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RESEARCH PAPER

The Water Disinfection with Different Type UV Lamp Systems on Bacterial Load in Small Scale Recirculating Aquaculture Systems

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Abstract

The present study was planned with the aim of inactivating the total bacterial load and species in tilapia fish tanks kept in fresh and seawater conditions with high stock density with different UV lamp models. In this context, the UVC+UVA-Led lamp system was compared with the conventional UVC lamp system and the total bacterial load in the tanks and the inactivation effect on the bacterial species were determined. Total bacterial load on the medium and bacteria species were identified in terms of their morphological characteristics using the spread plate method. Bacteria that emerged at different times in the trial sets were identified as *Edwardsiella tarda*, *Salmonella sp.*, *Aeromonas hydrophila, Pantoea sp., Citrobacter youngae, Serratia ficaria* and *Citrobacter freundii.* The total bacterial load in both freshwater and seawater environments in both lamp groups showed a decrease compared to the control group. With this, the conventional lamp model was more effective on the total bacterial load in the samples taken during the trial. Although all bacteria were inactive in both lamp groups, *Serratia ficaria* bacteria were not eliminated in the seawater environment. The results show that UV LEDs can be a better alternative to traditional UV mercury lamps for water disinfection.

Introduction

As a result of the rapid population growth in the world and the destruction of a considerable part of natural water resources, most of which is attributable to pollution and partly to global warming, it is getting harder to ensure access to sufficient healthy food for everyone. Fish consumption worldwide has doubled in the last 50 years since fish has proved to be part of a healthy diet (FAO, 2020). Recently, there has been heavy pressure on natural fish stocks due to overfishing and misguided methods. While this situation causes fish production through fishing from the seas to remain constant, it increases the interest in aquaculture products grown under controlled conditions (UVC ALLIANZ GMB, 2020). Thanks to the developments in technology supported by science, aquaculture studies can meet the increasing demand for aquatic products for the time being. Among these technologies, fish producers using the recirculating aquaculture system can produce intensively and benefit from the energy and total cost savings. However, some problems may be encountered during production. For example, surface waters commonly used in aquaculture, coastal waters or water brought to the facilities from rivers may contain some fish pathogens. Filtration and disinfection

processes must be applied before the water is brought from the source and given to the system to prevent the pests of the water used in aquaculture, which have the potential to cause disease and pollution (Beck et al., 2017). Recirculating aquaculture systems are suitable for managing optimum water quality, and their importance in providing high quality water conditions especially during the most sensitive period of larval growth is now better acknowledged. Thanks to the intensive fish stock and the feed given to the fish, an ideal breeding ground for various bacteria and viruses can be formed in the environment. For this reason, controlling potentially harmful pathogens –mostly heterotrophic bacteria– before the increase in their growth reaches a problematic level is an essential issue in intensive production (Schneider, Sereti, Machiels, Eding & Verreth, 2006; Rurangwa & Verdegem, 2014).

Tilapia *(Oreochromis sp.)* is a fish species that can live in fresh/sea water, can be produced extensively, semi-intensively and intensively all over the world, and has economic value (Welcomme, 1996). When the number of fish placed in the breeding pond increases, pollution, stress and changes in water conditions can increase the bacterial load in the water. Among these bacteria, pathogenic bacteria cause infection and adversely affect tilapia production as in other fish cultures. Harmful bacteria that have been detected in tilapia fish farming to date are: *Edwardsiella tarda* (Pirarat, Kobayashi, Katagiri, Maita & Endo, 2006; Zeng, Du, Liu, Li, Peng & Peng, 2017), *Aeromonas hydrophila* (Wang & Wang, 1997; Ahmed, 2019), *Listeria monocytogenes, Bacillus* sp., *Staphylococcus saprophyticus, Serratia* sp., and *Providentia stuartii* (Shinkafi & Ukwaja, 2010), *E. coli, E. coli O157: H7, Salmonella* sp., *Morganella morganii, Proteus* sp., *Enterobacter cloacae, Enterobacter cancerogenus, Hafnia alvei, Photobacterium damaselae* (Ahmed, 2019), *Plesiomonas shigelloides, Shewanella putrefaciens, Pseudomonas fluorescens*, and *Vibrio cholerae* (Pakingking Jr, Palma & Usero, 2015).

In aquaculture, chemical (chlorine, chlorine dioxide, ozone) or physical (heat treatment, filtration, ultra violet-UV) processes, which are disinfection technologies, are used to destroy or inactivate the microorganisms in the water. In UV disinfection, high-energy ultraviolet-C (UVC) rays with a wavelength of approximately 254 nm enter the cell membrane of microorganisms and cause cell death by stopping all cell activities, including reproduction. UV rays are absorbed by the DNA of pathogens in the water and they die before they can cause infection. This change in DNA is defined as inactivation (Song, Mohseni & Taghipour, 2016). Thus, UV systems can easily control the risk of harmful bacteria in recirculating or open water systems during production without changing other important water qualities such as pH and temperature. Furthermore, bacteria can't form disinfectant resistance against UV (Mori et al., 2007). At the same time, it is an environmentally friendly material that does not produce harmful disinfection by-products since UV's do not contain chemicals. When ozone and UV are used together, one of the molecular bonds breaks, which can instantly destroy ozone, a waste harmful to fish in the water (Summerfelt, 2003).

In addition to all these positive features, there are also some drawbacks because the glasses of toxic high pressure mercury lamps, which can produce UVC rays synthetically, are thin and fragile (Chevremont, Farnet, Coulomb & Boudenne, 2012). Besides, due to its low energy efficiency of 15-35%, a high-pressure mercury lamp consumes a significant amount of energy to work. Additionally, due to its short average lifespan, its effect on pathogens weakens and disappears if it is not renewed in time (Chatterley & Linden, 2010; Autin et al., 2013). On the other hand, UV-Led lamps are economical lighting and sterilization lamps made of semiconductor material and available in various wavelengths (Harris, Pagan & Batoni, 2013). These are lamps that offer various wavelengths (between 210 nm and 365 nm), have efficiency, compatibility with disinfection needs, and they also are environmentally friendly (mercury free), compact, long-lasting, and work with 75% wall socket efficiency (Taniyasu, Kasu & Makimoto, 2006; Autin et al., 2013; Ibrahim, MacAdam, Autin & Jefferson, 2014). There are few studies on inactivating some microorganisms in water using UV-Led's. Most of these studies have focused on whether the samples taken from the aquatic environment have an inactive response to various wavelengths in the laboratory (Table 1). Although a standardized protocol for microorganism inactivation with conventional UV mercury lamps has been established in studies conducted to date, it is

Table 1: Studies using UV-LEDs to neutralize some microorganisms in water

Bacteria Species	Literature
B. Subtilis	Morris (2012)
E.coli	Bowke,r Sain, Shatalov & Ducoste (2011), Chatterley & Linden (2010), Oguma, Kita, Sakai, Murakami & Takizawa (2013), Hamamoto et al., (2007), Mori et al., (2007), Xiong & Hu (2013)
Pseudomonas aeruginos	Bak, Ladefoged, Begovic & Winding (2010)
Qubevirus durum (Qβ) and *Escherichia virus* (ΦX174)	Aoyagi, Takeuchi, Yoshida, Kurouchi, Yasui & Kamiko (2011)
Bacteriophage MS-2 (*Emesvirus zinderi*)	Aoyagi, Takeuchi, Yoshida, Kurouchi, Yasui & Kamiko (2011) and Bowker, Sain, Shatalov & Ducoste (2011)
some mesophilic bacteria	Chevremont, Farnet, Coulomb & Boudenne (2012)

understood that a consistent methodology to obtain UV-Led dose response of microorganisms and a standard protocol for determining UV dose cannot be established (Song, Mohseni & Taghipour, 2016). In this context, the biological processes caused by UV-Led radiation may vary according to different microorganisms, and some organisms may be more sensitive to the flow rate. For this reason, in this study, the effect of different UV lamp technology on bacterial loads was determined by comparing the UVA+UVC-Led lamp system with the conventional UVC lamp system in fresh water and seawater under production conditions.

Materials and Methods

Experimental Design

The experiments were carried out in triplicate in aquarium sets with a volume of 500 L in small scale recirculating system. A bag filter and protein skimmer system with a 20-micron filtration capacity was used in the system. The water temperature in the sets was provided with an automatic water heater adjusted to 28±1°C. 16 hours of light and 8 hours of darkness were applied in the sets. A submersible motor with a 500 LPH capacity was used to ensure the water cycle. No water changes were made. The UV lamp assembly was placed after the bag filter system. The turbidity of the waters was measured with the WTW Turb 355T.

In this trial the sets (aquarium and lamp) were named A, B, C, D, E and F. Each sets fish were stocked at a stock density of 12 kg/m^3. Afterwards, the salinity of sets D, E and F were increased by ‰5 per day with artificial sea salt to ‰35. Fish were fed ad libitum daily in the morning and afternoon. Inedible feed and feces were siphoned away from the environment. The same amount of sterilized water was added to replace the decreased water. Two weeks later, the initial water sample was taken from the sets and analyzed, and after detecting bacterial growth, UV lamp systems were activated. The UV lamp systems were placed as follows: A and D (control) were not placed with UV lamps; In B and E, 12.5-watt UVC-Led (265-285 nm irradiance) + UVA-Led (395-405 nm irradiance) was used (Shenzhen Santang Lighting Co. Ltd); In B and 5, 12.5-watt UVC-Led (265-285 nm irradiance) + UVA-Led (395-405 nm irradiance) was used. In C and F, conventional mercury UVC lamps were used (12-watt, 185-254 nm irradiation: Tepro germicidal lamp h type). While the lamps used in B and E systems have a value of 6.4 mW/cm^2 (radiometric measurement), the conventional lamp used in C and F has a value of 3.2 mW/cm^2 (radiometric measurement). For bacterial load monitoring, after the UV systems were turned on, at the times when the water circulation of 25%, 50% and 100% of the water volume of each system was completed first from the sets. Afterwards, water samples were taken from the entrance point of the fish tank at the 24th hour, 48th hour, 72nd hour, 96th hour and 144th hour. In the control sets, the water turbidity measurement value of A was 1.92-1.96 NTU and D was 2.03-2.07 NTU, and in the other groups, the turbidity values of B, C, E, and F were measured as 1.37-1.44, 1.43-1.48, 1.41-1.46, 1.34-1.39 NTU, respectively.

Analyses

Microbiological Analysis

The analyses were performed 3 times for each group. The samples were taken into glass tubes that had been sterilized at 170°C for 1 hour (Pekbay, 2005) in a sterilizer (Nüve FN 400), next to the Bunsen burner, with the help of a disposable Pasteur pipette. The water samples were cultivated in 3 parallels at different dilution ratios, 10^1 and 10^2. Petri dishes were incubated at appropriate temperatures by cultivating in accordance with the spreading plate method. At the end of the incubation, the number of colonies was determined to be between 30 and 300 (Harrigan & McCance 1976).

Counting of Aerobic Mesophilic Microorganisms: Plate Count Agar medium (PCA, Merck, 1.05463.0500) was inoculated according to the spread plate method to determine the number of aerobic mesophilic bacteria in the water samples. The sample, taken 0.1 ml in the spreading plate method, was spread with the help of a glass spreader, and incubated at 35°C for 48 hours. All colonies formed after incubation was counted (Baumgart, Firnhaber & Spicher, 1986).

Bacteria Isolation and Identification: After incubation, bacterial species with different morphological structures growing in the media were purified by reassigning to where they grew. Identifying bacterial species with different morphologies developed after incubation was carried out with API kits The API 20 NE (Biomerieux) test kit was used for the identification of total mesophilic bacterial species (gram-negative bacteria such as *Aeromonas*), the bacterial species purified in the nutrient medium in which they grew. The API 20 E test kit was used for the determination of *Enterobacteriaceae* family species (Biomerieux, 2022).

Statistical Analyses

The non-parametric Kruskal-Wallis test analysis of variance (ANOVA) was used to determine statistically significant differences between bacterial load (Mean values) obtained from different UVC and UVC Led treatments for each time and were evaluated using the Mann–Whitney U-test. Significance was accepted when $p \leq 0.05$. Analyses were performed using IBM SPSS Statistics Version 25.

Results

Both UV systems prepared within the scope of the study worked without any problems during the trial

period. There was no power outage in the system during the experiment. Accordingly, no problems were encountered in both the disinfection of the water and the water cycle. In addition, no problems occurred in the plantings made from water samples taken from both freshwater and seawater environments at the beginning of the experiment.

LED power 40 mV for LED lamp; distance 2.5 cm; light intensity was 6.4 mW/cm^2 and the applied UV doses were calculated as 5.76, 11.52, 23.04, 552.96, 1105.92, 1658.88, 2211.84 and 3317.76 m J/cm^2, respectively. For standard UVC: UV power is 20 mV/cm^2, distance is 2.5 cm, light intensity is 3.2 mW/cm^2, and the applied UV doses were calculated as 2.88, 5.76, 11.52, 276.48, 552.96, 829.44, 1105.92 and 1658.88 m J/cm^2, respectively.

No fish death occurred in the sets during the study. Gram-negative bacteria (*Edwardsiella tarda, Salmonella sp., Aeromonas hydrophila, Pantoea sp., Citrobacter youngae, Serratia ficaria Citrobacter freundii*) were detected in the freshwater analysis. However, the difference in total bacterial load in the water samples taken from all three sets before the UV systems were activated was insignificant ($p>0.05$). On the other hand, at the 72nd hour of the experiment, it was determined that there was less total bacterial growth in B and C compared to A, and the difference was significant ($p<0.05$). The difference in total bacterial load in B and C was not significant ($p>0.05$) (Figure 1).

When the bacteria emerging in the sets are considered based on species, *Edwardsiella tarda* and *Salmonella sp*. were observed to appear at the end of the 96th hour in A, and neither of these bacterial species were found in other sets using UV systems. *Aeromonas hydrophila* on the other hand, was not found in C and was not seen again in B after the 30th minute when the water circulation was 100%.

Another bacterium detected was *Pantoea sp.,* which were seen in Sets A and B until the end of the fifteenth minute and were not seen again until the end of 96 hours. This bacterium was not detected in the samples taken after 144 hours. While *Citrobacter youngae* bacterium was detected until the end of the 48th hour in A and 2, and in C, it was only seen in the water sample taken before the UV lamp was activated and it was not detected again after that.

Serratia ficaria, another type of bacterium that appeared in the freshwater environment, was seen at the end of the 30th minute in A. In contrast, it appeared at the end of the 24th hour and 48th hour in B. In C, however, its presence could be detected until the end of the 15th minute. This bacterium appeared in all freshwater sets at the 96th hour.

According to the analyses performed with the UV system turned off in seawater sets, the difference between Sets D, E and F in terms of the total bacterial load was insignificant ($p>0.05$). The difference between the total bacterial load in D, E and F was significant from the 24th hour to the end of the 144th hour ($p<0.05$). However, at the end of the 24th hour, 96th hour and 144th hour, the difference between total bacterial loads was found to be significant according to the analysis performed on conventional UV and UV-Led lamp sets ($p<0.05$). At this stage, fewer bacteria growth was detected in F ($p<0.05$) (Figure 2).

Three bacterial species were detected in the sets in the seawater experiment. *Aeromonas hydrophila* was detected in D at the 60th minute and 24th hour. This bacterium was not seen in the other sets. While the bacterium *Citrobacter freundii* continued to be seen after the 30th minute, it appeared only at the end of 96 hours in E. In F, this bacterium was not seen at any stage. *Serratia ficaria* bacteria were found in all sets from the beginning to the end of the experiment.

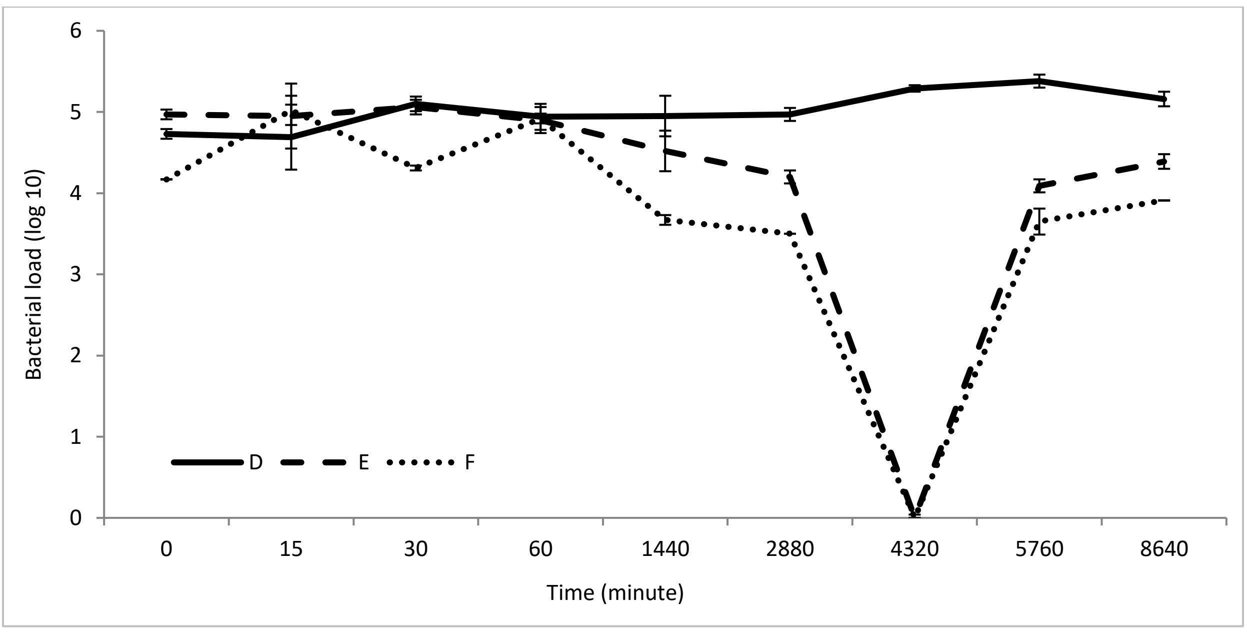

Figure 1. Change in total bacterial load in freshwater- UV trial.

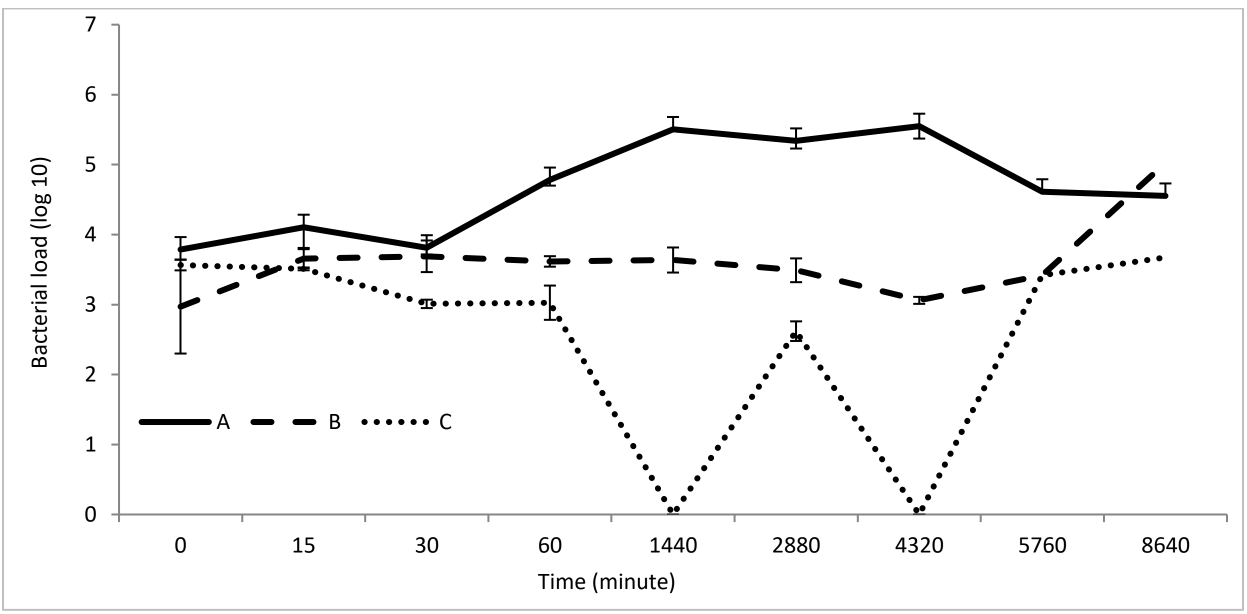

Figure 2. Change in total bacterial load in seawater- UV trial.

Discussion

In the study, the effects of different types of UV lamps on the total bacterial load and the emerging bacterial species in the fresh and seawater conditions where tilapia fish were stocked were investigated. Developing technologies for sterilizing water used in aquaculture, especially inactivation of pathogenic microorganisms is of great importance as access to safe water is essential for human health, hygiene and fish welfare. Ultraviolet radiation can inactivate various microorganisms in water effectively and is increasingly used to disinfect water (Hijnen, Beerendonk & Medema, 2006). UV radiation provides numerous advantages over conventional chemical disinfection (chlorination or ozonation) in terms of the formation of chemical additives and harmful disinfection by-products (DBPs) and being effective against disinfectant-resistant bacteria (Mori et al., 2007). Recent developments and advances in the semiconductor industry allow UV light emitting diodes (UV-Led) as a new source for UV radiation. The wavelength diversity provided by UV-Leds becomes highly compatible with the needs required for disinfection. Furthermore the variety of wavelengths provided, UV-Leds are environmentally friendly (mercury-free), compact and robust (more durable), have faster start-up time (no warm-up time) as well as a longer lifetime, and they consume potentially less energy and have features such as opening and closing at high frequency, all of which make these products important (Wurtele et al., 2011).

UV systems use safe, broad-spectrum and apply highly efficient technology that does not cause additional pollution or infect water quality. UV irradiation is used to remove ozone residues, denature DNA or RNA, or cause the death or loss of function of microorganisms, depending on the wavelength of the light and the transmitted energy. Although the most effective wavelength is 254 nm to destroy ozone residues, it can be inactivated below 100-400 nm (Summerfelt, 2003). The ideal UV radiation is between 250-260 nm. Moreover, the synergistic effect of UV on water purification can quickly remove ammonia and nitrogen from seawater and does not adversely affect the water temperature.

However, UV systems have some disadvantages. One disadvantage is the level of sterilization efficiency of UV light. The increase in turbidity in the growing medium gradually reduces the UV irradiation power; and the lamp gradually causes weakened irradiation intensity. For this reason, it is necessary to clean the lamp or the protective glass periodically. Another disadvantage is that the sterilization capacity is related to the irradiation time and intensity. In this context, when the water flow is too fast, or the irradiation dose cannot meet the requirements, the microorganisms subjected to UV irradiation develop a restructuring mechanism, which causes bacterial regeneration. This puts pressure on water quality (Zhu, Dang & Song, 2003; Pei, 2016).

Properties such as density, dose, contact time, particle size and particle density are essential for effective disinfection in UV systems. High doses of UV (generated by a U-shaped open channel with a 15W LP mercury lamp) have effectively destroyed about 98% of heterotrophic bacteria in closed circuits used in salmon farming (Sharrer & Summerfelt, 2007). Furthermore, to control the proliferation of pathogenic bacteria in closed-circuit systems, it is predicted that a 30W light source can be held at 4 mJ/cm^2 radiation in a system with a volume of 100 m^3 (Mamane, Colorni, Bar, Ori & Mozes, 2010).

UV-Leds can be produced with different semiconductor materials at various wavelengths. The

most used materials are III-nitride, including gallium nitride (GaN), aluminium gallium nitride (AlGaN) and aluminium nitride (AlN) (Khan, Shatalov, Maruska, Wang & Kuokstis, 2005). Wavelengths can be produced between 210-365 nm. The different wavelengths of UV-Leds are compatible with efficient disinfection requirements, making them a potential option because it is known that wavelength is an essential factor for water disinfection (Vilhunen, Sarkka & Sillanpaa, 2009). When the data obtained in this context were examined, it was determined that the UV-Led frequencies used in the study were compatible with other studies. At the same time, the effect of this frequency on bacterial load has been shown in the obtained data.

Moreover, they have a fast start-up time and potentially less energy consumption, thus have longer lifetime and they cause no heating problems as high-frequency switching increases the efficiency of these devices (Wurtele et al., 2011). Similar features were also described in the study. Especially considering that these two lamps have worked throughout the year, it has been calculated that the use of Leds consumes one-third less electricity than the conventional lamp to keep a volume of only 500 liters in a livable cycle, which is extremely important in terms of costs. A similar approach in terms of electrical efficiency is defined by Autin et al. (2013) and Ibrahim, MacAdam, Autin & Jefferson (2014). All factors suggest that UV-Leds can be an excellent alternative to conventional UV mercury lamps for water disinfection. This study revealed that using UV-Led lamp technology did not have a negative effect on commercial fish stock density.

In this study, we were able to sterilize the water by giving different doses of conventional UVC lamps with mercury and UV lamps with Leds to the bacteria we detected in the water. Both lamps were successful in reducing the number bacteria at different times. All detected bacteria are from the Gammaproteobacteria class and are mesophilic and gram-negative bacteria. Four bacteria detected are *Enterobacteriaceae*, and one belongs Aeromonadales (*A. hydrophila)*. The temperature limits at which these bacteria can multiply are 5-40°C. However, bacterial growth was observed at 28°C.

They were reported to inactivate Escherichia coli bacteria (Enterobacteriaceae family) with a UVC lamp at a wavelength of 260 nm-280 nm and a dose of 0.29 and 0.31 mJ/cm^2, respectively, and with conventional UV at a dose of 0.11 mJ/cm^2 (Beck et al., 2016). Similarly, Lui, Roser, Corkish, Ashbolt & Stuetz (2016) inactivated *E. coli* and *Enterococcus faecalis* bacteria with an LED lamp with much higher wavelengths (430 and 455 nm) than we used. Still, the time they used was shorter (exposure time; 6 minute). With UVA-Led at a wavelength of 365 nm, 3.9 log at a dose of 54,000 mJ/cm^2 (Mori et al. 2007), 2.89 log at a dose of 3852 mJ/cm^2 (Qi, Zhu, Shitu, Ye & Liu, 2020), 2.0 log with a dose of 3552 mJ/cm^2 (Nyangaresi, Qin, Chen, Zhang, Lu & Shen, 2019), 5.7 log at a dose of 315,000 mJ/cm^2 (Hamamoto et al., 2007) *E. coli* colony reduction was achieved irradiation.

Salmonella sp. in the same family as *E. coli*, is a zoonotic pathogen that can show resistance to some antibiotics (Helmi et al., 2020). It is hazardous to human health. In our experiment, neither bacteria type appeared on sets with UV lamps. However, both were detected only in the control group at the 97th hour in freshwater sets. It is suspected that this situation is caused by faeces or food remains that could not be removed from the environment of the fish. The other two members of the same family found in this study are *Citrobacter youngae* and *Citrobacter freundii*, facultative anaerobic enterobacteria found throughout the intestinal tract. For this reason, it can cause many fish deaths by contamination. We detected this bacterium at different times in all sets in our experiment with fresh water. However, in the first minutes of the experiment, after 25% water was recirculated in C, this bacterium was not found again in that set. We detected another member of the same family, *C. freundii*, at various times in the control group of our sets filled with seawater. After this bacterium was found at the 96th hour of E, it was not found again. In F, it was never found to be present. In our study, we eliminated *C. youngae*, and *C. freundii* bacteria with a new generation Led lamp with a UV dose of 1105.92 mJ/cm^2 and 2211.84 mJ/cm^2, respectively. The main reason for the high UV doses applied in this study is that using high doses aims to eliminate the bacterial load resulting from the dynamics of production conditions. In addition, it is thought that different experimental setups, ambient conditions and controlled irradiation of other bacteria in the laboratory environment will cause differences in inactivation time and dose.

However, *Edwardsiella tarda* from the *Hafniaceae* family, which was detected during the experiment, is an anaerobic bacterium abundant in fresh and warm water, causing infections in fish, and common in aquaculture, which can cause serious economic losses. Likewise, *Pantoea* sp from the *Erwiniaceae* family are opportunistic Enterobacteria found in fresh waters and live in anaerobic environments (Ahmed, 2019). When the immune system is suppressed by stress or a minor injury to the skin, it has been stated that these bacteria progress rapidly and harm the production of tilapia under intensive production conditions (Morin, 2014). However, no previous literature report was identified for the inactivation of these bacteria we detected in the sets. This situation is important in determining the bacterial inactivation effect of applications. Similarly, although no results were presented for the inactivation of *Serratia ficaria* bacteria from the *Yersiniaceae* family, it is known that a close relative of the bacterium, *Serratia marcescens* (Chan, Chang, Hong, Tee, Yin & Chan, 2013), is a harmful pathogenic bacterium for tilapia fish. Unfortunately, we detected this bacterium in all sets in the seawater trial at all trial times, and we found that the conventional/new system did not affect

this bacterium. It can be guessed that this bacterium enters photoreactivation by repairing its DNA. The first appearance of this bacterium was ten years ago, but its effect on fish farming is not fully known yet. Considering its close relatives, we think it is necessary to design experiments in which this bacterium can be inactive, with the possibility of pathogenicity, with shorter wavelength UV lamps or by increasing the transit time of water in front of the UV lamp. Separately, *Aeromonas hydrophila* from the *Aeromonadaceae* family is a heterotrophic and anaerobic bacterium. It can be found in fresh or brackish water regions with mild climate. It can survive in aerobic and anaerobic environments. It is resistant to many antibiotics and cold temperatures. It was not seen after the 30th minute in sets 1 and 2 of the freshwater part of our experiment. In seawater sets, it was only seen in the control set. It was found that this bacterium did not reappear after 24 hours. It was thought that the UV system is quite effective in preventing it from being found again.

The effectiveness of the UV dose required for the removal of pathogenic organisms may be possible by providing many factors simultaneously in the culture medium. However, the wavelength energy of the UV light per unit surface area and the water quality is the basic input for a successful production. Within the framework of the present study, all factors (reducing the number of bacteria, duration of inactivation) showed that UV-Leds can be a good alternative to conventional UV mercury lamps for water disinfection. Although the bacterial loads fluctuated in the production cycle, the total bacterial loads were always below the control group. Both lamps were successful in reducing the number of bacteria at different times. However, considering that bacteria and viruses constantly modify to survive, conventional methods, standard protocols, and models with different designs may not always be expected to give full results in water disinfection. Currently, there are very limited studies on eliminating bacteria and viruses and water disinfection in the production environment. For this reason, it is thought that it would be beneficial to increase the number of similar trials targeting production conditions outside the laboratory environment to understand the effects.

Ethical Statement

Not applicable

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Author Contribution

Mustafa Uyğun, Muammer Kürşat Fırat: Conceptualization, data handling and analysis, visualization, writing–original draft, review done editing, supervision. **Onurkan Antepli:** data handling and analysis, visualization, writing–original draft, reviewing and editing. **Fevziye Nihan Bulat:** Microbiological analysis, data handling. **Müge Aliye Hekimoğlu:** analyzed the sequencing data**. Muhammet Kürşat Bağcı, Fatih Güleç, İbrahim Köse:** performed and analysis. **Cüneyt Suzer, Şahin Saka, Berna Kılınç:** Formal analysis, data handling. All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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