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STERILIZATION OF BROILER CHICKEN MANURE USING THERMAL AND NON-THERMAL PROCESSING TECHNIQUES

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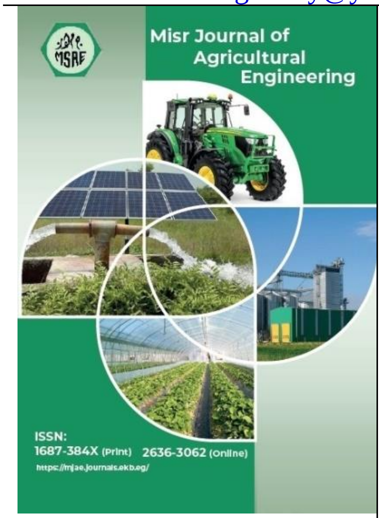

Keywords:
Sterilization;
Manure;
Sun drying;
Ultraviolet;
Exposure time.

ABSTRACT

The current research was conducted to study the use of thermal and non-thermal processing techniques in the sterilization of broiler chicken manure through different periods of exposure. The sterilization process was studied using various thermal processing techniques (sun drying and electric drying) and non-thermal processing techniques (ultraviolet) for exposure times of 1 to 6 hours, as well as re-exposing previously sun-dried and electric-dried manure to UV-C for exposure times of 5, 10, 15, 30, and 60 minutes. The sterilization process was studied based on microbial count, sterilization efficiency, specific energy, and sterilization cost. Findings clarified that sterilizing chicken manure through sun drying is ineffective. Sun drying for 6 hours and subsequently exposure to a UV-C intensity of 1960 μW/cm^2 for 5 minutes resulted in a sterilization efficiency of 100%, the lowest specific energy of 0.163 kW.h/kg, and a sterilization cost of 0.228 LE/kg compared to other treatments. Chicken manure can be sterilized using electric drying for up to 5 hours at a specific energy of 58.88 kW.h/kg and a sterilization cost of 82.43 LE/kg. While using electric drying for 2 hours followed by 60 minutes of exposure to a UV-C intensity of 1960 μW/cm^2, the manure was sterilized with a specific energy of 25.51 kW.h/kg and a sterilization cost of 35.71 LE/kg. Exposing manure to 1470 μW/cm^2 UV-C intensity for 6 hours achieved 100% sterilization efficiency, 8.80 kW.h/kg specific energy, and 12.31 LE/kg sterilization cost. In conclusion, using UV-C is an energy-saving and economical processing technique for sterilizing chicken manure.

INTRODUCTION

Animal waste, such as poultry litter, contains a wide range of nutrients as well as a high concentration of organic matter and a type of nitrogen ideal for growing nutritious food **(Shaji *et al*., 2021)**. The poultry operation generates enormous amounts of solid waste, such as bedding material, manure, feed, feathers, hatchery waste, mortality waste, and disinfection of chicken farms and slaughterhouses (**Muduli *et al*., 2019**). A chicken is predicted to produce 80 to 100 g of manure each day, which accounts for 3–4% of its body weight (**Abdeshahian *et al*., 2016**). According to **Ibrahim *et al.* (2022)**, chicken manure is high in organics, phosphorus, ammonia-nitrogen, pathogens, and microbial-degrading bacteria. Poultry manure decomposes immediately following excretion, releasing ammonia, which can harm the health and production of birds as well as the health of farm laborers (**Mahmoud, 2017**). Poultry wastes can cause significant environmental contamination due to disagreeable odors and the promotion of fly and rodent reproduction (**Nwobodo *et al*., 2023**). Increased microbial loads in soil amendments have the potential to pollute agricultural soil and groundwater, posing food safety threats to fresh produce and, ultimately, human health (**Aswathi *et al*., 2019**). Pathogens such as *E. coli*, Salmonella spp., and Listeria monocytogenes were transmitted into the food supply chain by poultry manure (**Black *et al*., 2021**). As a result, establishing efficient pathogen-eradication procedures is critical for reducing the potential for disease spread through croplands (**Van Esse *et al*., 2020**). According to **Maharjan *et al.* (2019)**, future strategies of microbial reduction and elimination should be cost-effective and easy to implement. These procedures should not alter the appearance, smell, taste, or nutritional qualities of the items being treated. They should also not leave a residue or be harmful to the environment. Drying poultry manure can turn it into a safe product that may be used as organic fertilizer or animal feed (**Manogaran *et al*., 2022**). The drying of poultry manure is possibly the earliest method of preparing waste for re-feeding. Thin layer heated air drying of poultry manure resulted in a safe and nutritious feed for ruminants **(Ghaly and MacDonald, 2012b)**. Research has demonstrated the potential of using poultry manure as an alternative to soybean meal in fish feed **(Amesa *et al*., 2018)**. Proper processing of poultry manure can improve its nutritional quality, making it a sustainable and cost-effective ingredient in fish feed, improving the nutritional value of the feed, and reducing the environmental impact of the poultry industry **(Samad, 2023)**. Proper processing is necessary to reduce pathogenic microorganisms and produce pathogen-free poultry waste **(Kawata *et al*., 2006)**. Dried poultry waste is said to contain about 30% protein, with about 60% coming from non-protein nitrogenous sources (**Aravinth and Prakash, 2015**). Drying in the natural air under sunlight is one of the most cost-effective and practical solutions for tropical regions. Drying reduces deterioration from chemical and biological activity and prevents environmental hazards related to raw manure decomposition. Drying also decreases the stickiness of manure, making it easier to handle (**Pezzolla *et al*., 2021**). Drying manure using heated air has several advantages over unheated air drying, including a faster rate of oxidation and pathogen eradication (**Li *et al*., 2020**). Solar energy, on the other hand, has several advantages over other energy sources: it is abundant all year, has a higher rate of oxidation, results in good odor control and waste stabilization, and has a higher rate of pathogen destruction (**Ortíz-Rodriguez *et al*., 2022**). Thin layer (1-3 cm) drying of poultry manure is effective at temperatures between 40 and 60°C produced by solar dryers (**Singh *et al*., 2018**). By creating products that give benefits in an effective, efficient, and safe manner, increasingly sophisticated technology will minimize risk to near 0% and improve success to 100% (**Mugiharto *et al*., 2022**).

Sterilization by exposure to ultraviolet radiation is attracting particular attention because it presents an effective and convenient technique for pathogenic microorganism inactivation **(Matsumoto *et al*., 2022)**. UV light is classified into three categories based on the wavelengths between 315 and 450 nm in the electromagnetic spectrum. Only UV-C with a wavelength of 250–270 nm has the ability to cleave the hydrogen bond of microbial DNA, resulting in its destruction (**Cela *et al*., 2023**). Most bacterial species exhibit the strongest bactericidal impact in the range of 250–260 nm. UV-C inactivation or killing of organisms is dependent on exposure time and UV-C intensity (**Lombini *et al*., 2023**). In comparison to UV-C radiation treatments, they offer the benefit of not requiring complex, costly ray-proofing precautions or specifically created facilities for use. Germicidal UV lamps emit energy with a focus point of 253.7 nm, allowing them to be used safely in a variety of food industry applications. The most frequent performance efficiency indices are overall energy consumption efficiency and specific energy consumption (SEC). SEC is an extremely valuable and practical statistic in energy analysis (**Firouzi *et al*., 2017**). **Baldasso *et al*. (2021)** reported 1.8, 2.7, and 5.0 mW s/cm^2 inactivation doses for *C. jejuni*, *Y. enterocolitica*, and *E. coli*, respectively. UV-C sunlight, according to **Soro *et al*. (2021)**, lowers the quantity of pathogens on eggs with visually clean or somewhat stained surfaces. Germicide UVC lamps are widely used as environmental sterilizers in food filling equipment, conveyor belts, containers, and work surfaces (**Bintsis *et al*., 2000**). Sterilizing UV lights are commonly used for aseptic packing, a technology that is projected to expand in the next few years. Therefore, the objective of this research is to investigate the sterilization of broiler chicken manure using thermal (sun drying and electricity drying) and non-thermal (UV-C radiation) processing techniques at different periods of exposure for use in fish feed.

MATERIALS AND METHODS

The present study was carried out during the period from June to August 2022 at the Department of Agricultural and Biosystems Engineering, Faculty of Agriculture, Alexandria University, Egypt.

Chicken manure collection and preparation

Fresh broiler chicken manure was obtained from breeding broiler chicken house at Poultry Production Department farm, Faculty of Agriculture, Alexandria University. The manure was collected under battery cages of a broiler chicken house accommodating approximately 120 chicks. The manure samples were collected and placed 250 g in clean plastic bags and transported to the Animal and Fish Production Department Laboratory in an icebox to conduct chemical analysis of the manure sample.

Analytical chicken manure

The properties of the manure were determined before drying. These were moisture content, dry matter (DM), organic matter (OM), pH, crude protein (CP), ether extract (EE), crude fibre (CF), carbohydrate, ash, and minerals (calcium, phosphorus, and potassium) as percentages. The moisture content, pH, total plate count, pathogens, and nutritional analyses were performed on the dried samples as dry matter. Samples of approximately 10 g were dried at 103°C for 24 h in a forced drying air oven and the total moisture content was calculated. The pH was measured in chicken manure using a pH meter (Crison instrument, Spain) according to the procedure described in the Methods.

Then, the samples were chemically analysed according to **AOAC (1990)** assays for DM (ID number 930.15), OM (ID number 942.05), CP (as 6.25×N; ID number 954.01), ether extract

(EE; ID number 920.39), crude fiber (CF; ID number 920.85), and total carbohydrate (micro-kjeldahl). Determination of ash content using approximately 10 g of the dried and finely pulverized sample (chicken manure) was weighed into Porcelain Crucible recorded and placed in Muffle furnace preheated at 600 °C for 2 hours (**AOAC, 2005**). Then transferred into the desiccators to cool and weighed immediately and weight was recorded. The elemental calcium, phosphorus, and potassium analysis were carried out based on dry matter of micro-kjeldahl method, at Animal and Fish Department laboratory, Faculty of Agriculture, Alexandria University using flame atomic adsorption spectroscopy.

Experimental Procedure

Two experiments were conducted in this study. The first experiment investigated the impact of three different processing techniques (sun drying, electric drying, and UV-C radiation) on the sterilization of broiler chicken manure under different periods of exposure (1, 2, 3, 4, 5, and 6 hr). For UV-C, sterilization of broiler chicken manure was investigated at different radiation intensities: low intensity, 980 µW/cm^2 (4 lamps), medium intensity, 1470 µW/cm^2 (6 lamps), and high intensity, 1960 µW/cm^2 (8 lamps). Each treatment was divided into 6 groups; each group was divided into 5 homogenized replicates with an average weight of 25 g, then prepared and placed in glass petri dishes (NunclonTM, Nunc; diameter 15.0 cm) with an approximately 1.0 cm manure height.

The second experiment investigated re-exposing all samples that had been previously treated with sun drying and electric drying for periods of exposure from 1 to 6 hours to high-intensity UV-C radiation for periods of 5, 10, 15, 30, and 60 minutes.

Sun drying

Manure samples in the sun drying processing technique were exposed to sun light for 6 hours, from 10:00 to 16:00. A typical day, dated June 20, 2022, has been selected for conducting the experiment. The variation of climatic conditions (ambient air temperature and relative humidity) with respect to time of day during experimentation is shown in Fig. 1. It is clear that ambient air temperature varied from 27.8 to 31.7 ^{o}C. It gradually increases from morning hours and reached its highest value of 31.7 ^{o}C at 14:00. While air relative humidity varied from 61 to 55 % from 10:00 to 14:00.

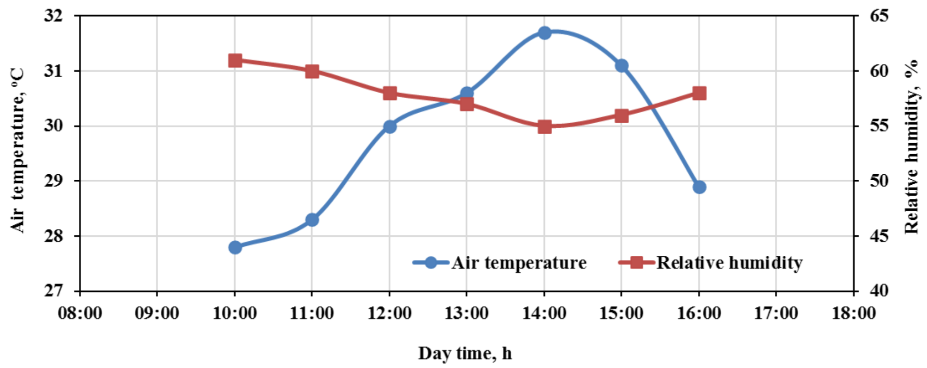

Fig. (1): The climatic conditions of sun drying experiment.

Electric drying

The electric drying treatment was carried out in an experimental forced cross-flow dryer, as illustrated in Fig. 2. It basically consisted of two centrifugal fans (G1323A3, Hengshui

Yongdong Scientific Inc., Hengshui, China), an electric heater (BXCP101, Shenzhen FHS Scientific Inc., Shenzhen, China), a humidifier (HTJ-2027B, Jiangmen Honetian Technology Co., Ltd., Jiangmen, China), a humidity and temperature sensor, and a proportional controller (JWSK-5ACWD, Beijing Kunlunhai Technology Co., Ltd., Beijing, China). The power of the electric dryer is 5 kW. Chicken manure samples of approximately 25 g were placed in glass petri dishes at 80°C for 1, 2, 3, 4, 5, and 6 h.


Fig. (2): Images of the electric drying.

Ultraviolet-C radiation device

A UV-C device with a light-impermeable acrylic chamber as described by **(El-Maghawry *et al.*, 2024)** was used to sterilize chicken manure samples, as shown in Fig. 3. The UV-C device is housed in an enclosed steel cabinet with external dimensions of 71.0 cm x 51.0 cm x 35.5 cm (length x width x height). The internal dimensions represented the maximum size of the object to be irradiated. The system is fully enclosed by a fiberglass case to prevent exposure of UV-C radiation to operators and is also equipped with a safety switch that prevents the lamps from energizing while the case is open. The UV device was designed to eliminate total bacteria count as an economical alternative to sterilization. The UV-C radiation device had eight Philips germicidal lamps with wattages of 83W (LTC80T5/4 UV-C Germicidal Lamp), a wavelength of 253.7 nm (100 h), and an intensity 245 µw/cm^2. The surface area of the device belt on which the samples are placed is up to 0.24 m^2, while the area of the Petri dish is 0.0177 m^2.


Fig. (3): Images of the ultraviolet-C radiation device.

Microbial counts

The total bacteria count (TBC) of each broiler chicken manure sample was performed according to the plate counting of bacteria method. The experiments were completed on the day of sampling, and the number of colonies was recorded. Colonies were counted after incubation for 24 h at 37 °C.

Sterilization efficiency (SE)

Sterilization efficiency was calculated according to **Matsumoto *et al.* (2022)** using the following formula:

$$Sterilization\ efficiency\ (\%) = \frac{N_b - N_a}{N_b} \times 100$$

Where:

N_b = colony forming units of the microorganisms before processing.

N_a = colony forming units of the microorganisms after processing.

Specific energy

The specific energy for the sterilization process using the electric dryer can be calculated as follows:

$$SE = \frac{P_e \times T \times A_d}{A_e \times Q_m}$$

Where:

SE, specific energy (kW.h/kg); P_e, electric dryer power (kW); T, exposure time (h); A_d, petri dish area (cm^2); A_e, electric dryer area (cm^2); Q_m, amount of manure (kg).

The specific energy for the sterilization process using the UV-C device 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).

Sterilization cost

The sterilization cost of the electric dryer and UV-C device can be calculated as follows:

$$Sterilization\ cost\ (L.E./\ kg) = SE \times 1.40$$

1.40 - Electricity price, L.E./kW.h.

The price of a kilowatt-hour of electricity in Egyptian pound was determined according to the official price of the Egyptian Electricity Holding Company at the time of the experiment.

Statistical analysis

Means and standard errors were estimated for each studied treatment. Data were analyzed using the **SAS version 9.2 (2004)** program, using a general linear model. Significant differences among treatments were separated using Duncan's multiple range procedure. The statistical significance was accepted at $P \leq 0.05$.

RESULTS AND DISCUSSIONS

Results

Chemical analysis of broiler chicken manure

Chicken manure is routinely composted or utilized as fish feed at a moisture content ranging from 60–70% to 20–30% (**Miles *et al.*, 2011**; **Sistani *et al.*, 2003**). At this moisture level, pathogens can be greatly inactivated by sun drying, electric drying, or UV radiation, but total pathogen removal may not be possible in a short period of time. At moisture levels of 20–30%, UV can successfully eliminate pathogens in chicken manure to a certain extent, increasing its acceptability as a soil amendment or for safe fish feed. A fixed thickness of chicken manure (1 cm) was used in all sterilizing treatments. As shown in Table 1, the chemical content of chicken manure was not significantly affected by all the treatments studied, such as the percentages of protein, fiber, and fat. The temperature and manure layer depth did not affect the elemental composition of the dried manure.

Table 1: Effect of using sun drying, electric drying, and UV-C for an exposure time of 6h on chemical composition and calculated analysis of broiler chicken manure.

Chemical analysis	**Control**	**Sun drying**	**Electric drying**	**UV-C, 1960 μW/cm²**	***P*-value**
Total moisture, %	16.85	16.54	16.48	16.78	0.311
DM, %	83.15	82.95	83.11	83.21	0.675
OM, % DM	78.60	78.45	78.58	78.64	0.799
pH	7.32	7.18	7.14	7.22	0.103
CP, %	26.45	26.14	26.12	26.53	0.204
EE, %	1.94	1.86	1.88	1.92	0.186
CF, %	15.87	15.92	15.86	15.84	0.397
Carbohydrate, %	19.42	19.40	19.44	19.45	0.356
Ash, %	10.54	10.52	10.56	10.50	0.615
Calcium, %	2.32	2.36	2.30	2.30	0.107
Phosphorus, %	1.87	1.85	1.84	1.90	0.159
Potassium, %	1.78	1.79	1.78	1.78	0.746

Means in the same row having different superscripts are non-significantly different at $P \leq 0.05$.

Microbial count and sterilization efficiency

The total bacteria count and sterilization efficiency of broiler chicken manure at different sterilization techniques (sun drying, electric drying, and different intensities of UV-C) under exposure times of 1, 2, 3, 4, 5, and 6 h are shown in Table 2. Exposure time to different sterilization techniques had an effect on TBC, measured by the number of colonies recorded. However, the bacterial population over time varied between the different methods. For sun drying, it was noted that TBC decreased, and SE increased over the duration of 6 hours of sun drying.

A peak TBC decrease occurred between 3 and 6 hours of exposure, with no significant differences observed. However, sun drying did not reach the sterilization stage, as the highest rate of decrease in TBC and increase in SE occurred at 6 hours ($1.92*10^2$ and 99.9999%) compared to the control group ($3.4*10^8$ and 0.00%), respectively. As for electric drying, the results showed that electric drying was effective in reducing TBC and increasing SE at exposure times ranging from 2 to 6 hours. Sterilization was achieved after 5 and 6 hours of exposure (0.00 TBC and 100% SE).

Table 2: Effect of using sun drying, electric drying, and different intensities of UV-C for exposure times of 1 to 6 h on total bacteria count and sterilization efficiency of broiler chicken manure.

Items		Time, h							*P*-value
		0	1	2	3	4	5	6	
Sun drying	TBC, CFU g^{-1}	$3.04*10^{8a}$	$2.42*10^{8b}$	$4.57*10^{7c}$	$2.84*10^{6d}$	$1.55*10^{5d}$	$2.50*10^{3d}$	$1.92*10^{2d}$	0.0001
	SE, %	0.0000^{d}	20.2553^{c}	84.9352^{b}	99.0644^{a}	99.9489^{a}	99.9991^{a}	99.9999^{a}	0.0001
Electric drying	TBC, CFU g^{-1}	$3.04*10^{8a}$	$3.38*10^{7b}$	$1.04*10^{5c}$	$2.10*10^{3c}$	$0.52*10^{2c}$	0.00^{c}	0.00^{c}	0.0001
	SE, %	0.0000^{c}	88.8626^{b}	99.9659^{a}	99.9993^{a}	99.9999^{a}	100.00^{a}	100.00^{a}	0.0001
UV-C_L	TBC, CFU g^{-1}	$3.04*10^{8a}$	$6.38*10^{7b}$	$1.48*10^{6c}$	$7.24*10^{4c}$	$4.63*10^{3c}$	$1.42*10^{3c}$	$2.67*10^{2c}$	0.0001
	SE, %	0.0000^{c}	78.9592^{b}	99.5121^{a}	99.9761^{a}	99.9985^{a}	99.9995^{a}	99.9999^{a}	0.0001
UV-C_M	TBC, CFU g^{-1}	$3.04*10^{8a}$	$3.95*10^{6b}$	$5.64*10^{5b}$	$1.05*10^{4b}$	$2.03*10^{3b}$	$1.14*10^{2b}$	0.00^{b}	0.0001
	SE, %	0.0000^{d}	98.6990^{c}	99.8141^{b}	99.9966^{a}	99.9993^{a}	99.9999^{a}	100.00^{a}	0.0001
UV-C_H	TBC, CFU g^{-1}	$3.04*10^{8a}$	$2.56*10^{6b}$	$2.42*10^{5b}$	$4.24*10^{3b}$	$0.78*10^{2b}$	0.00^{b}	0.00^{b}	0.0001
	SE, %	0.0000^{d}	99.1563^{c}	99.9202^{b}	99.9986^{a}	99.9999^{a}	100.00^{a}	100.00^{a}	0.0001

$^{a, b,..}$ Means in the same row having different superscripts are significantly different at $P \leq 0.05$.
TBC, total bacteria count; SE, sterilization efficiency; UV-C_L, 980 µW/cm^2; UV-C_M,1470 µW/cm^2; UV-C_H, 1960 µW/cm^2.

Regarding the UV-C radiation exposure technique, the results show that the low intensity throughout the 6-hour experiment did not reach the sterilization stage; the TBC was reduced to $2.67*10^2$, with a SE of 99.9999%.

However, the use of medium- and high-intensity UV-C radiation allowed for sterilization at 6 and 5 hours, respectively. Tables 3 and 4 show the results of re-exposing samples that had previously been sun-dried for periods of exposure ranging from 1 to 6 hours to high-intensity UV-C radiation for periods of 5, 10, 15, 30, and 60 minutes. The raw manure contained a high number of TBC (3.04×108 CFU/g). After one hour of exposure to sun drying, the number of TBC was reduced by 20.26%. The TBC was partially reduced by UV-C radiation after 1 hour of sun drying, but it did not reach the sterilization stage after 5 to 60 minutes of UV-C exposure, as the lowest rate of decrease of TBC reached after 60 minutes was 3.29*106 with a SE of up to 98.92%. It was also found that the TBC gradually decreased when manure was treated with high-intensity UV-C radiation for periods ranging from 5 to 60 minutes after being sun-dried for 2 and 3 hours. The decrease of TBC did not reach the sterilization stage after 60 minutes of UV exposure, as the lowest reduction of TBC achieved after 60 minutes of UV exposure was 2.76*104 and 8.15*103, with SE reaching 99.9909 and 99.9973% after sun drying exposure for 2 and 3 hours, respectively.

Table 3: The effect of re-exposing previously sun-dried manure to UV-C intensity of 1960 $\mu W/cm^2$ for 1 to 3 h on TBC and sterilization efficiency of broiler chicken manure.

Treatment	**TBC, CFU g^{-1}**	**SE, %**
Control (fresh)	$3.04*10^{8a}$	0.0000^{g}
After 1 h of sun drying	$2.42*10^{8b}$	20.2553^{f}
UV-C for 5 min	$9.27*10^{7c}$	69.4463^{e}
UV-C for 10 min	$4.17*10^{7d}$	86.2566^{d}
UV-C for 15 min	$1.76*10^{7e}$	94.2023^{c}
UV-C for 30 min	$9.89*10^{6ef}$	96.7427^{b}
UV-C for 60 min	$3.29*10^{6f}$	98.9154^{a}
P-value	0.0001	0.0001
Control (fresh)	$3.04*10^{8a}$	0.0000^{g}
After 2 h of sun drying	$4.57*10^{7b}$	84.9352^{f}
UV-C for 5 min	$1.35*10^{7c}$	95.5541^{e}
UV-C for 10 min	$5.84*10^{6cd}$	98.0757^{d}
UV-C for 15 min	$3.71*10^{6d}$	98.7774c
UV-C for 30 min	$1.98*10^{6d}$	99.3467^{b}
UV-C for 60 min	$2.76*10^{4d}$	99.9909^{a}
P-value	0.0001	0.0001
Control (fresh)	$3.04*10^{8a}$	0.0000^{f}
After 3 h of sun drying	$2.84*10^{6b}$	99.0644^{e}
UV-C for 5 min	$1.08*10^{6b}$	99.6446^{d}
UV-C for 10 min	$6.32*10^{5b}$	99.7917^{c}
UV-C for 15 min	$2.18*10^{5b}$	99.9281^{b}
UV-C for 30 min	$4.89*10^{4b}$	99.9839^{a}
UV-C for 60 min	$8.15*10^{3b}$	99.9973^{a}
P-value	0.0001	0.0001

[a, b,..] Means in the same row having different superscripts are significantly different at $P \leq 0.05$.

Table 4 indicated that TBC decreased at a greater rate when applying UV-C for exposure times ranging from 5 to 60 min after exposure to sun drying for 4, 5, and 6 hours. Manure treated with high-intensity UV-C for 60, 15, and 5 minutes was noted to be 100% sterilized after being sun-dried for 4, 5, and 6 hours, respectively. As shown in Table 5, increasing the UV-C radiation exposure times of manure from 5 to 60 minutes after being exposed to electric drying for 1 hour led to TBC decreasing from 1.08*107 to 2.69*105; however, the percentage of decrease did not reach the sterilization stage after 60 minutes, achieving a SE of 99.9112%. As for manure treated with high-intensity UV-C for 60, 10, and 5 minutes, it was observed to be 100% sterilized after being electric-dried for 2, 3, and 4 hours, respectively.

Specific energy and sterilization cost

As shown in Table 6, no specific energy or sterilization cost values were recorded for sun drying because it is a natural energy source. It was noted that exposing manure to high-intensity UV-C for 60, 15, and 5 minutes after sun-drying for 4, 5, and 6 hours resulted in specific energy and sterilization cost values of 1.955, 0.489, and 0.163 kW.h/kg and 2.737, 0.684, and 0.228 L.E., respectively. In comparison to the other treatments, sun drying for 6 hours followed by UV-C radiation for 5 minutes resulted in the lowest specific energy and sterilization cost. Electric drying for 2, 3, and 4 hours, followed by UV-C radiation exposure for 60, 10, and 5 minutes, resulted in 100% SE of chicken manure, with values of 25.51, 35.65, and 47.26 kW.h/kg and 35.71, 49.91, and 66.17 L.E. for specific energy and sterilization cost, respectively.

Table 4: The effect of re-exposing previously sun-dried manure to UV-C intensity of 1960 μW/cm^2 for 4 to 6 h on TBC and sterilization efficiency of broiler chicken manure.

Treatment	TBC, CFU g^{-1}	SE, %
Control (fresh)	$3.04*10^{8a}$	0.0000^{g}
After 4 h of sun drying	$1.55*10^{5b}$	99.9489^{f}
UV-C for 5 min	$7.69*10^{4b}$	99.9747^{e}
UV-C for 10 min	$4.08*10^{4b}$	99.9865^{d}
UV-C for 15 min	$6.44*10^{3b}$	99.9979^{c}
UV-C for 30 min	$3.84*10^{2b}$	99.9999^{b}
UV-C for 60 min	0.00^{b}	100.00^{a}
P-value	0.0001	0.0001
Control (fresh)	$3.04*10^{8a}$	0.0000^{c}
After 5 h of sun drying	$2.50*10^{3b}$	99.9992^{b}
UV-C for 5 min	$1.43*10^{2b}$	99.9999^{a}
UV-C for 10 min	61.00^{b}	99.9999^{a}
UV-C for 15 min	0.00^{b}	100.00^{a}
P-value	0.0001	0.0001
Control (fresh)	$3.04*10^{8a}$	0.0000^{c}
After 6 h of sun drying	$1.92*10^{2b}$	99.9999^{b}
UV-C for 5 min	0.00^{b}	100.00^{a}
P-value	0.0001	0.0001

[a, b,..] Means in the same row having different superscripts are significantly different at $P \leq 0.05$.

Using electric drying for 5 and 6 hours resulted in 100% SE, with specific energy and sterilization costs of 58.89 kW.h/kg and 82.43 L.E., and 70.65 kW.h/kg and 98.91 L.E., respectively. In terms of UV-C radiation, it can be concluded that using medium-intensity UV-C for 6 hours and high-intensity UV-C for 5 hours resulted in specific energy and sterilization costs of 8.80 kW.h/kg and 12.31 L.E., and 9.77 kW.h/kg and 13.68 L.E. Medium-intensity UV-C produced the best results when compared to other treatments. The optimal conditions for medium UV-C radiation intensity after 6 hours of exposure time resulted in an 85.1% reduction in specific energy and sterilization cost, while also improving sterilization effectiveness, when compared to electric drying after 5 hours.

Table 5: The effect of re-exposing previously electric-dried manure to UV-C intensity of 1960 μW/cm^2 on TBC and sterilization efficiency of broiler chicken manure.

Treatment	TBC, CFU g^{-1}	SE, %
Control (fresh)	$3.04*10^{8a}$	0.0000^{e}
After 1 h of electric drying	$3.38*10^{7b}$	88.8626^{d}
UV-C for 5 min	$1.08*10^{7c}$	96.4509^{c}
UV-C for 10 min	$9.59*10^{6cd}$	96.8384^{c}
UV-C for 15 min	$1.71*10^{6cd}$	99.4360^{b}
UV-C for 30 min	$6.06*10^{5d}$	99.8001^{ab}
UV-C for 60 min	$2.69*10^{5d}$	99.9112^{a}
P-value	0.0001	0.0001
Control (fresh)	$3.04*10^{8a}$	0.0000^{g}
After 2 h of electric drying	$1.04*10^{5b}$	99.9659^{f}
UV-C for 5 min	$2.75*10^{4b}$	99.9909^{e}
UV-C for 10 min	$9.83*10^{3b}$	99.9968^{d}
UV-C for 15 min	$5.30*10^{3b}$	99.9982^{c}
UV-C for 30 min	$1.92*10^{2b}$	99.9999^{b}
UV-C for 60 min	0.00^{b}	100.0000^{a}
P-value	0.0001	0.0001
Control (fresh)	$3.04*10^{8a}$	0.0000^{d}
After 3 h of electric drying	$2.10*10^{3b}$	99.9993^{c}
UV-C for 5 min	$2.84*10^{2b}$	99.9999^{b}
UV-C for 10 min	0.00^{b}	100.0000^{a}
P-value	0.0001	0.0001
Control (fresh)	$3.04*10^{8a}$	0.0000^{b}
After 4 h of electric drying	$0.52*10^{2b}$	99.9999^{a}
UV-C for 5 min	0.00^{b}	100.0000^{a}
P-value	0.0001	0.0001

[a, b,..] Means in the same row having different superscripts are significantly different at $P \leq 0.05$.

Discussions

Temperature, humidity, pH, physical composition of composting materials, waste type, and microbial competition all have an impact on pathogen survival in manure (**Hess *et al*., 2004**). **El-Deek *et al*. (2009)** dried poultry manure at 80 °C and obtained a final crude protein content of 19.10%. **Obasa *et al.* (2009)** sun-dried poultry manure and found a final protein content of 28.6%. The protein content of the dried poultry manure obtained in the current study is among the highest reported in the literature, most likely due to the low moisture content of the manure sample used and the use of various techniques for sterilization in this study. The manure used in this study was dry, with a moisture content of approximately 16.85% (w/w), as opposed to fresh fecal droppings, which contain at least 50–60% moisture. **Chumpolbanchorn *et al.***

(2006) discovered that the moisture content of the environment surrounding the bacteria plays an important role in the bacteria's survival period. The study's findings are consistent with a decrease in pH levels with the use of various drying and sterilization techniques, as indicated by **Lopez-Mosquera *et al.* (2008)**, who observed a pH drop (from 8.5 to 7.9) when drying poultry manure for pelletization as fertilizer. **Dikinya and Mufwanzala (2010)** found that dried poultry manure had lower pH values than fresh poultry manure. **Sistani *et al.* (2001)** investigated the changes in broiler litter pH after air drying, hot air drying (65 and 105 °C), and freeze drying and discovered that hot air drying at 105 °C caused a significant drop in manure pH.

Table 6: Effect of using sun drying, electric drying, and UV-C for different exposure times on specific energy and sterilization cost of broiler chicken manure.

Treatment	Specific energy, kW.h/kg	Sterilization cost, L.E./kg
After 4 h of sun drying	-	-
$UV\text{-}C_H$ for 30 min	0.977	1.368
$UV\text{-}C_H$ for 60 min	1.955 (Nil)	2.737 (Nil)
After 5 h of sun drying	-	-
$UV\text{-}C_H$ for 5 min	0.163	0.228
$UV\text{-}C_H$ for 10 min	0.326	0.456
$UV\text{-}C_H$ for 15 min	0.489 (Nil)	0.684 (Nil)
After 6 h of sun drying	-	-
$UV\text{-}C_H$ for 5 min	0.163 (Nil)	0.228 (Nil)
After 2 h of electric drying	23.550	32.970
$UV\text{-}C_H$ for 30 min	24.527	34.338
$UV\text{-}C_H$ for 60 min	25.505 (Nil)	35.707 (Nil)
After 3 h of electric drying	35.325	49..455
$UV\text{-}C_H$ for 5 min	35.488	49.683
$UV\text{-}C_H$ for 10 min	35.651 (Nil)	49.911 (Nil)
After 4 h of electric drying	47.100	65.940
$UV\text{-}C_H$ for 5 min	47.263 (Nil)	66.168 (Nil)
After 5 h of electric drying	58.875 (Nil)	82.425 (Nil)
After 6 h of electric drying	70.650 (Nil)	98.910 (Nil)
$UV\text{-}C_L$ for 6 h	5.864	8.21
$UV\text{-}C_M$ for 5 h	7.330	10.262
$UV\text{-}C_M$ for 6 h	8.796 (Nil)	12.314 (Nil)
$UV\text{-}C_H$ for 4 h	7.819	10.946
$UV\text{-}C_H$ for 5 h	9.773 (Nil)	13.683 (Nil)
$UV\text{-}C_H$ for 6 h	11.728 (Nil)	16.419 (Nil)

Torto and Rhule (1997) discovered a decrease in crude protein content in poultry manure following heated air drying (80 °C) and sun drying. The number of microorganisms used as biological indicators to confirm sterilization processes in accordance with the rules established by various regulatory agencies is summarized **(Jildeh *et al.*, 2021)**. Pathogenic microorganisms' survival and inactivation are influenced by a number of environmental and physicochemical factors, including manure dryness, pH, manure type, temperature, sunlight exposure, heat drying exposure, and UV radiation. Sunlight-mediated microorganism inactivation has a wide range of applications **(Moran and Zepp, 2000)**. **Li *et al.* (2020)** discovered that during the drying process, the mean log10 reduction values of total bacteria were 2.29, 2.54, and 2.28 at 15 °C, 25 °C, and 35 °C, respectively. **Ghaly and Alhattab (2013)** found that drying poultry manure at 40–60 °C effectively eliminated *E. coli*, yeast, and mold. **Ghaly and MacDonald**

(2012a) discovered that the hot air temperature and manure layer thickness influence the water loss rate of poultry manure, and they demonstrated that drying can be used to reduce the environmental impact of poultry manure while also creating a value-added product for farmers (animal feed or organic fertilizer). The thinner the manure layer (1 cm) used in our study, the less moisture it contained, and thus the shorter the time required to drive off the moisture. Heat drying at high temperatures, such as 80 °C, has been shown to be the most effective method for rapid pathogen decay in manure. However, heat drying is an expensive process due to high investment costs and energy consumption **(Bux *et al.*, 2002)**. The primary advantage of dry heat sterilization is that chemical sterilants are not required to achieve sterility, resulting in no sterilant residuals at the end of the sterilization process. UV treatments are simple to apply and can inactivate a wide range of pathogenic and spoilage microorganisms with minimal changes to nutritional and sensory quality **(Castillejo *et al.*, 2021)**. **Bosshard *et al.* (2010)** found evidence that sunlight damages bacterial cell membranes. According to some studies, failure to reach the sterilization stage through sun drying could be caused by the effects of wavelength on some types of bacteria, such as *E. coli*. According to **Niño-Gomez *et al.* (2021)**, microorganisms have varying sensitivity and can be more resistant to certain conditions. The UV dose required varies with the type of bacteria. Currently, the drying industry requires significant traditional energy, necessitating the development of energy-saving drying technologies (**Motevali *et al*., 2011**). The performance of a drying system can be expressed in a number of ways. Some are appropriate for analyzing overall drying-specific energy and sterilization costs, while others are used to compare different dryer types, such as drying capacity and drying rate, and still others are better suited to analyze energy utilization across drying and sterilization processes (**Jokiniemi, 2016**). solar drying is a cost-effective and environmentally friendly method that takes advantage of the sun's abundant, renewable energy **(Ortiz-Rodríguez *et al.*, 2022)**. Solar drying saves more energy than traditional electrical-heated drying methods. UV-C radiation is one of the most efficient methods for the inactivation of pathogens in chicken manure **(El-Maghawry *et al.*, 2024)**. When comparing electrical energy by order of decrease and sterilization process, UV-C was the most effective sterilization method due to its low energy consumption and increased efficiencies; sterilization can occur at a low energy cost. In this study, chicken manure was sterilized using a variety of processing techniques, including UV-C, transforming it from a product with a low economic value of about 4000 L.E./ton to a feed product with a high economic value of at least 17000 L.E./ton. Considering the cost of laboratory operation, we find that the use of UV-C on a commercial scale reduces the final cost increase by approximately half and increases the profitability of the final product, thus making chicken manure more economically viable in the fish feed industry. By using poultry manure, fish farmers can reduce the cost of feed production and increase profitability.

CONCLUSION

The purpose of this study is to look into the use of thermal (sun drying and electricity drying) and non-thermal (UV-C radiation) processing techniques on the sterilization of broiler chicken manure at different exposure times. Based on the results of the present study, it is clear that the application of electric drying or UV-C radiation techniques for chicken manure has sufficient effects on the inactivation of microorganisms and sterilization of chicken manure.

Using UV-C radiation for chicken manure sterilization is proven to be an effective and economical processing technique compared to sun and electric drying. Sun drying is an ineffective technique to sterilize chicken manure; thus, high-intensity UV-C of 1960 µW/cm^2 can be used for an exposure time of 5 minutes after sun drying for 6 hours to achieve sterilization. The electric drying technique can be used to sterilize chicken manure for 5 hours. Using electric drying for 2 hours, followed by high-intensity UV-C for 60 minutes, can complete the sterilization process in less time and at a lower cost. Solar energy can be used in agricultural and industrial processes, with benefits to the economy, environment, and society. It is possible to design and develop adaptable dryers for sterilization processes using solar energy, fully renewable energy, or hybrid technology that uses UV radiation energy. Sun drying followed by UV-C radiation has proven to be the most energy-efficient and cost-effective sterilization technique among all methods used. Generally, it can be concluded that the use of UV-C radiation is an effective processing technique for sterilizing chicken manure.

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تعقيم روث دجاج التسمين باستخدام تقنيات المعالجة الحرارية وغير الحرارية

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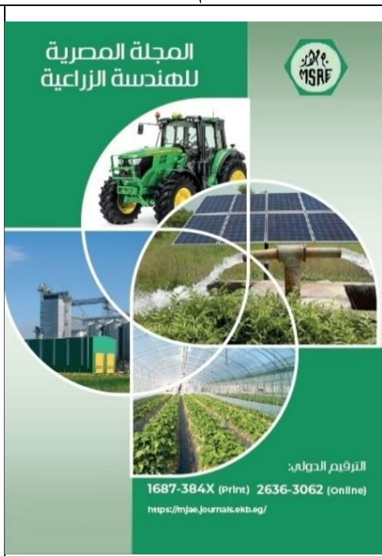

الملخص العربي

أجري البحث الحالي بهدف دراسة استخدام تقنيات المعالجة الحرارية وغير الحرارية في تعقيم روث الدجاج اللاحم خلال أزمنة تعرض مختلفة.
تمت دراسة عملية التعقيم باستخدام تقنيات المعالجة الحرارية المختلفة (التجفيف الشمسي والتجفيف الكهربائي) وتقنيات المعالجة غير الحرارية (الأشعة فوق البنفسجية) في أزمنة تعرض تتراوح من ١ إلى ٦ ساعات، وكذلك تم إعادة تعريض الروث المجفف الذي سبق تجفيفه بالتجفيف الشمسي والتجفيف الكهربائي للأشعة فوق البنفسجية المبيدة للجراثيم خلال أزمنة تعرض ٥، ١٠، ١٥، ٣٠، و٦٠ دقيقة. تمت دراسة عملية التعقيم بناءًا على العد الميكروبي، كفاءة التعقيم، الطاقة اللازمة لعملية التعقيم، تكاليف التعقيم.
أوضحت النتائج أن تعقيم روث الدجاج عن طريق التجفيف الشمسي غير فعال. أدى التجفيف الشمسي لمدة ٦ ساعات ومن ثم التعرض للأشعة فوق البنفسجية بكثافة ١٩٦٠ ميكرو وات/سم٢ لمدة ٥ دقائق إلى كفاءة تعقيم بنسبة ١٠٠٪، وأقل طاقة لعملية التعقيم تبلغ ٠,١٦٣ كيلووات ساعة/كجم، وتكلفة تعقيم قدرها ٠,٢٢٨ جنيه مصري/كجم مقارنة بالمعاملات الأخرى. يمكن تعقيم روث الدجاج باستخدام التجفيف الكهربائي لمدة تصل إلى ٥ ساعات بطاقة نوعية تبلغ ٥٨,٨٨ كيلووات ساعة/كجم وتكلفة تعقيم ٨٢,٤٣ جنيهًا مصريًا/كجم. بينما استخدام التجفيف الكهربائي لمدة ساعتين متبوعًا بـ ٦٠ دقيقة من التعرض للأشعة فوق البنفسجية البالغة ١٩٦٠ ميكرووات/سم٢، ادى إلى تعقيم الروث بطاقة نوعية قدرها ٢٥,٥١ كيلووات ساعة/كجم وتكلفة تعقيم قدرها ٣٥,٧١ جنيهًا مصريًا/كجم. أدى تعريض الروث إلى ١٤٧٠ ميكرو واط/سم٢ من الأشعة فوق البنفسجية لمدة ٦ ساعات إلى تحقيق كفاءة تعقيم بنسبة ١٠٠٪، وطاقة نوعية تبلغ ٨,٨٠ كيلووات ساعة/كجم، وتكلفة تعقيم تبلغ ١٢,٣١ جنيهًا مصريًا/كجم.
ختامًا، يعد استخدام الأشعة فوق البنفسجية في تعقيم روث الدجاج تقنية معالجة موفرة للطاقة واقتصادية.

الكلمات المفتاحية:
التعقيم؛ الروث؛ التجفيف الشمسي؛ الأشعة فوق البنفسجية؛ زمن التعرض.