Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development
Vol. 24, Issue 3, 2024
PRINT ISSN 2284-7995, E-ISSN 2285-3952

STERILIZE AQUACULTURE WASTEWATER BY UTILIZATION LOCALLY UV UNIT AS A WAY TO SUSTAIN CIRCULAR ECONOMY

Atef Mohamed ELSBAAY, Aml AMER, Mona M. KASSEM

Kafrelsheikh University, Faculty of Agriculture, Agricultural Engineering Department, Egypt. Phone: 00201007503876; E-mails: atef.ahmed@agr.kfs.edu.eg, amlamer2391991@icloud.com, omar2442010@gmail.com

Corresponding author: atef.ahmed@agr.kfs.edu.eg

Abstract

Water shortage is a global problem, especially in the Arab Republic of Egypt. The aim of this study was the effect of ultraviolet sterilizers on the bacterial load in the water of the aquaponic system, especially coliform bacteria. To determine the state of food safety, by conducting some engineering studies affecting the microbial load in the water of fish farms used in aquaculture, in order to produce healthy food for humans. Providing quantities of water and fertilizers. Microbial analysis of the total number of bacteria and coliforms was conducted in the water company's laboratories and the prevalence of the total number of bacteria and coliforms in the systems in three replicates. The study parameters were for different flow rates over time at 2, 4, 6 and 10 minutes with water heights of 2.5, 5, 7.5 and 10 cm at lamp heights of 10, 20 and 30 cm. Water quality and the total number of bacteria and total coliforms in the water were measured before and after treatment using a UV sterilization unit. The results showed that the ultraviolet sterilizer gave lower results for the microbial load of coliform bacteria in the treatments under study compared to the treatments before using the sterilizer.

Key words**:** *aquaculture, aquaponic system, water quality, ultraviolet sterilizer, bacteria, coliforms, wastewater*

INTRODUCTION

The ever-increasing demand for food to meet the needs of a growing population combined with the challenges of resource scarcity and the need for high-quality foods with excellent nutritional properties demonstrates the importance of efficient, intensive and sustainable food production systems [12]. Aquaponic is a soil-less agricultural system that synergistically combines aquaculture with hydroponics in a closed cycle. Since a few years ago, aquaponics, as a sustainable production alternative to traditional aquaculture, has attracted increasing attention worldwide [5], [9]. Aquapnic has become popular and attractive conceptual agricultural technology and been considered as a potentially sustainable method of industrialized food production [7]. Alternative cultivation systems that can restrict chemical fertilizer use by replacing it with more sustainable nutrient sources are required. Aquaponics is a promising solution that addresses all the above-mentioned issues by turning waste into resource under the circular economy concept [1], [13]. This approach is especially promising for urban area to meet the needs of food nearby as the urbanization develops rapidly [8]. The technique combines fish production in recirculating aquaculture systems (RAS) and crop cultivation through hydroponics [11]. The factors that influence the water quality in the system include the stocking density of the fish, feeding rate, fish growth rate, and environmental conditions [15]. Water quality is an essential factor in aquaculture. Unlike terrestrial animals, aquatic organisms are immersed in water. Therefore, all of their important metabolic processes occur in water, including feeding, digestion, excretion, and growth. These organisms are sensitive to any change in water quality, especially in high stocking densities. The importance of controlling these pathogenic bacteria is highlighted by the fact that the aquaponics industry is growing globally, and the number of aquaponics producers [7]. Light emitting diodes (LED) and UV-A are two main safe sources of lights for photodynamic inactivation which have been used to improve sanitation of food products Thus, to address the

potential challenges in water sanitation in Recirculating Aquaculture Systems (RAS) and aquaponics [2], [14]. RAS is a healthy and environmental option for food production which has encouraged research into many different aspects One of the main difficulties related to aquaponics system is the potential dissemination of pathogens Diseases control is mainly based on disinfecting water methods at various points of the aquaponics systems, depending on the method [10], because water recirculation and controlled parameters such as temperature provides the perfect environment for pathogen proliferation [4]. Microbes perform the important role of fundamental biological filtration of water to provide the required nutrients for plant growth Therefore, microbes in aquaponics may affect the system performance, water quality, and the growth and quality of the plants and fish [6]. Bacteria also have direct implications for the fish, as they are highly abundant in the water and in constant contact with the mucosal surfaces of the skin, gills and gut. Bacteria can give positive effects through metabolic and immunological relations, such as improved utilization of nutrients in the gut and protection against in the microbial community structures in RAS are shaped by physicochemical variables and competition for nutrients and space, and this selection has consequences for the composition of the microbial communities as ion of pathogens [3]. This approach compromises the environmental footprint of the system, nullifying its main advantage, which is nutrient recovery, and re-use among the three components (i.e., fish, bacteria, plants). Additionally, the closed loop aquaponics operation is primarily based on the maintenance of an equilibrium among the above-mentioned components [17]. For example, a series of studies conducted in California and New York examined the transfer of E. coli from wildlife feces to pre-harvest lettuce by spraying during irrigation. Similar field studies have been conducted to examine pathogen survival and transfer to production from soil, irrigation water, and other environmental sources. However, the majority of research has focused on soil-based field and greenhouse environments, and there is limited data on food safety risks in soilless production environments, such as hydroponics (i.e., producing plants in a liquid medium rather than soil) [16]. The main objective of this study was reducing the microbial load for aquaculture wastewater by using UV sterilizing unit locally manufactured.

MATERIALS AND METHODS

The UV sterilizer unit

The two units were made from local materials. Everyone was designed in the form of a cuboid cross-section. Its dimensions are 63 * 56 * 15 cm. It has a number of holes with a diameter of 5 cm for lamp and holes of outlet water with a diameter of 1 cm as presented in Photo 1 which shows a photograph of the structure unit. A schematic diagram of the unit is shown in Fig. 1, for front view, side view and plan view of the unit. The UV sterilizer is a robust unit used for the disinfection of water. Disinfection of the water takes place when the water flows past the built-in UV Lamp. There are various models for different flow rates, all easy to install and made to the highest quality with a stainless-steel housing and external control box with monitoring capabilities. The UV lamp was used for sterilizer of water. It blows on three heights different 10, 20 and 30 cm from water surface with in unit. The UV lamp (Philips Lightning IBRS 10461 – 5600VB NL ' TL' 20 W/ 52, is a type of UV lamp manufactured by Philips. It operates at a power of 20 watts and has a model designation of TL 20 W/52. This UV lamp emits ultraviolet light with a wavelength of around 365 nanometers, which is effective for killing or deactivating microorganisms and for inducing fluorescence in certain materials. Table 1 shows the manufacturing specification for the UV lamp.

Microbiological Analysis

Sampling analysis has been conducted in KafrEl-Sheikh Company for water and waste water - Central Laboratory for Drinking water. The sample was taken after each transaction and saved in an ice tank to save the samples, then send it to the laboratory to conduct the microbial analysis for them, where the total number of bacteria count/ ml (T. B. CFU/ml)

and total coliform count/ 100 ml (T. C. CFU/100 ml) were measured.

Photo 1. A photo reflecting the structure of the unit
Source: Photography by the author's camera.

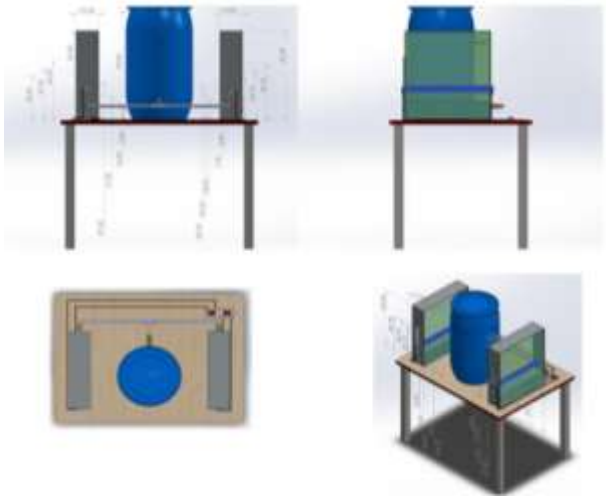

Fig. 1. A schematic of diagram isometric for the structure of the unit
Source: Author's schematic drawing.

Experimental Procedure

The main experimental work was carried out from July 2021 to October 2021. When experimental system was constructed, each component was checked and the water temperature and quality were set at the desired levels. The water used was brought in the experiment from the experimental units of intensive fish pond of *Nile Tilapia, Oreochromis Niloticus* attached to the Faculty of Aquatic and Fisheries Science, KafrEl-Sheikh University, on October 1, 2021. The analyze of the most important physical and chemical characteristics of the study of water quality have been performed. Then the tank connected to the sterilizer unit of ultraviolet rays was filled with water, and various study transactions were conducted from the height of the lamp (H.L, cm), the height of the water (H.W, cm) and the duration (time, min) of the survival water flow rate (Q L/min). Samples were collected in an ice tank to save physical and chemical characteristics and sent to the laboratory to conduct the basic microbial analyzes on them (the total number of bacterial count CFU/ ml and total coliform count CFU/ 100 ml) on the same day.

Table 1. specification of UV lamp according to Philips Company.

General Information	Controls and dimming
	
Useful Life (Nom) 2,000 hour(s)	Mechanical and Housing
Light Technical	
Color Code 52	Approval and Application
Luminous Flux 318 lm	Mercury (Hg) Content (Nom) 8.0 mg
Order product name TL 20W/52 SLV/25	
Operating and Electrical	Full product name TL 20W/52 SLV/25
Power Consumption 19.3 W	Full product code 871150064302540
Lamp Current (Nom) 0.36 A	Order code 928003505203
Voltage (Nom) 59 V	Material Nr. (12NC) 928003505203
Voltage (Nom) 59 V	Numerator - Quantity Per Pack 1

Source: The manufacture company.

Rate of change Percentage %:

To find out the relationship between the factors that affected the total number of bacteria and total coliform that were measured in the study samples, it was calculated the rate of change using the equation (1).

$$\textbf{Rate of change \%} = \frac{N_0 - N_t}{N_0} \quad \text{.....(1)}$$

where:
N_0 = the initial concentration
N_t = the concentration after a specific UV exposure time, of total bacteria (CFU/mL) and total coliform (CFU/100 mL).

Statistical Analysis

The bench-scale experiments were conducted based on a laboratory, full-factorial design. All experiments were duplicated independently with three method replicates for each sample. The data was analyzed statistically by two software, the first one was Smart-PLS version (4), smart-pls is a software with graphical user interface for variance-based Structural

Equation Modeling (SEM) using the Partial Least Squares (PLS) Path Modeling method, the second was the latest version of XLSTAT, it is a powerful yet flexible. The data was conducted two different types of analysis and they are partial least square (PLS) path model for the main effect of height of lamp (H L) and flow of water (Q) for the total number of bacterial (CFU/ml) and the total number of coliform (CFU/100 ml), with mediating factor height of water (H L) and time (t). The direct effect of the parameters under the study and the non – significant results were studied, another analysis was made using the indirect effect using mediation variable and the type of mediation was determined based on the positive values the path coefficient, so it would be complementary mediation and the negative values the path coefficient, so it would be competitive mediation. The total effect has also been studied.

RESULTS AND DISCUSSIONS

Effect of UV-LED Sterilizer for all Parameters under Study

Fig. 2 shows the number of total bacterial count (CFU / ml) and the total number of coliform count (CFU/100 ml) for all study parameters such as time (min), H.L (cm), H.W (cm). The highest value of number of total bacteria count was 415 CFU/ml at the parameter of study 2 min, 10 cm and 10 cm for t, H.W and H.L respectively, compared to the value of the total bacterial count which was 450 CFU/ml before treatment using the sterilization unit. The lowest value of rate of change percentage for total bacterial was 20 CFU/ml at the parameter of study 10 min, 2.5 cm and 20 cm for t, H.W and H.L respectively. The highest value of the total number of coliform count was 62 (CFU/100 ml) at the parameter of study 2 min, 10 cm and 30 cm for t, HW and H.L respectively, compared to the value of the total bacterial count which was 63 CFU/ 100 ml before treatment using the sterilization unit. The lowest value of the total number of coliform count was 5 (CFU/100 ml) at the parameter of study 10 min, 2.5 cm and 20 cm for t, H.W and H.L respectively.

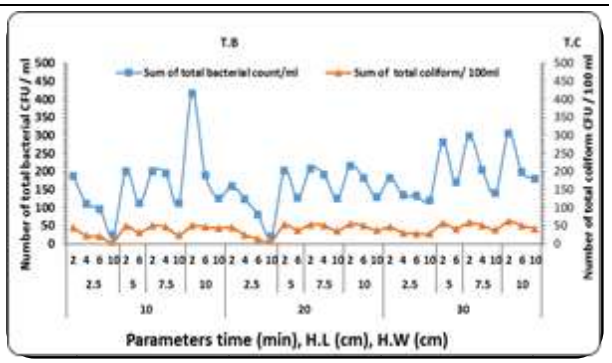

Fig. 2. The Number of total bacterial count (CFU/ml) and the total number of coliform count (CFU/100 ml) for all study parameters.
Source: Own calculation.

Rate of change Percentage

The preliminary analysis of the data by some descriptive statistics like the rate of change percentage of the total number of bacteria (CFU/ml) and the total number of coliform (CFU/100 ml), are represented graphically as shown in the Fig. 3. To find out the relationship between the factors that affected the total number of bacteria and total coliform that were measured in the study samples. It was calculated from the equation (1). UV exposure flow of water, of total number of bacteria (CFU/mL) and total number of coliform (CFU/100 mL).

Fig. 3 shows the rate of change percentages for the total number of bacterial (%) and the total number of coliform (%) calculated from equation (1). The values in the Figure 3 under the x – axis, the direction of the arrow is down and the values are all negative, this means that all the values for bacterial counts before the study are lower than their numbers after the study. The highest value of rate of change percentages for total bacterial was 95.56 % ▽ at the parameter of study 0.2 L/min, 10 min, 2.5 cm and 20 cm for Q, t, H.W and H.L respectively. The lowest value of rate of change percentages for total bacterial was 7.78 % ▽ at the parameter of study 4.2 L/min, 2 min, 10 cm and 10 cm for Q, t, H.W and H.L respectively. The highest value of rate of change percentages for total coliform was 92.06 % ▽ at the parameter of study 0.2 L/min, 10 min, 2.5 cm and 10 cm for Q, t, H.W and H.L respectively. The lowest value of rate of change percentages for total coliform was 1.59 % ▽ at the parameter of study 4.2

L/min, 2 min, 10 cm and 30 cm for Q, t, H.W and H.L respectively.

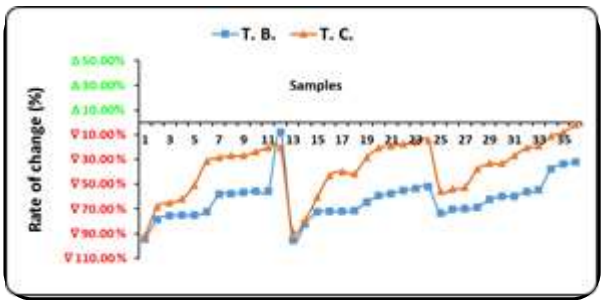

Fig. 3. The rate of change % for T. B. and T. C. for all study samples.
Source: Own calculation.

Fig. 4 shows the average rate of change percentage the total number of bacterial (CFU/ml) and the total number of coliform (CFU/100 ml) for all flow rates of water.

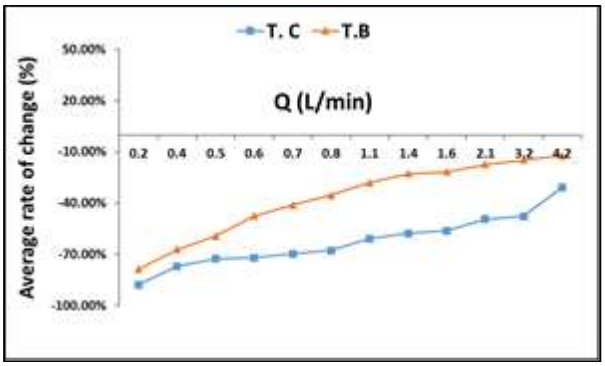

Fig. 4. Average rate of change % for total number of bacterial (T. B.) and total number of coliform (T. C.) for all flow rates of water.
Source: Own calculation.

The values in the Fig. 4 under the x – axis, the direction of the arrow is down and the values are all negative, this means that all the values for bacteria counts before the study are lower than their numbers after the study. The highest value of average rate of change percentages for total bacterial was 87.85 % ▽ at flow rate 0.2 L/min. The lowest value of average rate of change percentages for total bacteria was 30.74 % ▽ at flow rate 4.2 L/min. This means that the relationship between average rate of change percentages of bacteria and flow rates are positive. The highest value of average rate of change percentages for total coliform was 78.84 % ▽ at flow rate 0.2 L/min. The lowest value of average rate of change percentages for total bacterial was 12.17 % ▽ at flow rate 4.2 L/min. This means that the relationship between average rate of change percentages of coliform and flow rates are positive.

The first one Analysis for PLS Path Model for Total Bacteria count

The first one analysis for PLS Path Model was conducted. The first model for total bacteria (T.B) was conducted as shown in Fig. 5 and Table 2. The path coefficients for the height of lamp and water flow factors (0.172 and 0.349) respectively weren't statistically significant whereas the p-values were equal to (0.091 and 0.161) respectively which was greater than the level of significance (0.05) for the total number of bacterial. Regarding to the path coefficients for the height of water factor was equal to (0.362) with p-values was equal to (0.017) which means the path coefficient for total bacterial was statistically significant. Whereas the second value for total coliform was statistically significant. The second main effect in this table was water flow factor, the path coefficients were equal to (-0.668 and 0.540) with p-values (0.00 and 0.00) respectively, which means they were statistically significant in time and height of water. The last main effect in this table was time factor, the path coefficients was equal to (-0.442) with P-values (0.029) which means it was statistically significant in total bacteria. The statistical analysis indicated that there was a statistically significant for mediation role only with water flow factor because the p-value in case total indirect effect was equal to (0.016) less than (0.05) with path coefficient (0.491) which means the water flow affect positively on T.B with path coefficient (0.349) and the mediation was complementary mediation. The total effect of Q factor on T.B in this table was a statistically significant the path coefficients were equal to (0.839) with p-values (0.00).

The Fig. 5 showed that the flow chart of PLS Path Model for total bacterial count for (Q, H.L) component with mediation (T, H.W) factors. The direct, indirect and total effects of parameters under study are shown in the figure and coefficient of determination $R^{2,}$ so its value was 0.795 the highest of total effect from data analysis.

The second model for total coliform (T. C) was conducted as shown in Figure 6 and Table 3.

The path coefficients for the water flow factors (-0.196) weren't statistically significant whereas the p-values were equal to (0.242) which was greater than the level of significance (0.05) for the total number of coliforms. Regarding to the path coefficients for the height of lamp, the height of water and time factors were equal to (0.248, 0.774 and -0.783) with p-values was equal to (0.00, 0.00 and 0.00) respectively, which means the path coefficient for total coliform was statistically significant. The second main effect in this table was water flow factor, the path coefficients were equal to (-0.668 and 0.540) with P-values (0.00 and 0.00) respectively, which means they were statistically significant in time and height of water. The statistical analysis indicated that there was a statistically significant for mediation role only with water flow factor because the p-value in case total indirect effect was equal to (0.00) less than (0.05) with path coefficient (0.941) which means the water flow affect positively on T. C. with path coefficient (-0.196) and the mediation was competitive mediation. The total effect of Q factor on T. C. in this table was a statistically significant the path coefficients were equal to (0.745) with p-values (0.00).

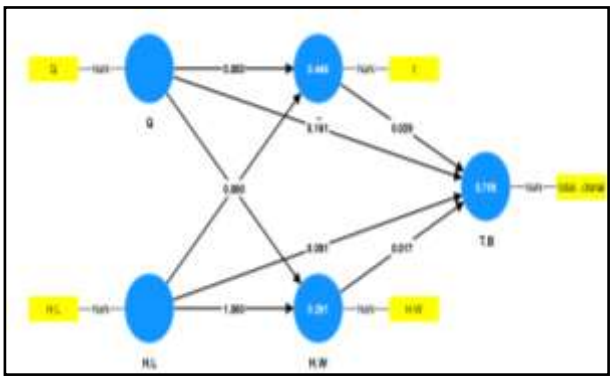

Fig. 5. Flow chart of PLS Path Model for total bacterial for (Q, H.L) component with mediation (T, H.W) factors.
Source: Own calculation.

Table 2. PLS Path Model for total bacteria for (Q, H.L) component with mediation (T, H.W) factors.

Path Direction (Total Bacterial)	Path Coefficient	CI (97.5) %	T-Test	P-value P < 0.05	Mediation
Direct Effect					
H.L -> T.B.	0.172	[0.003 – 0.386]	1.691	0.091	
H.W -> T.B.	0.362	[0.104 – 0.704]	2.395	0.017	
Q -> T.B.	0.349	[(-0.164) – 0.801]	1.403	0.161	
Q -> T	-0.668	[(-0.785) – (-0.544)]	10.889	0.00	
Q -> H.W.	0.540	[0.315 – 0.734]	5.106	0.00	
T -> T.B.	-0.442	[(-0.884) – (-0.103)]	2.178	0.029	
Total Indirect Effect					
Q -> T.B.	0.491	[0.125 – 0.925]	2.417	0.016	Complementary Mediation
Total Effect					
Q -> T.B.	0.839	[0.721 – 0.946]	14.473	0.00	

Source: Own calculation.

The second model Analysis for PLS Path Model for Total Coliform count

The Figure 6 showed that the flow chart of PLS Path Model for total coliform count for (Q, H. L) component with mediation (T, H.W) factors.

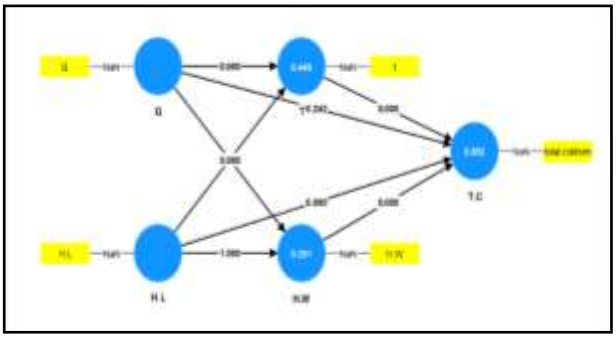

Fig. 6. Flow chart of PLS Path Model total coliform for (Q, H.L) component with mediation (T, H.W) factors.
Source: Own calculation.

The direct, indirect and total effects of parameters under study are shown in the figure and coefficient of determination $R^{2,}$ so its value was 0.853 the highest of total effect from data analysis.

Table 3. PLS Path Model for (Q, H.L) component with mediation (T, H.W) factors

Path Direction (Total Coliform)	Path Coefficient	CI (97.5) %	T-Test	P-value P < 0.05	Mediation
Direct Effect					
H.L -> T.C	0.248	[0.112 – 0.380]	3.630	0.00	
H.W -> T.C	0.774	[0.570 – 1.065]	6.188	0.00	
Q -> T.C	-0.196	[(-0.529) – 0.138]	1.170	0.242	
Q -> T	-0.668	[(-0.785) – (-0.544)]	10.889	0.00	
Q -> H.W.	0.540	[0.315 – 0.734]	5.106	0.00	
T -> T.C	-0.783	[(-1.132) – (-0.489)]	4.818	0.00	
Total Indirect Effect					
Q -> T.C	0.941	[0.647 – 1.279]	5.994	0.00	**Competitive Mediation**
Total Effect					
Q -> T.C	0.745	[0.672 – 0.835]	18.267	0.00	

Source: Own calculation.

UV sterilizers have positively affects water quality in recirculating aquaculture systems (RAS) without altering its chemical composition. UV treatment contributes to sustainable aquaculture practices by providing a chemical-free method of maintaining water quality. This approach aligns with environmental conservation efforts and the water remains safe and healthy for the species being cultured, without the risk of chemical build up in the system. This process helps to prevent the spread of infections among the selected species, leading to healthier, more robust growth and higher survival rates. This approach aligns with water conservation efforts in the world.

CONCLUSIONS

This study showed that the homemade experimental unit, which is a sterilizer using ultraviolet rays to reduce the microbial load in aquaponic water, was effective compared to treatment before use. It is hoped that the unit used in this study will contribute to the development of standard experimental procedures and validation protocols for UV water disinfection. Finally, a more holistic approach to the design and implementation of UV disinfection systems will enable the development of "fit-for-purpose" technologies. This will then encourage the identification of wide-ranging UV applications that take advantage of the unique advantages Technology offers. Identifying specific disinfection applications for UV lamps as a solution will also serve as a catalyst for further innovation and development. This work presents a new paradigm for the use of UV lamps for disinfection and more broadly the role of UV light on the inactivation of human pathogens of clinical importance.

REFERENCES

[1]Blidariu, F., Radulov, I., Lalescu, D., Drasovean, A., Grozea, A., 2013, Evaluation of Nitrate Level in Green Lettuce Conventional Grown under Natural Conditions and Aquaponic System. Scientific Papers: Animal Science and Biotechnologies (Vol. 46, Issue 1).

[2] de Oliveira, E. F., Tosati, J. V., Tikekar, R. V., Monteiro, A. R., & Nitin, N., 2018, Antimicrobial activity of curcumin in combination with light against Escherichia coli O157:H7 and Listeria innocua: Applications for fresh produce sanitation. Postharvest Biology and Technology, 137, 86–94. https://doi.org/10.1016/j.postharvbio.2017.11.014

[3]Fossmark, R. O., Vadstein, O., Rosten, T. W., Bakke, I., Košeto, D., Bugten, A. V., Helberg, G. A., Nesje, J., Jørgensen, N. O. G., Raspati, G., Azrague, K., Østerhus, S. W., Attramadal, K. J. K., 2020, Effects of reduced organic matter loading through membrane filtration on the microbial community dynamics in recirculating aquaculture systems (RAS) with Atlantic salmon parr (Salmo salar). Aquaculture, 524. https://doi.org/10.1016/j.aquaculture.2020.735268

[4]Goddek, S., Joyce, A., Kotzen, B., Burnell Editors, G. M., 2019, Aquaponics Food Production Systems

Combined Aquaculture and Hydroponic Production Technologies for the Future.
[5]Greenfeld, A., Becker, N., Bornman, J. F., Angel, D. L., 2019, Identifying knowledge levels of aquaponics adopters. https://doi.org/10.1007/s11356-019-06758-8/Published
[6] Kasozi, N., Abraham, B., Kaiser, H., Wilhelmi, B., 2021, The complex microbiome in aquaponics: significance of the bacterial ecosystem. Annals of Microbiology (Vol. 71, Issue 1). BioMed Central Ltd. https://doi.org/10.1186/s13213-020-01613-5
[7]Kledal, P. R., Thorarinsdottir, R., 2018, Aquaponics: A Commercial Niche for Sustainable Modern Aquaculture. In Sustainable Aquaculture (pp. 173–190). Springer International Publishing. https://doi.org/10.1007/978-3-319-73257-2_6
[8]Kyaw, T. Y., Ng, A. K., 2017, Smart Aquaponics System for Urban Farming. Energy Procedia, 143, 342–347. https://doi.org/10.1016/j.egypro.2017.12.694
[9]Love, D. C., Fry, J. P., Li, X., Hill, E. S., Genello, L., Semmens, K., Thompson, R. E., 2015, Commercial aquaponics production and profitability: Findings from an international survey. Aquaculture, 435, 67–74. https://doi.org/10.1016/j.aquaculture.2014.09.023
[10]Mori, J., Smith, R., 2019, Transmission of waterborne fish and plant pathogens in aquaponics and their 7 control with physical disinfection and filtration: a systematized review. Veterinary Medicine Basic Sciences Building Office #2535.
[11]Nichols, M.A, Sabidov, N.A., 2012, Aquponics- A nutrient and water efficient production system. Acta Horticulturae, 947: 129-132.Conference II International Symposium on soilless Culture and Hydroponics.
[12]Nuwansi, K. K. T., Verma, A. K., Tiwari, V. K., Prakash, C., Chandrakant, M. H., 2017, . Standardization of the stocking density ratios of koi carp (Cyprinus carpio var. koi): Goldfish (Carassius auratus) in polyculture aquaponic recirculating system. Turkish Journal of Fisheries and Aquatic Sciences, 17(6), 1271–1278. https://doi.org/10.4194/1303-2712-v17_6_20
[13]Silva, L., Valdés-Lozano, D., Escalante, E., Gasca-Leyva, E., 2018, Dynamic root floating technique: An option to reduce electric power consumption in aquaponic systems. Journal of Cleaner Production, 183, 132–142.https://doi.org/10.1016/j.jclepro.2018.02.086
[14]Subedi, S., Du, L., Prasad, A., Yadav, B., Roopesh, M. S., 2020, Inactivation of Salmonella and quality changes in wheat flour after pulsed light-emitting diode (LED) treatments. Food and Bioproducts Processing, 121, 166–177. https://doi.org/10.1016/j.fbp.2020.02.004
[15]Thorarinsdottir, R., 2015, Aquaponics guidelines. Haskolaparent, Reykjavik, Iceland.
[16]Trier, A. M., Mack, M. R., Kim, B. S., 2019, The Neuroimmune Axis in Skin Sensation, Inflammation, and Immunity. The Journal of Immunology, 202(10), 2829–2835. https://doi.org/10.4049/jimmunol.1801473
[17]Tsoumalakou, E., Mente, E., Kormas, K. A., Katsoulas, N., Vlahos, N., Kapsis, P., Levizou, E., 2022, Precise Monitoring of Lettuce Functional Responses to Minimal Nutrient Supplementation Identifies Aquaponic System's Nutrient Limitations and Their Time-Course. Agriculture (Switzerland), 12(8).https://doi.org/10.3390/agriculture12081278