general linear model to estimate means and standard errors, was applied to each studied trait of the chemical composition of chicken manure. The second analysis method, chicken manure bacteria counts, was estimated in a two-way factorial experiment in a completely randomized design (CRD) design (32) by adapting the tests of between-subject effects of the statistical software SPSS version 14.01 (SPSS Inc., Chicago, IL, USA): $Y_{ijk}=\mu+I_i+T_j+IT_{ij}+e_{ijk}$ in which Y_{ijk} is each dependent variable under study, μ is the overall mean, I_i is the fixed effect of the UV-C intensity, i the treatments (980, 1470, and 1960 $\mu W/cm^2$), T_j is the effect of different exposure times, j the times (5, 10, 15, 30, 60, and 90 min), IT_{ij} is the interaction between treatments of intensity and different exposure times, and e_{ijk} is the random residue error. Significant differences among means were evaluated using Duncan multiple range tests. The statistical significance was accepted at $P \leq 0.05$.

RESULTS AND DISCUSSIONS

Results

Chemical composition of chicken manure

Table 1 shows the effect of different intensities and exposure times of UV-C irradiation on the chemical composition of the broiler chicken manure content at 35 days of age. The obtained results indicated that the UV-C irradiation intensity of 1960 $\mu W/cm^2$ at exposure times from 30 to 90 min gave positive results related to the OM, CP, carbohydrate, and phosphorus content compared with the other treatments but was not statistically significant.

Table 1: Effect of UV-C intensity of 1960 $\mu W/cm^2$ on chemical composition and calculated analysis of the broiler chickens' manure content at different exposure times.

Chemical analysis	Control	Treated broiler manure						*P*-value
		Exposure time to UV-C, min						
		5	10	15	30	60	90	
Total moisture, %	14.15	14.14	14.16	14.15	14.14	14.15	14.16	0.478
DM, %	85.85	85.86	85.84	85.85	85.86	85.85	85.84	0.658
OM, %	81.36	81.37	81.37	81.38	81.40	81.38	81.42	0.722
pH	7.39	7.39	7.41	7.42	7.42	7.40	7.40	0.441
CP, %	28.89	28.89	28.90	28.90	28.91	28.90	28.91	0.845
EE, %	1.87	1.87	1.88	1.86	1.87	1.88	1.85	0.866
CF, %	14.12	14.11	14.10	14.10	14.09	14.14	14.08	0.535
Carbohydrate, %	18.18	18.18	18.19	18.21	18.21	18.19	18.21	0.611
Ash, %	11.48	11.45	11.46	11.45	11.44	11.48	11.45	0.694
Calcium, %	2.45	2.45	2.45	2.44	2.45	2.44	2.48	0.325
Phosphorus, %	1.94	1.96	1.95	1.94	1.95	1.96	1.97	0.473
Potassium, %	1.81	1.82	1.82	1.81	1.82	1.80	1.84	0.294

Means in the same row with different superscripts differ at $P \leq 0.05$

DM, dry matter; OM, organic matter; CP, crude protein; EE, ether extract; Litter Density (lb/cu.ft.) = 77.29 - 0.643 TS (total solids, %); CF, crude fiber.

Microbial count of chicken manure

Concerning the effect of UV-C intensity on the microbial count in chicken manure, results in Table 2 showed that increasing UV-C intensity from 980 to 1960 µW/cm^2 significantly decreased TBC, coliform, and *E. coli* counts in chicken manure. Broiler manure exposed to a UV-C intensity of 1960 µw/cm^2 showed significant ($P \leq 0.05$) lower counts of 1.7, 1.9, and 2.2 log CFU g^{-1} decreases for TBC, coliform, and *E. coli*, respectively, when compared with the control group.

Table 2: Effect of UV-C intensity and exposure time on the microbial count of broiler chicken manure.

Items	TBC, CFU g^{-1}	Coliform, CFU g^{-1}	*E. coli*, CFU g^{-1}
UV intensity:			
UV0	$2.75*10^{8a}$	$4.50*10^{5a}$	$2.50*10^{5a}$
UV L	$5.63*10^{7b}$	$1.77*10^{4b}$	$3.04*10^{4a}$
UV M	$2.83*10^{7c}$	$1.12*10^{4b}$	$8.59*10^{3b}$
UV H	$6.02*10^{6c}$	$5.52*10^{3b}$	$1.67*10^{3c}$
P -value	0.001	0.031	0.001
Time:			
T0	$2.75*10^{8a}$	$4.50*10^{5a}$	$2.50*10^{5a}$
T5	$9.71*10^{7b}$	$5.17*10^{4b}$	$3.67*10^{4b}$
T10	$4.55*10^{7c}$	$6.17*10^{3c}$	$2.36*10^{4c}$
T15	$2.02*10^{7d}$	$4.13*10^{3c}$	$1.69*10^{4d}$
T30	$1.01*10^{7e}$	$3.27*10^{3c}$	$2.25*10^{3e}$
T60	$5.43*10^{6e}$	$2.27*10^{3c}$	$1.75*10^{3e}$
T90	$3.07*10^{6e}$	$1.20*10^{3c}$	$2.03*10^{2e}$
P -value	0.001	0.001	0.001
Interaction:			
T0 x UV0	$2.75*10^{8a}$	$4.50*10^{5a}$	$2.50*10^{5a}$
T_5 x UV_L	$2.05*10^{8b}$	$8.10*10^{4b}$	$8.10*10^{4b}$
T_5 x UV_M	$7.30*10^{7c}$	$5.10*10^{4b}$	$3.50*10^{4e}$
T_5 x UV_H	$1.32*10^{7d}$	$2.30*10^{4b}$	$4.00*10^{3fg}$
T_{10} x UV_L	$6.90*10^{7d}$	$8.65*10^{3bc}$	$6.00*10^{4c}$
T_{10} x UV_M	$5.80*10^{7d}$	$6.85*10^{3bc}$	$9.20*10^{3f}$
T_{10} x UV_H	$9.42*10^{6fg}$	$3.00*10^{3c}$	$1.60*10^{3fg}$
T_{15} x UV_L	$3.40*10^{7e}$	$6.50*10^{3bc}$	$4.60*10^{4d}$
T_{15} x UV_M	$2.10*10^{7ef}$	$3.20*10^{3c}$	$3.20*10^{3fg}$
T_{15} x UV_H	$5.47*10^{6fg}$	$2.70*10^{3c}$	$1.60*10^{3fg}$
T_{30} x UV_L	$1.81*10^{7fg}$	$4.80*10^{3c}$	$3.30*10^{3fg}$
T_{30} x UV_M	$8.25*10^{6fg}$	$2.80*10^{3c}$	$2.01*10^{3fg}$
T_{30} x UV_H	$4.00*10^{6fg}$	$2.20*10^{3c}$	$1.45*10^{3g}$
T_{60} x UV_L	$7.50*10^{6fg}$	$3.50*10^{3c}$	$2.00*10^{3fg}$
T_{60} x UV_M	$6.60*10^{6fg}$	$1.80*10^{3c}$	$2.00*10^{3fg}$
T_{60} x UV_H	$2.20*10^{6g}$	$1.50*10^{3c}$	$1.25*10^{3g}$
T_{90} x UV_L	$4.40*10^{6fg}$	$1.60*10^{3c}$	$3.50*10^{2g}$
T_{90} x UV_M	$3.00*10^{6g}$	$1.30*10^{3c}$	$1.55*10^{2g}$
T_{90} x UV_H	$1.80*10^{6g}$	$7.05*10^{2d}$	$1.05*10^{2g}$
P -value	0.001	0.043	0.001

[a,b,..] Means in the same column with different superscripts differ at $P \leq 0.05$

TBC, total bacteria count; UV_L, 980 µW/cm^2; UV_M,1470 µW/cm^2; UV_H, 1960 µW/cm^2; T_0, control group; T_5, T_{10}, T_{15}, T_{30}, T_{60}, and T_{90}, exposure times at (5, 10, 15, 30, 60, and 90 min), respectively.

No statistical significance in counts reduction was observed between UV-C intensities of 1470 and 1960 µW/cm^2 for TBC and between 980 and 1960 µW/cm^2 for Coliform. Relating to the effect of exposure time to UV-C radiation on the microbial count in manure, results indicated that TBC, coliform, and *E. coli* counts in manure decreased significantly ($P \leq 0.001$) as exposure time increased from 5 to 90 min. Broiler manure exposed to UV-C radiation showed 2.0, 2.6, and 3.1 log CFU g^{-1} decreases in counts within 90 min for TBC, coliform, and *E. coli*, respectively, compared to the control group. No statistical significance in counts reduction was shown for exposure time to UV-C from 30 to 90 min for TBC and *E. coli*, as well as from 10 to 90 min for Coliform.

Representative reduction in the count of TBC, coliform, and *E. coli* versus exposure time to UV-C are given through different UV-C intensities in Fig. 3. The findings indicated that increasing UV-C exposure time from 5 to 90 min showed 1.8, 2.0, and 2.2 log CFU g^{-1} decreases in TBC counts at UV-C intensities of 980, 1470, and 1960 µW/cm^2, respectively.

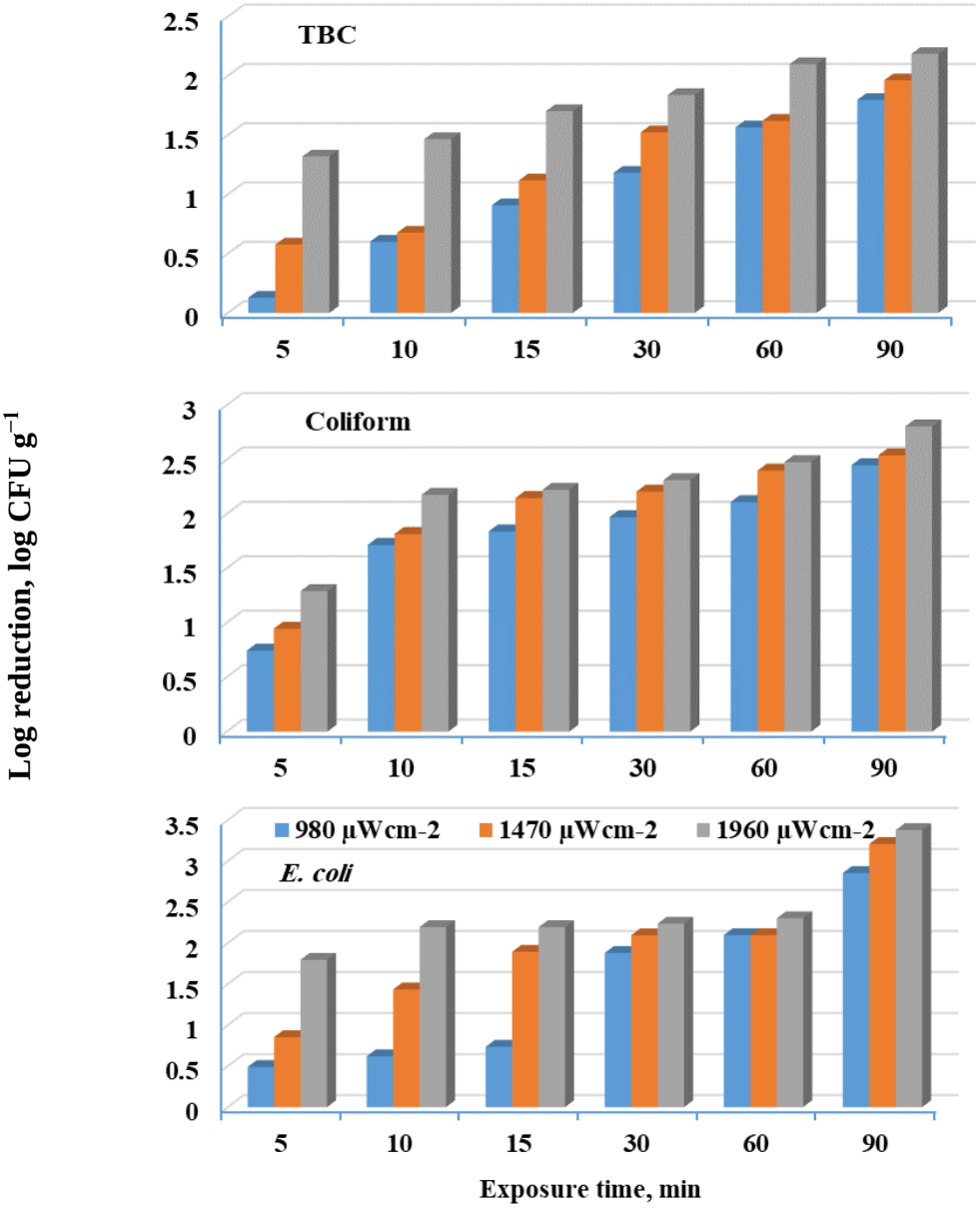

Fig. (3): Effect of exposure time and UV-C intensity on log reduction.

There were 2.4, 2.5, and 2.8 log CFU g^{-1} decreases in coliform counts, as well as 2.9, 3.2, and 3.4 log CFU g^{-1} decreases in *E. coli* counts at the same previously mentioned UV-C intensities. The effect of the interaction between UV-C intensities and exposure times on TBC, coliform, and *E. coli* counts was statistically significant for all groups compared to the control group. For TBC counts, the highest significant ($P \leq 0.001$) effect is evident at a UV-C intensity of 1960 µW/cm^2 within 10 min. Regarding coliform count, manure exposed to a UV-C intensity of 1960 µW/cm^2 within an exposure time of 90 min achieved the highest effect of a significant ($P \leq 0.0432$) decrease compared to the other different groups and the control group as well. While the highest significant ($P \leq 0.001$) effect on the decrease in *E. coli* count was evident at a UV-C intensity of 1960 µW/cm^2 within an exposure time of 5 min.

Disinfection efficiency

Disinfection efficiency of chicken manure was examined at different UV-C intensities from 980 to 1960 µW/cm^2 and different exposure times to UV-C radiation from 5 to 90 min. Results presented in Fig. 4 indicated that the disinfection efficiency of chicken manure was significantly affected by different UV-C intensities and exposure times to UV-C radiation for TBC, coliform, and *E. coli* compared with the control group.

Relating to the effect of UV-C intensity on disinfection efficiency, the obtained data showed that increasing UV-C intensity from 980 to 1960 µW/cm^2, increased disinfection efficiency from 79.53 to 97.81, from 96.07 to 98.77, and from 87.84 to 99.33% for TBC, coliform, and *E. coli*, respectively.

It's obvious that disinfection efficiency values were significantly increased by increasing UV-C intensity up to 1470 µW/cm^2 for TBC and 980 µW/cm^2 for coliform; increasing UV-C intensity up to 1960 µW/cm^2 did not significantly improve disinfection efficiency. Therefore, UV-C intensity of 1470 µW/cm^2 for TBC, 980 µW/cm^2 for coliform, and 1960 µW/cm^2 for *E. coli* resulted in the most effective disinfection efficiency.

Considering to the effect of exposure time to UV-C radiation on disinfection efficiency, results clarified that increasing exposure time to UV-C from 5 to 90 min, increased disinfection efficiency from 64.69 to 98.88, from 88.51 to 99.73, and from 85.32 to 99.92 % for TBC, coliform, and *E. coli*, respectively. It is clear that disinfection efficiency values increased by increasing exposure time to UV-C radiation up to 30 min for both TBC and *E. coli* and 10 min for coliform; any further increase in exposure time up to 90 min didn't show any proportional increase in disinfection efficiency. Representative values of disinfection efficiency versus exposure time to UV-C at various UV-C intensities for TBC, coliform, and *E. coli* are shown in Fig. 4. Results showed that increasing exposure time from 5 to 90 min, the disinfection efficiency is followed by an increase from 25.45 to 98.40, from 73.46 to 98.91, and from 95.20 to 99.35% for TBC, from 82 to 99.64, from 88.67 to 99.71, and from 94.89 to 99.84% for coliform, and from 67.60 to 99.86, from 86 to 99.94, and from 98.40 to 99.96% for *E. coli* under UV-C intensities of 980, 1470, and 1960 µW/cm^2.

Relating to the effect of UV-C intensity on disinfection efficiency at different exposure times to UV-C, the results in Fig. 4 showed that increasing UV-C intensity from 980 to 1960 µW/cm^2, disinfection efficiency increased from 25.45 to 95.2, from 74.91 to 96.58, from

87.64 to 98.01, from 93.42 to 98.55, from 97.27 to 99.20, and from 98.40 to 99.35% for TBC, from 82 to 94.89, from 98.08 to 99.33, from 98.56 to 99.40, from 98.93 to 99.51, from 99.22 to 99.67, and from 99.64 to 99.84% for coliform, and from 67.60 to 98.40, from 76 to 99.36, from 81.60 to 99.36, from 98.68 to 99.42, from 99.20 to 99.50, and from 99.86 to 99.96% for *E. coli* under exposure times to UV-C of 5, 10, 15, 30, 60, and 90 min.

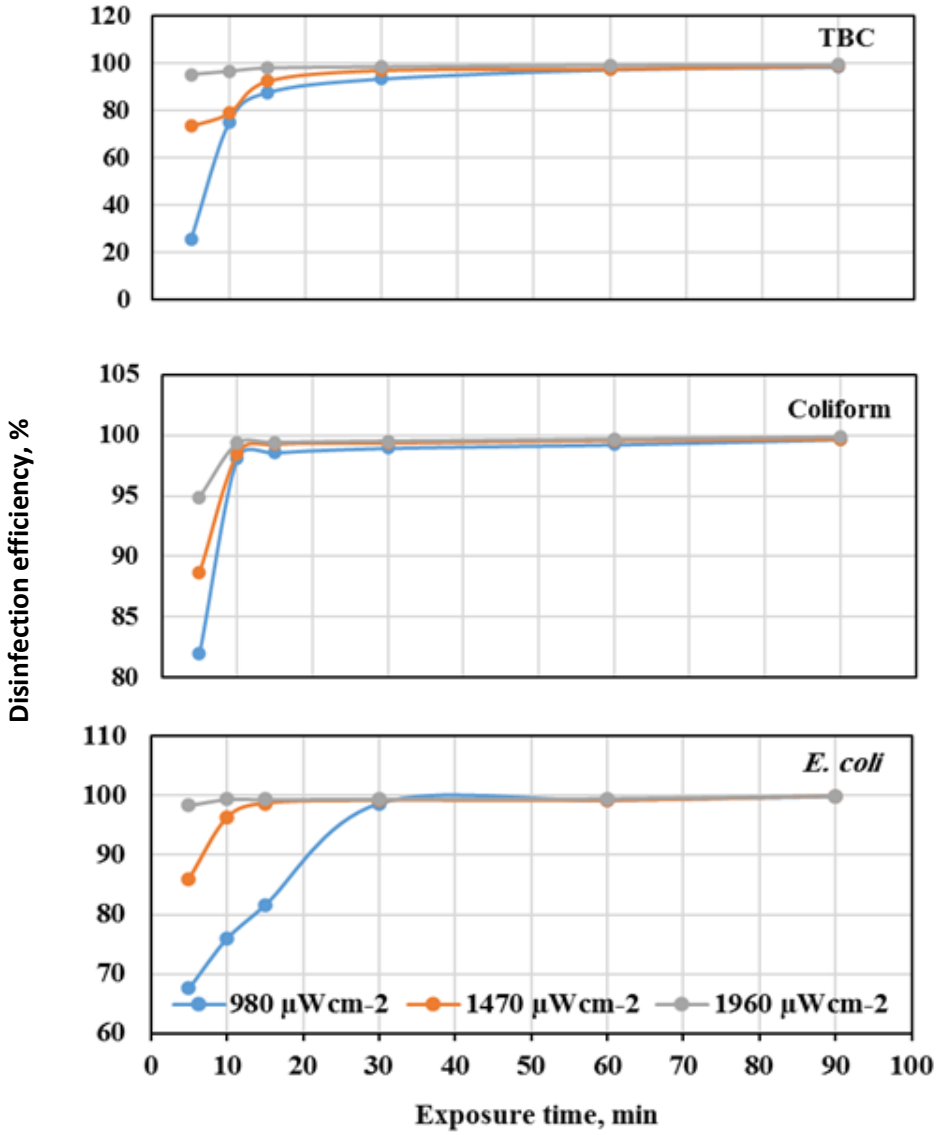

Fig. (4): Effect of exposure time and UV-C intensity on disinfection efficiency.

Specific energy

Regarding to the effect of different UV-C intensities on the specific energy, results in Table 2 showed that there were no significant differences between UV-C intensities of 1470 and 1960 µW/cm^2 on TBC, corresponding to disinfection efficiencies of 89.71 and 97.81% and specific energy values of 0.86 and 1.14 kW.h/kg, respectively. Hence, applying a UV-C intensity of 1470 µW/cm^2 for TBC is preferred to be used for saving consumed power. Also, it was noted that there were no significant differences between the different UV-C intensities used on coliform; therefore, the UV-C intensity of 980 µW/cm^2 was the most accepted as it consumed a less specific energy of 0.57 kW.h/kg. As for *E. coli*, results showed a significant effect at a

UV-C intensity of 1960 µW/cm^2 with disinfection efficiency of 99.33% and specific energy of 1.14 kW.h/kg.

As to the effect of exposure time to UV-C on the specific energy, results showed that despite exposure time of 90 min achieving the highest disinfection efficiency values of 98.88%, 99.73, and 99.92 for TBC, coliform, and *E. coli*, respectively, it did not differ significantly from exposure time of 30 min achieving disinfection efficiency values of 96.33% and 99.10 for TBC and *E. coli* and from exposure time of 10 min achieving disinfection efficiency value of 98.63% for coliform. As a result, an exposure time of 30 min for TBC and *E. coli* is optimal, as the specific energy was reduced by 66.82% when compared to a 90-minute exposure. Furthermore, an exposure time of 10 min for coliform is preferred because it reduces specific energy by 89.09%. As shown in Fig. 5, specific energy is closely related to UV exposure time under all UV-C intensities. Experimental data show that increasing UV exposure time increased the specific energy. Considering the effect of exposure time on the specific energy, results show that increasing exposure time from 5 to 90 min, the specific energy increased from 0.08 to 1.47, from 0.12 to 2.20, and from 0.16 to 2.93 kW.h/kg at UV-C intensities of 980, 1470, and 1960 µW/cm^2, respectively.

As to the effect of UV-C intensity on specific energy, obtained data in Fig. 5 show that increasing UV-C intensity from 980 to 1960 µW/cm^2, increased the specific energy from 0.08 to 0.16, from 0.16 to 0.33, from 0.24 to 0.49, from 0.49 to 0.98, from 0.98 to 1.96, and from 1.47 to 2.93 kW.h/kg at UV exposure times of 5, 10, 15, 30, 60 and 90 min, respectively. The increase in specific energy by increasing exposure time and UV-C intensity is attributed to the increase in the consumed power to complete the disinfection process. It was noted that the optimal UV-C intensity of 1960 µW/cm^2 within 10 min of exposure resulted in a significant reduction in the count of TBC with a specific energy decrease of 88.74% compared to the same intensity within 90 min. For coliform, a 90-minute exposure time and a UV-C intensity of 1960 µW/cm^2 resulted in the most significant decrease in coliform counts at a specific energy of 2.93 kW.h/kg. A UV-C intensity of 1960 µW/cm^2 within an exposure time of 5 min resulted in a significant reduction in *E. coli* counts, which corresponded to a specific energy reduction of 94.54% compared to an exposure time of 90 min at the same previously mentioned intensity.

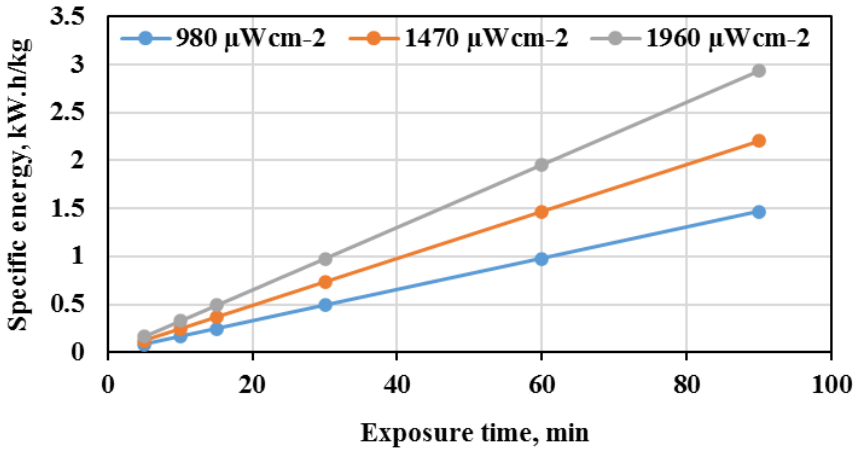

Fig. (5): Effect of exposure time and UV-C intensity on specific energy.

Disinfection cost

With regard to the effect of different UV-C intensities on disinfection cost, results indicated that UV-C intensities of 1470 and 980 µW/cm^2 for TBC and coliform reduced disinfection costs by 25 and 50%, respectively. At a disinfection cost of 0.085 USD /kg, a significant decrease in *E. coli* counts was seen at a UV-C intensity of 1960 µW/cm^2. Regarding the effect of exposure time to UV-C on disinfection cost, it has been clarified that for TBC and *E. coli*, the optimal exposure time of 30 min decreased the disinfection cost by 66.56% versus 90 min of exposure. In addition, a 10-minute exposure time for coliform is recommended, as it lowers the disinfection cost by 88.96%.

Fig. 6 shows the effect of both exposure time to UV-C and UV-C intensity on disinfection cost. Considering the effect of exposure time to UV-C under all UV-C intensities on disinfection cost, results show that increasing exposure time to UV-C from 5 to 90 min, increased disinfection cost from 0.006 to 0.109, from 0.009 to 0.164, and from 0.012 to 40.218 USD/kg at UV-C intensities of 980, 1470, and 1960 µW/cm^2, respectively. Relating to the effect of UV-C intensity on disinfection cost, the obtained data show that increasing UV-C intensity from 980 to 1960 µW/cm^2, increased disinfection cost from 0.006 to 0.012, from 0.012 to 0.024 from 0.018 to 0.036, from 0.036 to 0.073, from 0.073 to 0.145, and from 0.109 to 0.218 USD/kg at UV exposure

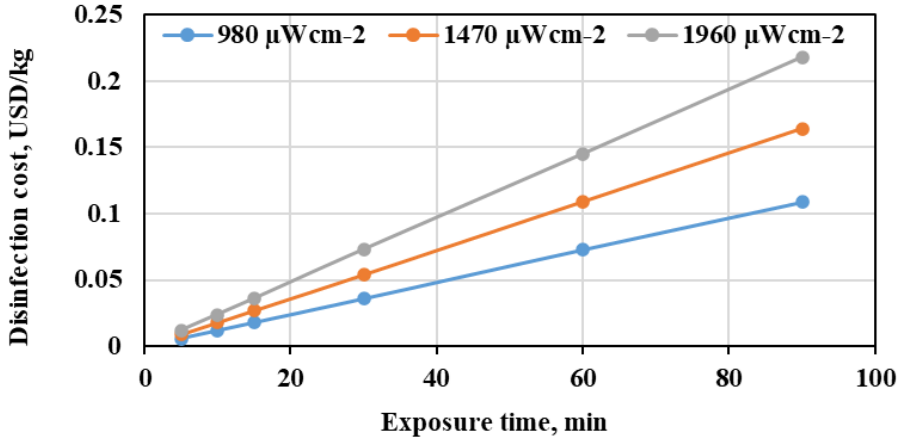

Fig. (6): Effect of exposure time and UV-C intensity on disinfection cost.

Discussions

UV-C is a nontoxic technique with many benefits, including the absence of chemical residues, producing no waste, being cost-effective, simple to implement, having low energy consumption, minimal impact on chicken manure quality and chemical composition parameters, and being a good, healthy product, which agrees with **Yemmireddy *et al.* (2022)**.

It is worth noting in our study that 1960 µW/cm^2 UV-C intensity at exposure times from 30 to 90 min yielded positive results in terms of the chemical composition of chicken manure. In agreement with our findings, some investigators illustrated that the effect of UV-irradiation increases the bioavailability of natural organic matter in all cases.

UV radiation accelerates the degradation of organic matter either by photolysis or by oxidation of organic compounds to CO_2, often followed by enhancing the bioavailability of complex organic substrates to microbes **(Paul *et al.*, 2012)**. Significant changes in the carbohydrate, protein, and fat contents were observed, with little variation in the total fibres

comprising the chia seeds after exposure to UV radiation for different times at dissimilar distances **(Ebrahim *et al.,* 2022)**. The significance of UV irradiation is that it disinfects the manure without the use of any chemicals; consequently, no disinfection by-products are generated, so it does not alter the physicochemical and nutritional properties of the manure after treatment **(Spiehs and Goyal, 2007)**. The protein concentration in each fraction of wheat flour changed significantly after UV-C irradiation **(Kumar *et al.,* 2021)**. UV exposure results in more total phenolic compounds, flavonoids, and antioxidants under opposing conditions **(Del Valle *et al.,* 2020)**. The polyphenols act as a photosensitizer and intensify the effect of UV radiation to modify the protein and starch of the flour by promoting the free radical formation and chain reactions **(Shahabi-Ghahfarrokhi *et al.,* 2019)**. The change of UV spectra increased the proportion of molecular weight components of dissolved organic matter **(He *et al.,* 2021)**.

The effect of UV-C intensity on TBC, coliform, and *E. coli* counts in chicken manure showed that increasing intensity up to 1960 µW/cm^2 significantly decreased TBC, coliform, and *E. coli* counts. While no statistical significance in counts reduction was noted between intensities of 1470 and 1960 µW/cm^2 for TBC and between 980 and 1960 µW/cm^2 for Coliform. This result is in line with **Xu *et al.* (2005)**, who revealed that up to 5 µW/cm^2 of effective UV fluence rate, the inactivation rate increased linearly with it. Higher fluence rates did not result in a corresponding rise in the inactivation rate. UV radiation eliminates only microbes on a material's surface and in the air **(Nicklin *et al.,* 1999)**. **Sharrer *et al.* (2005)** demonstrated that total coliform bacteria were more susceptible to UV inactivation, and that complete inactivation of coliform bacteria was consistently achieved at the lowest applied UV dose of 77 mWs/cm^2. **Yang *et al.* (2019)** demonstrated that UVC irradiation for 15 minutes resulted in a significant reduction in the number of bacteria colonies sampled from various surfaces.

In this study, data showed that UV-C intensity of 1470 µW/cm^2 for TBC, 980 µW/cm^2 for coliform, and 1960 µW/cm^2 for E. coli resulted in the most effective disinfection efficiency. This result is in agreement with **Niño-Gomez *et al.* (2021)**, who clarified that not all microorganisms die when exposed to the same quantity of ultraviolet radiation. Sensitivity differs, and some microorganisms have greater protection and are able to resist than others; thus, the type of microorganism determines the UV dose required. Obtained results showed that increasing exposure time, increased the disinfection efficiency. This is consistent with the findings of **Nguyen *et al.* (2022)**, who demonstrated that the inactivation rates of *E. coli* carried by poultry dust particles decreased in accordance with contact times. As the exposure time of airborne *E. coli* to radiation decreased, so did the UV irradiance doses exposed to *E. coli*, resulting in lower inactivation rates. Under experimental conditions, UV-C irradiation could inactivate more than 3-4 log10 vegetative organisms in 15-93 minutes **(Nerandzic *et al.,* 2014)**.

Chicken manure disinfection with UV-C radiation is a more sustainable choice than other technologies, providing additional savings in costs due to lower machinery and electricity consumption. The lamp's number and types of UV light sources, the radiation intensity, and the exposure duration all have an impact on the UV system's specific energy and disinfection costs, as well as its operational costs. **Wang *et al.* (2013)** conducted an economic analysis of UV-C technology for oil and gas industry wastewater. According to the findings of this study,

the cost of UV treatment for 12,000 hours (1.4 years), including electricity, cleaning, investment costs, operation, maintenance, and depreciation, is 0.008 US$/$m^3$ of treated water, while the average cost of chemicals and biocides is 0.035 US$/$m^3$ of treated water. UV-C food processing has operational costs that range from 0.01 to 0.05 $/liter for liquid foods and 0.02 to 0.10 $/kg for solid commodities **(Tchonkouang *et al.*, 2023)**. Pulsed UV has previously been proposed as an energy and economic alternative to continuous irradiation **(Hunter *et al.*, 2023)**. In conclusion, UV-C technology could be roughly one-fifth the cost of applying chemical products. However, studies in these areas have revealed issues such as quality, limited capacity, safety, and energy costs **(Esua *et al.*, 2020)**.

CONCLUSION

UV-C technology is an eco-friendly, cost-effective, and energy-efficient application, owning significant germicidal properties in chicken manure disinfection from microbiological pathogens. In order to enhance the quality of manure for long-term storage purposes, preserve its nutritional value, and minimize the energy and costs required of the disinfection process, it is necessary to control exposure time to UV-C and UV-C intensity as important operating parameters affecting the disinfection process of chicken manure. From the obtained data, it can be concluded that:

- Exposure time to UV-C as well as UV-C intensity are considered very important variables affecting the performance of the UV-C disinfection system. Optimal exposure time to UV-C of up to 30 min for TBC and *E. coli* and 10 min for coliform significantly enhanced disinfection efficiency. UV-C intensities of 1470, 980, and 1960 µW/cm^2 resulted in a significant reduction in TBC, coliform, and *E. coli* counts, respectively.
- The interaction between exposure time to UV-C and UV-C intensity revealed a significant reduction in counts (1.5, 2.8, and 1.8 log CFU g^{-1}), disinfection efficiency (96.58, 99.84, and 98.40%), specific energy (0.33, 2.93, and 0.16 kW.h/kg), and disinfection cost (0.024, 0.218, and 0.012 USD/kg) when exposed to 1960 µW/cm^2 for 10, 90, and 5 min for TBC, coliform, and *E. coli*, respectively.

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تطبيق الأشعة فوق البنفسجية المبيدة للجراثيم في تطهير روث الدجاج لتعزيز الاستدامة الزراعية

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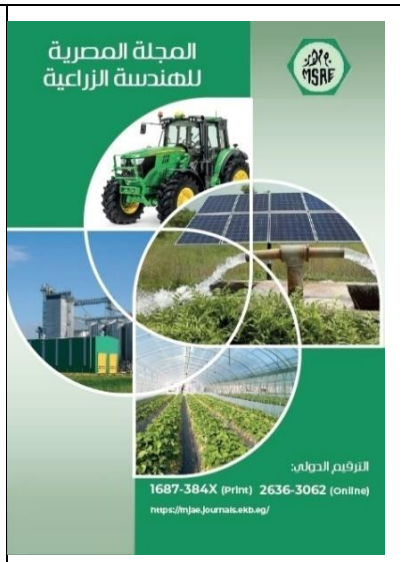
الملخص العربي

يعتبر روث الدجاج موردًا قيمًا عندما تتم إدارته بشكل صحيح، في حين أن سوء إدارة الروث غالبًا ما يؤدي إلى تحديات خطيرة ومخاوف تتعلق بالصحة العامة. تعد الإدارة الصديقة للبيئة لروث الدجاج أمرًا بالغ الأهمية لتحقيق الاستدامة الزراعية. إحدى استراتيجيات تعزيز الإدارة المستدامة لروث الدجاج هي تطبيق تقنية الأشعة فوق البنفسجية.

ومن ثم تم إجراء البحث الحالي بهدف تطبيق وتقييم أداء نظام التطهير بالأشعة فوق البنفسجية المبيد للجراثيم (UV-C) كتقنية مستدامة لتطهير روث الدجاج. تمت دراسة أداء نظام التطهير بالأشعة فوق البنفسجية كدالة للتغيرات في كثافة الأشعة فوق البنفسجية (٩٨٠، ١٤٧٠، ١٩٦٠ ميكروواط/سم^{٢}) وزمن التعرض للأشعة فوق البنفسجية (٥، ١٠، ١٥، ٣٠، ٦٠، ٩٠ دقيقة). وقد تم التقييم أخذًا في الاعتبار كلًا من العد الميكروبي، كفاءة التطهير، الطاقة اللازمة لعملية التطهير، تكاليف التطهير.

كشفت النتائج التجريبية أن الحدود المثلى لتقليل العدد الكلي للبكتيريا، والقولونيات، والإشريكية القولونية (١,٥، ٢,٨، ١,٨ $\log \text{CFU g}^{-1}$)، وكفاءة التطهير (٩٦,٥٨، ٩٩,٨٤، ٩٨,٤٠ ٪)، والطاقة اللازمة لعملية التطهير (٠,٣٣، ٢,٩٣، و٠,١٦ كيلووات.ساعة/كجم)، وتكاليف التطهير (٠,٠٢٤، ٠,٢١٨، و ٠,٠١٢ دولار أمريكي/كجم) تم تحقيقها عند كثافة الأشعة فوق البنفسجية البالغة ١٩٦٠ ميكروواط/سم^{٢} وأزمنة التعرض ١٠ و٩٠ و٥ دقائق على التوالي. وفقًا لهذه الدراسة، يوفر التطهير بالأشعة فوق البنفسجية بديلاً مستدامًا بيئيًا للمركبات الكيميائية للتحكم في التلوث الميكروبيولوجي في روث الدجاج.



الكلمات المفتاحية:
الأشعة فوق البنفسجية المبيدة للجراثيم؛ روث الدجاج؛ التطهير؛ شدة الإشعاع؛ العد الميكروبي.