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Application of degradation technology of light-emitting diode and auto-monitoring system for harmful substances in farrowing areas of a specific pathogen-free pig farm

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Abstract

In pig farms, disinfectants are applied for the effective cleaning and disinfection regimen. Moreover, the ideal detergents should be left no residue after use which might harbour micro-organisms. Additionally, it should be non-toxic to pigs and must have minimal environmental impacts. Therefore, in order to avoid detergent residues and possible effects on pigs, staffs, and environment, the development of a novel technology without chemicals to kill micro-organisms, degrade atmospheric fine particulate matter and harmful gases in the pig farms is pioneering and future potential. In this study, application of degradation technology of light-emitting diode (LED) and auto-monitoring system for harmful substances in farrowing area of a specific pathogen-free pig farms. The LED light exhibit an antibacterial efficacy of up to 89.1%. They are capable of reducing ammonia concentrations within the environment by 45%, hydrogen sulfide levels by 68.8%, and curbing $PM_{2.5}$ concentrations by 80%. Collectively, these findings underscore the considerable potential of this degradation technology via visual light in effectively eliminating detrimental substances.

Keywords: Antimicrobial efficacy; Atmospheric fine particulate matter; Auto-monitoring system; Degradation; Harmful substances; Light-emitting diode; Specific pathogen-free pig farm

1 Introduction

Pig farms, like other livestock operations, can potentially release harmful substances into the environment due to the waste generated by the animals and the management practices employed. Some of the harmful substances associated with pig farms include as ammonia (NH_3) is a gas released from pig waste, primarily from urine. It can contribute to air pollution, leading to respiratory problems in both animals and humans, as well as contributing to the formation of particulate matter and smog. Methane (CH_4) is a potent greenhouse gas that is released from pig manure during decomposition in anaerobic conditions. It contributes to climate change and has a significantly higher global warming potential than carbon dioxide over a shorter time frame. Hydrogen sulfide (H_2S) is released from pig manure and can cause odor problems in the surrounding areas. It has a strong rotten egg smell and can have negative health effects on humans when inhaled in high concentrations. Particulate matters like dust and particulate matter can be released into

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the air from pig confinement areas, feed handling, and manure management. These particles can contain allergens, pathogens, and other pollutants, potentially causing respiratory issues in both humans and animals. In addition, pig waste can contain various pathogens such as bacteria, viruses, and parasites. If not properly managed, these pathogens can spread to the environment, water bodies, and even nearby communities, potentially causing disease outbreaks. Moreover, pig manure is rich in nitrogen and phosphorus, which are essential nutrients for crops. However, if manure is not properly managed and applied to land in excessive amounts, it can contribute to water pollution through runoff and leaching, leading to eutrophication in water bodies. Furthermore, the use of antibiotics and other pharmaceuticals in pig farming can lead to the presence of these substances in manure. If manure is not adequately treated, these compounds can enter the environment, potentially contributing to the development of antibiotic-resistant bacteria and affecting aquatic ecosystems. Pig diets can sometimes contain heavy metals like copper and zinc. These metals can accumulate in pig manure and, if not properly managed, may lead to soil contamination and potential environmental hazards. Volatile organic compounds (VOCs) are emitted from pig waste and can contribute to air pollution and odor issues. These compounds can also react with other pollutants in the atmosphere to form secondary pollutants. To mitigate the harmful effects of pig farming on the environment and public health, proper waste management practices, waste treatment systems, and regulatory measures are crucial. Many countries have regulations and guidelines in place to manage the environmental impact of livestock operations, including pig farms [1, 2].

Ultraviolet (UV) light has been utilized for surface decontamination; however, its application comes with inherent limitations and potential risks to both humans and animals [1, 2]. In pursuit of safer alternatives, the development of antimicrobial light-emitting diode (LED) visible light has gained attention. Notably, visible light at a wavelength of 405 nm has exhibited the capability to eliminate microorganisms while sparing exposed mammalian cells from harm [3, 4]. Beyond this wavelength, LEDs operating at 405 nm, 460 nm, 470 nm, and 520 nm have also displayed antibacterial properties against diverse foodborne pathogens [2, 5, 6, 7, 8, 9, 10, 11, 12]. The underlying mechanism driving the antimicrobial efficacy of LEDs typically involves the generation of reactive oxygen species (ROS), which effectively combat pathogens. This ROS-mediated process encompasses the production of superoxide anions ($O_2^{\bullet -}$) and hydroxyl radicals (•OH), as well as triplet oxygen and/or reactive singlet oxygen. Consequently, the antimicrobial action induced by LEDs triggers a series of cellular cytotoxic responses [11, 13, 14, 15, 16]. In recent times, it has been observed that the hot season yields a more oxidative atmospheric condition compared to the cold season. Notably, a pronounced positive correlation between $PM_{2.5}$ and O_3 has been prominent in samples collected during periods of elevated air temperatures. This interrelation is particularly conspicuous in situations characterized by high O_3 concentrations within a robust oxidative context. In such scenarios, the prevalence of larger secondary particles is encouraged, a phenomenon that could contribute to the reduction of atmospheric $PM_{2.5}$ levels. However, further investigation is required to establish a definitive link between LED-induced $PM_{2.5}$ degradation and factors like air temperature and O_3 levels [17, 18].

The conventional pig industry's gas emissions exert a considerable impact on both the environment and the climate. Within pig husbandry practices, notable gases produced include ammonia (NH_3), carbon dioxide, nitrous oxide, and methane. Notably, NH_3 emerges as a toxic gas with direct adverse consequences for pigs, personnel, and the surrounding environment. The principal origin of NH_3 lies in pig urine, prompting the exploration of methods to counter its effects. One such approach involves enhancing ventilation to mitigate NH_3 levels within pig farms. However, there is a pressing need for the development of additional efficacious tools or methods to address NH_3 elimination within the pig husbandry domain [19].

2 Material and methods

2.1 Experimental Animals and Conditions of SPF Pig Farms

Certifications in the SPF swine farms, Agricultural Technology Research Institute include AAALAC International certification, ISO 9001: 2015, and ATRI SPF certification. SPF piglets are obtained by the SPF pregnant sows via the natural production. All SPF animals in SPF pig farms are raised in the barrier which is free from major diseases. No animal experiment involved zoonoses is allowed in these facilities. Even though, personnel entering the animal barrier have to take shower and change into cleanroom to put on personal protective equipment, such as clothing, shoes, gloves, mask, and cap, or wear disposable suits, depending on the barrier level to ensure the health and well-being of animals. Personnel also have to preform health check and vaccination to minimize the risk of exposure to potential animal allergens and zoonotic diseases. The environments of SPF pig farms were maintained room temperature (22-24°C) and 70%-75% humidity with a photoperiod of 12-hr light/12-hr dark cycle. Normal laboratory diet and fresh water were supplied to SPF pigs continuously ad libitum. The study will begin after a week acclimation. The Institutional Animal Care and Use Committee (IACUC) of Agricultural Technology Research Institute inspected all animal experiments and this study comply with the guidelines of protocol IACUC 110095 approved by the IACUC ethics committee.

2.2 Development of Innovative Visible Light Emitting Diode (LED) Technology and Its Application for Mitigating Harmful Substances in Pig Farming

2.2.1 Anti-Microbial Efficacy after LED Lighting System Installation in a SPF Pig Farm

A comprehensive analysis of microbial deposition was conducted within a SPF pig farming area. Portable impact-style samplers were strategically positioned beneath pathway lights, at the center of pathways, and beneath pig enclosures to collect microbial samples. These samples, containing microorganisms, were transported back to the laboratory for cultivation, subsequently enabling statistical analysis of colony growth.

2.2.2 Efficacy of Harmful Gas and Airborne Particulate Degradation after LED Lighting System Installation in a SPF Pig Farm

Gas detectors and air quality monitors were strategically placed at the heart of SPF pig farming area. These instruments drew in air from the surroundings to analyze the concentrations of NH_3, H_2S, CH_4, and $PM_{2.5}$. The objective was to quantify the levels of harmful gases and airborne particulates present in the air.

2.3 Assessment of Antimicrobial Effectiveness in Laboratory

Utilizing portable impact-style samplers, microbial samples were collected from SPF pig farming areas. These collected samples, containing microorganisms, were then exposed to LED light for a duration of 8 hours in the laboratory. Subsequently, they were incubated in a culture chamber for 24 hours, followed by a statistical analysis of microbial colony growth.

2.4 Establishment of a Harmful Substance Monitoring System

Harmful gas sensors were strategically integrated into SPF pig farming area. These sensors possessed both reception and reporting capabilities, facilitating real-time monitoring of harmful gas conditions within the environment. In this study, the harmful gas sensors were interconnected through a wireless network. Whenever the concentration of harmful gases surpassed the predefined threshold, the sensors activated the LED lights via the wireless network. Conversely, the LEDs were deactivated as the gas concentrations subsided.

2.5 Statistical Analysis

The data were expressed as mean ± SD (standard deviation). All comparisons were made by one-way ANOVA and all significant differences are reported at $^{*}p < 0.05$.

3 Results

3.1 Application of LED for Antimicrobial Efficacy in the animal housing facility

Upon the installation of the innovative LED lighting system and harmful substance sensors in the animal housing facility (Figure 1), a series of tests were carried out to evaluate microbial deposition, antimicrobial effects, as well as the concentrations of harmful gases and airborne particulates. The results were showed that prior to the installation of LED lighting system, microbial counts were recorded respectively 425.00 ± 56.65 CFU at the beneath pathway lights, 493.67 ± 80.75 CFU at the center of pathways, and 387.78 ± 135.51 CFU beneath pig enclosures. After LED installation, microbial counts respectively reduced to 220.67 ± 39.68 CFU at the beneath pathway lights, 249.67 ± 18.56 CFU at the center of pathways, and 255.67 ± 40.62 CFU beneath pig enclosures (Figure 2).

Figure 1 Progression of installing and employing the state-of-the-art LED lighting system and harmful substance sensors within a specific pathogen-free pig farm. (A) Before Installation of LED lighting system in the animal housing facility. (B-E) After Installation of LED lighting system and integration of harmful substance sensors in the animal housing facility. (F) Testing conducted subsequent to harmful substance sensor installation in the animal housing facility

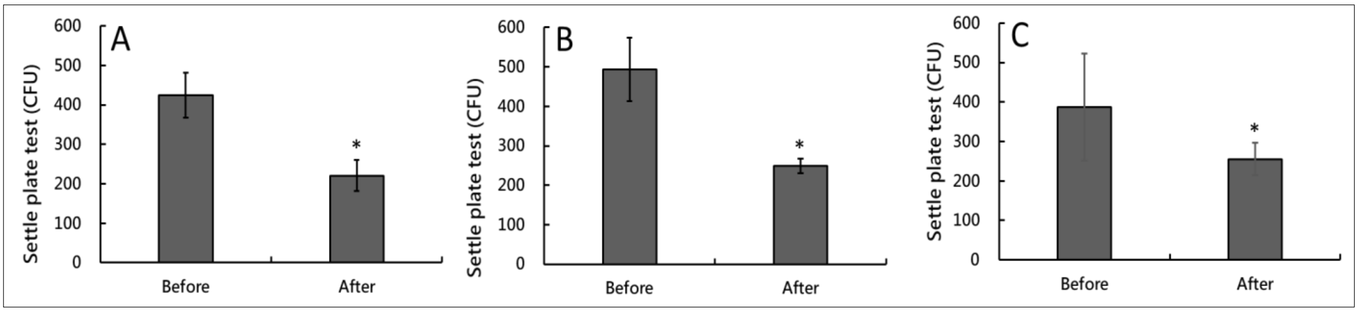

Figure 2 Assessment of microbial presence in the animal housing facility. Microbial counts were evaluated both prior to and subsequent to the implementation of LED lighting system in various farrowing areas of a specific pathogen-free pig farm. (A) Microbial Presence under pathway lights in the feeding area. (B) Microbial presence at the middle of pathways. (C) Microbial presence beneath pig enclosure lights. All data are expressed as mean ± SD. The significant differences are reported at $^{*}p < 0.05$

3.2 Application of LED for Harmful Gases and $PM_{2.5}$ Degradation

Prior to LED lighting system installation, the recorded values for NH_3, H_2S, and CH_4 were 0.83 ± 0.24 ppm, 0.72 ± 0.25 ppm, and 0.67 ± 0.33 ppm, respectively. Following LED installation, no values for NH_3, H_2S, and CH_4 were detected, falling below the instruments' detection limits (Figures 3A-C). In addition, before LED lighting system installation, the detected $PM_{2.5}$ concentration was 9.00 ± 1.25 μg/m^3. Following LED lighting system installation, the detected $PM_{2.5}$ concentration decreased to 4.33 ± 1.15 μg/m^3 (Figure 3D).

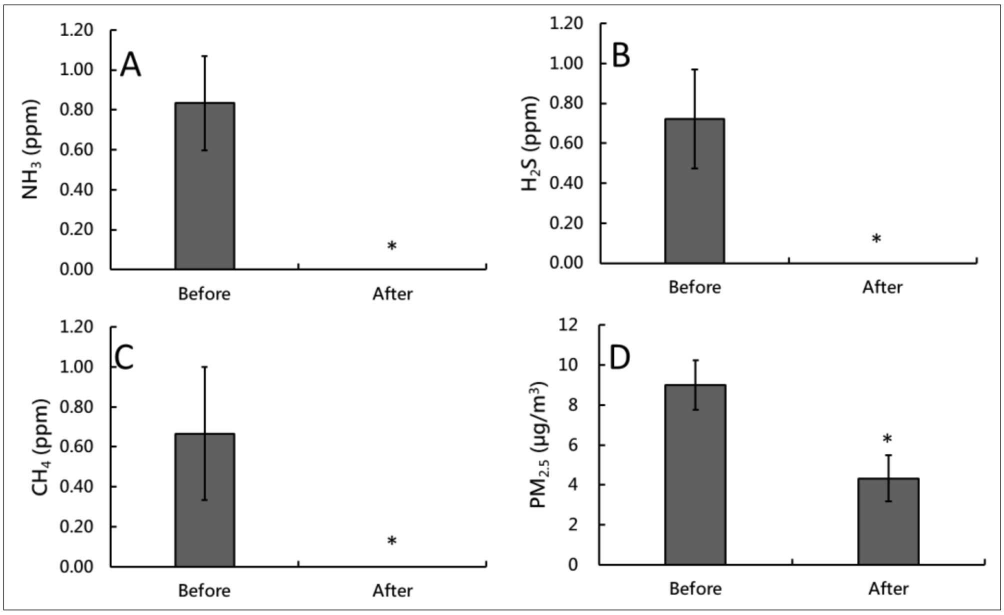

Figure 3 Evaluation of harmful gases and airborne particulates within a specific pathogen-free pig farm. The concentrations of harmful gases and levels of airborne particulate matter were assessed before and after the installation of LED lighting system. (A) Ammonia gas concentration; (B) Hydrogen sulfide gas concentration; (C) Methane gas concentration; (D) $PM_{2.5}$ concentration. All data are expressed as mean ± SD. The significant differences are reported at $^{*}p < 0.05$

3.3 Collection of Air Bacteria in the Animal Housing Facility then Applied LED Lighting for the Evaluation of Antimicrobial Efficacy in the Laboratory.

Microbial samples collected from the animal housing facility were exposed to an 8-hour LED light treatment in the laboratory, followed by a 24-hour incubation period. The results indicated that the control group had a colony count of 140.869 ± 26.72 CFU, while the LED-treated group exhibited a colony count of 64.86 ± 12.62 CFU (Figure 4).

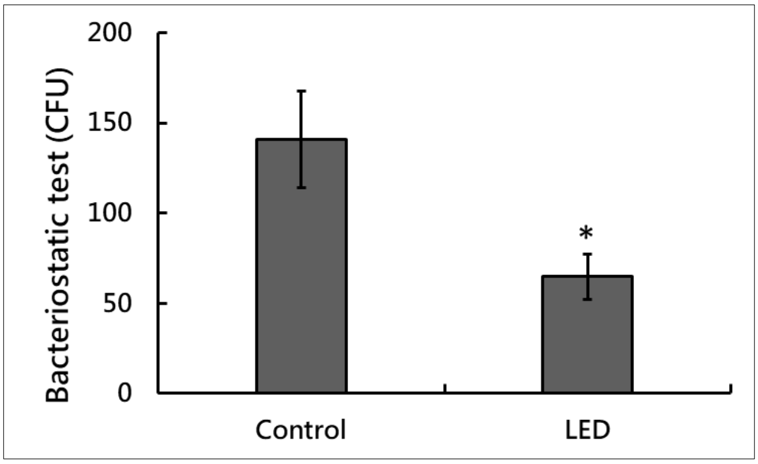

Figure 4 Evaluation of antimicrobial effectiveness in inhibition tests. The figure highlights the antimicrobial efficacy were presented before and after the installation of LED lighting system within a specific pathogen-free pig farm. All data are expressed as mean ± SD. The significant differences are reported at $^{*}p < 0.05$

4 Discussion

As the scope of livestock farming within our domestic industry undergoes intensification and expansion, there is a simultaneous increase in the presence of detrimental substances, including gases, fine suspended particles in the atmosphere, and pathogens within animal shelters. This escalation aligns with the scale of breeding operations.

Consequently, a pressing requirement emerges for the development of inventive, modular, and astutely managed techniques that accurately address the distinctive conditions inherent to pig farming environments in our nation.

Harmful substances in pig farms as gases present within animal shelters that adversely affect the well-being and productivity of livestock or the health and efficiency of workers are collectively referred to as detrimental gases. These detrimental gases typically encompass $PM_{2.5}$-PM_{10}, NH_3, H_2S, CO_2, CO, CH_4, and fecal odors. They primarily arise from the respiration of livestock, the breakdown of manure, and the decomposition of feed. Elevated levels of detrimental gases can exert negative impacts on livestock health and productivity, potentially leading to poisoning and even fatalities if left unaddressed. Common parameters for environmental monitoring in animal shelters encompass $PM_{2.5}$ concentrations, NH_3 and H_2S levels, and oxygen availability. Employing instruments to gauge whether harmful gas concentrations within breeding areas exceed permissible limits proves to be an effective strategy for monitoring the animal shelter environment.

In our previous publication [20], we highlighted the significant cytotoxic effects of our LED device operating at a 450 nm wavelength on HT-29 and CT-26 colon cancer cell lines *in vitro.* Furthermore, we observed substantial suppression of tumor growth in CT-26-bearing mice when the same LED device was employed *in vivo* [20]. Notably, our research also showcased the ability of the 450 nm LED to eradicate *Staphylococcus aureus* and *Pseudomonas aeruginosa*, as well as to degrade atmospheric fine particulate matter ($PM_{2.5}$) during laboratory experimentation. This multiple functionality, encompassing both $PM_{2.5}$ degradation and antimicrobial potency, was pioneeringly demonstrated by our LED devices [21].

Building on these achievements, we recently extended our investigations to a new application domain, pig farms, to assess the feasibility of implementing our LED devices in such environments. This experimental study encompassed both a SPF pig farm and a traditional pig farm. The outcomes of our study revealed notable antimicrobial effectiveness associated with our LED devices. Specifically, after subjecting the SPF pig farm to 8 hours of LED lighting, we observed antimicrobial efficacy ranging from approximately 34.87% to 91.63%. Interestingly, the efficacy of our LED device's antimicrobial action was contingent on the height of the light source. Additionally, the investigation encompassed the degradation of ammonia, with results indicating a degradation percentage ranging from about 8.98% to 9.58% in the SPF pig farm. Notably, the degradation efficacy of our LED device exhibited a correlation with the duration of light exposure. Transitioning to the traditional pig farm setting, our LED devices demonstrated significant efficacy in reducing $PM_{2.5}$ and PM_{10} particles, with degradation percentages ranging from approximately 8.89% to 86.67% and 12.5% to 85.0%, respectively [22]. Once again, the degradation efficiency showcased a dependence on the duration of light exposure. As for antimicrobial efficacy in the traditional pig farm subjected to 8 hours of LED lighting, we observed efficacy rates spanning from about 11.58% to 13.33% [22]. Interestingly, the antimicrobial efficiency of our LED device in this context did not exhibit dependence on the height of the light source. Based on our latest research findings and subsequent publications, we have successfully engineered a cutting-edge LED module that boasts a triad of functional capabilities. This innovative module not only excels in degrading $PM_{2.5}$/PM_{10} and harmful gases but also exhibits remarkable antimicrobial efficacy. This breakthrough development represents a novel and efficient tool for cleansing and disinfection, potentially finding wide-ranging application within pig farms. By implementing this advanced solution, we anticipate a prospective reduction in disease occurrences and subsequent economic losses within pig farming operations [22].

In this study, the statistical findings collectively demonstrate that the installation of the novel LED lighting system in the in farrowing areas of a SPF pig farm led to a reduction in microbial deposition and a decrease in $PM_{2.5}$ levels. Furthermore, with regards to harmful gas monitoring, it is evident that the presence of harmful gases was detectable prior to LED installation but became undetectable after installation. The outcomes of the antimicrobial efficacy test affirm that the novel LED lighting system effectively restrains bacterial growth. Taken these information together, we have successfully conducted microbial deposition tests, assessments of harmful gas degradation efficacy, antibacterial efficacy evaluations, and examinations of airborne particulate degradation efficacy within SPF pig farming areas. Moreover, accomplished the establishment of a robust harmful substance monitoring system. At present, the novel technology utilizing LED lighting systems, developed by the Agricultural Technology Research Institute, has displayed promising outcomes during initial tests aimed at mitigating harmful substances within SPF pig farming facilities.

5 Conclusion

Moving forward, our plans involve the integration of cutting-edge visible LED technology with auto-monitoring system for harmful substances to develop a real-time monitoring system. This system aims to establish an environment detection framework that purifies and monitors conditions within animal housing facilities. It will possess the capability to instantaneously monitor harmful elements, such as gases, airborne particulate matter, and pathogens present in the animal housing environment. By leveraging the collected data, the system will promptly activate the novel LED technology to degrade these harmful components in real time. The ultimate aim is to enhance animal welfare, ensure the health and safety of personnel, and mitigate potential economic losses in the industry. This will be achieved through the simultaneous purification and real-time monitoring of the animal housing environment.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare no conflict of interest.

References

[1] Maclean M, MacGregor SJ, Anderson JG, Woolsey G. Inactivation of bacterial pathogens following exposure to light from a 405-nanometer light-emitting diode array. Appl Environ Microbiol. 2009; 75: 1932-7.

[2] Kim MJ, Mikš-Krajnik M, Kumar A, Yuk HG. Inactivation by 405 ± 5 nm light emitting diode on Escherichia coli O157: H7, Salmonella Typhimurium, and Shigella sonnei under refrigerated condition might be due to the loss of membrane integrity. Food Control. 2016; 59: 99-107.

[3] Dai T, Gupta A, Huang YY, Yin R, Murray CK, Vrahas MS, Sherwood ME, Tegos GP, Hamblin MR. Blue light rescues mice from potentially fatal Pseudomonas aeruginosa burn infection: efficacy, safety, and mechanism of action. Antimicrob Agents Chemother. 2013; 57: 1238-45.

[4] McDonald RS, Gupta S, Maclean M, Ramakrishnan P, Anderson JG, MacGregor SJ, Meek RM, Grant MH. 405 nm Light exposure of osteoblasts and inactivation of bacterial isolates from arthroplasty patients: potential for new disinfection applications? Eur Cell Mater. 2013; 25: 204-14.

[5] Kim MJ, Bang WS, Yuk HG. 405 ± 5 nm light emitting diode illumination causes photodynamic inactivation of Salmonella spp. on fresh-cut papaya without deterioration. Food Microbiol. 2017; 62: 124-32.

[6] Guffey JS, Wilborn J. Effects of combined 405-nm and 880-nm light on Staphylococcus aureus and Pseudomonas aeruginosa in vitro. Photomed Laser Surg. 2006; 24: 680-3.

[7] Brovko LY, Meyer A, Tiwana AS, Chen W, Liu H, Filipe CD, Griffiths MW. Photodynamic treatment: a novel method for sanitization of food handling and food processing surfaces. J Food Prot. 2009; 72: 1020-1024.

[8] Luksienė Z, Kokstaite R, Katauskis P, Skakauskas V. Novel approach to effective and uniform inactivation of Gram-positive Listeria monocytogenes and Gram-negative Salmonella enterica by photosensitization. Food Technol Biotech. 2013; 51: 338-44.

[9] Ghate V, Ng KS, Zhou W, Yang H, Khoo GH, Yoon WB, Yuk HG. Antibacterial effect of light emitting diodes of visible wavelengths on selected foodborne pathogens at different illumination temperatures. Int J Food Microbiol. 2013; 166: 399-406.

[10] Kumar A, Ghate V, Kim MJ, Zhou W, Khoo GH, Yuk HG. Antibacterial efficacy of 405, 460 and 520 nm light emitting diodes on Lactobacillus plantarum, Staphylococcus aureus and Vibrio parahaemolyticus. J Appl Microbiol. 2016; 120: 49-56.

[11] Kumar A, Ghate V, Kim MJ, Zhou W, Khoo GH, Yuk HG. Kinetics of bacterial inactivation by 405 nm and 520 nm light emitting diodes and the role of endogenous coproporphyrin on bacterial susceptibility. J Photochem Photobiol B. 2015; 149: 37-44.

[12] De Lucca AJ, Carter-Wientjes C, Williams KA, Bhatnagar D. Blue light (470 nm) effectively inhibits bacterial and fungal growth. Lett Appl Microbiol. 2012; 55: 460-6.

[13] Gillespie JB, Maclean M, Given MJ, Wilson MP, Judd MD, Timoshkin IV, MacGregor SJ. Efficacy of pulsed 405-nm light-emitting diodes for antimicrobial photodynamic inactivation: effects of intensity, frequency, and duty cycle. Photomed Laser Surg. 2017; 35: 150-6.

[14] Luksiene Z, Brovko L. Antibacterial photosensitization-based treatment for food safety. Food Eng Rev. 2013; 5: 185-199.

[15] Ramakrishnan P, Maclean M, MacGregor SJ, Anderson JG, Grant MH. Cytotoxic responses to 405 nm light exposure in mammalian and bacterial cells: involvement of reactive oxygen species. Toxicol In Vitro. 2016; 23: 54-62.

[16] Luksiene Z. Photosensitization for food safety. Chemine Technologija. 2009; 4: 62-5.

[17] Jia M, Zhao T, Cheng X, Gong S, Zhang X, Tang L, Liu D, Wu X, Wang L, Chen Y. Inverse relations of PM2.5 and O3 in air compound pollution between cold and hot seasons over an urban area of East China. Atmosphere. 2007; 8: 59.

[18] Zhu J, Chen L, Liao H, Dang R. Correlations between PM2.5 and Ozone over China and associated underlying reasons. Atmosphere. 2019; 10: 352.

[19] Mihina S, Sauter M, Palkovičová Z, Karandušovská I , Brouček J. Concentration of harmful gases in poultry and pig houses. Anim Sci Pap Rep. 2012; 30: 395-406.

[20] Hung YW, Tsung CS, Lin YH, Chiu CF, Chiu CC, Chiu HW, Tsai WH, Hung SW. Study of phototoxicity of LED light for colon cancer. Biomed J Sci Tech Res. 2019; 13: 10167-9.

[21] Chi TY, Li CL, Tsung CS, Chen CC, Hung YC, Lin CY, Hung YW, Chiu CF, Chiu CC, Chiu HW, Lin YH, Tsai WH, Lin JS, Hung SW. Research and development of dual functional features of light-emitting diode: degradation of atmospheric fine particulate matter and antimicrobial efficacy. Biomed J Sci Tech Res. 2019; 20: 15273-7.

[22] Lin YH, Chi TY, Chang YX, Lin CY, Wang YP, Chen HY, Huang PM, Chen GH, Hung YC, Wu TH, Lu YJ, Chiu CC, Chiu CF, Chiu HW, Tsai WH, Chen CC, Hung SW. Application of the novel environment-cleaned light-emitting diode devices in various test fields. Int. J. Adv. Sci. Technol. 2022; 1: 20-32