A Critical Review on Antimicrobial Photodynamic Inactivation Using Light Emitting Diode (LED)

T. Purushothaman
Head, Department of Biotechnology and Research
Shri Nehru Maha Vidyalaya College of Arts and Science, Coimbatore Tamil Nadu, India
https://orcid.org/0000-0002-5030-4606

K. Irfana Mol
Department of Biotechnology and Research
Shri Nehru Maha Vidyalaya College of Arts and Science, Coimbatore, Tamil Nadu, India
https://orcid.org/0000-0003-1263-8071

OPEN ACCESS

Manuscript ID:
ASH-2021-08033476

Volume: 8

Issue: 3

Month: January

Year: 2021

P-ISSN: 2321-788X

E-ISSN: 2582-0397

Received: 14.10.2020

Accepted: 02.12.2020

Published: 01.01.2021

Citation:
Purushothaman, T., and K. Irfana Mol. "A Critical Review on Antimicrobial Photodynamic Inactivation Using Light Emitting Diode (LED)." *Shanlax International Journal of Arts, Science and Humanities*, vol. 8, no. 3, 2021, pp. 124-130.

DOI:
https://doi.org/10.34293/sijash.v8i3.3476

Abstract
The light-emitting diode (LED) is an advanced technology with a wide range of applications in our day-to-day life. It has numerous advantages over conventional light, such as controlling the spectrum of light, the specificity of the wavelength, cool emitting surface, and cost-effectiveness. The novel technologies and developments have proved the efficacy of LEDs in eliminating microbes rather than being an effective lighting source. The LED employs Photodynamic Inactivation to eliminate micro-organisms with the help of various photo-sensitizers. Photodynamic inactivation is a non-chemical based technique that helps fight against the microbes without developing the resistant microbial strains. The illumination of LED at a specific narrow wavelength exhibits antimicrobial activity against a wide range of microbes, including resistant strains. Getting rid of harmful micro-organisms is one of the effective ways to reduce health risks and promote quality of life. Hence, the LEDs with specific narrow wavelengths can be employed to sterilize the medical equipment, healthcare environment, and food preservation without using chemicals. The Photodynamic Inactivation using LED as a light source will be a promising source for eradicating harmful micro-organisms, including nosocomial and foodborne pathogens.
Keywords: LED, Light, Photodynamic inactivation, Antimicrobial activity, Photosensitizers, Micro-organisms

Introduction

The lighting systems also play a vital role in the everyday life of people, and it can also improve safety, creates suitable spaces rather than illumination. The sun as the natural lighting source produces light in 400-700 nm, which possess sterilizing properties. Many biological studies also have reported the significance of lighting systems in influencing the psychological and behavioral activities of humans. Besides that, innovations and technologies have also proved the potential of light to eliminate micro-organisms. It is one of the advanced technologies which uses the specific wavelength of the narrow spectrum of visible to exhibit the disinfecting property. The light exhibits antimicrobial activity according to the wavelength which it is emitted. The visible light of the narrow wavelength can be used to eliminate the wide variety of microbes, including bacteria, fungi, viruses, yeast, etc. (Gwynne and Maurice, 2018). The light-emitting diode (LED) is considered to be safer and effective disinfect than ultra-violet rays. Many studies have demonstrated the photodynamic inactivation of LED blue light to kill the harmful microbes. Photodynamic inactivation is a technique that employs photosensitizers that absorb the visible

light for its activation to form reactive oxygen species as well as singlet oxygen. The Reactive Oxygen Species (ROS) undergoes oxidation of biomolecules and lysis of cells. It has the potential to treat diseases and infections without causing any drug resistance as like as antibiotic treatment (Hamblin, 2016). Antibiotic resistance is also a major problem for eradicating microbes. It is due to the rapid evolution of microbes, which promotes the adaptation to constituents present in the media (Manaia, 2017).

Besides that, the airborne micro-organisms such as bacteria, viruses, and fungi are commonly known as bio-aerosols, which have a prominent role in the environment and human health. (Prussin et al., 2015). The adverse health effects and risks are caused by indoor microbes exceeding their maximum limits, especially in the healthcare centers. There is a wide range of studies have already described the role of micro-organisms in causing diseases (Setlhare et al., 2014) and factors promoting microbial growth for inducing food spoilage (Preetha, and Narayanan, 2020). So, Photodynamic inactivation plays a pivotal role in eliminating the indoor and outdoor micro-organisms responsible for causing various diseases. So, this approach can be applied to sterilize medical equipment, healthcare environments, and also for food preservation rather than using harmful chemicals. In this review, we have summarized the evidence for the Antimicrobial Photodynamic Inactivation carried out with LED as the lighting source to eliminate the microbes such as bacteria, fungi, and virus.

Light Emitting Diode

In the olden days, people used burning wood, candles, oil lamps, kerosene lamps, and gas lamps as the lighting source, and those innovations eventually lead to the development of CFL and fluorescent lamps (Weisbuch, 2018). There have been increasing alternations and innovations in lighting technologies to create an excellent lighting system. Thus, the requirement of high grade of light and energy effective in the household and many sectors paves the way for the development of LED technology (Perdahci et al., 2018). During the last years, the furtherance of LED technology led to playing a crucial role in the day-to-day life of the human (Lin et al., 2019). This solid-state device is highly efficient, reliable, and durable over the other forms of the lighting system, which results in the rapid growth of the LED industry (Soh et al., 2017). Producing light by LED varies from other conventional lighting systems because it is a semiconductor diode (Soni, and Devendra, 2008). The LED is the light-emitting diode that uses the terminal devices such as positive (anode) and negative (cathode), and the working is based on the PN Junction.

Doping is the process of adding the impurities such as Si, GaN, and GaAs to get the P-type as well as N-type semiconductor (Gayral, 2017). The N-type semiconductor provides free electrons, whereas the P-type semiconductor lacks free electrons, thereby creating the holes (Bourget, 2008). The emission of light happens when the electrons in the valence band move to the conduction band, thereby creating an empty state in the valence band (Gayral, 2017). The electrons started to recombine into the holes as soon as the suitable voltage is applied. The electrons fall into a lower energy state after the meeting of electrons with holes. Then, it releases energy in the form of photons, and the light is produced as the result of the emission of photons (Ahemen et al., 2014). The materials used in the semiconductor and also the energy gap of the semiconductor determines the color of the light (Yeh, and Jen-Ping Chung, 2009). The LEDs are well known for their unique properties such as temporal settings of produced light, radiant intensity, and the adjustment of spectral characteristics (Branas et al., 2013). Now, the LEDs are used in many lighting systems because it has many advantages over the conventional lighting system. It is mainly a very cost-effective approach, and it has a long life expectancy. LEDs are well known for their low emission of radiant heat (D'Souza et al., 2015. The expeditious development and extensive potential in energy efficiency and lumen output prove that LEDs can be a remarkable light source (Pattison et al., 2016) with a board range of applications.

Photodynamic Inactivation and Photosensitizers

The photodynamic inactivation is an alternative approach to kill harmful microbes such as bacteria, fungi, etc. It is also called Photodynamic Antimicrobial Therapy (PACT) or Antimicrobial

Photodynamic Inactivation (PDI) (Awad et al., 2016). Photodynamic inactivation employs photosensitizers, which absorb the visible light to activate the formation of reactive oxygen species and singlet oxygen. Harmless visible light combined with non-toxic dyes called photosensitizers is used to kill the micro-organisms (Joli et al., 2011).

Light, along with oxygen, and the non-toxic photosensitized are the essential requirements for this approach. The photon of the specific wavelength gets absorbed by the photosensitizer, and thus it gets activated from the excited state. The electrons present in the ground state level of photosensitizer promote higher energy to form the triplet state. The transformations of excited states proceed in two photochemical pathways (Ghorbani et al., 2018).

The type-1 mechanism involves the formation of Reactive Oxygen Species (ROS) by transferring the electron from the excited state. The type-2 mechanism involves the production of a single oxygen radical and then promotes the destruction of cell walls and DNA via oxidative stress (Denis et al., 2011). The reactive oxygen species causes harmful effects to the cell, so this phenomenon is employed in antibacterial treatment. The ROS can be created by visible light via absorbing porphyrins, cytochromes, which are endogenous cellular photosensitizers (Lavi et al., 2004). The endogenous photosensitizers are present in bacteria also respond to the illumination of high-intensity light, which in turn produces ROS at the highest level, and it leads to bacteria. For instance, Propionibacterium acnes is a bacteria, destroyed easily by visible light due to the high amount of endogenous photosensitizers (Lipovsky et al., 2009). The exposure of photosensitizers to visible light undergoes the photochemical process to produce ROS, which will ultimately damage the microbial cells. The oxidative stress is induced by hydrogen peroxide, hydroxyl radicals, and single oxygen. The fungal structures include hyphae and conidia and can be eliminated by using photosensitizers (Smijs et al., 2009). The efficacy of photosensitizers depends upon the physicochemical properties of the microbial cell wall (Usacheva et al., 2001). This method helps to inactivate the micro-organisms without disturbing the physiological flora, and it also functions very rapidly in a short period (Ryskova et al., 2010). The antimicrobial photodynamic inactivation also plays a vital role in inactivating the various virulence factors, and it also can reduce the activity of enzymes such as lipases, proteases, and as well as secreted toxins (Fila et al., 2017). Moreover, antimicrobial photodynamic inactivation doesn't exhibit any phototoxic, cytotoxic effect, and mutagenic effect towards the eukaryotic cells (Grinholc et al., 2015).

Anti-Bacterial Effects

The visible light of 400-500 nm wavelength has also been reported for the excellent bactericidal effect against various pathogens (Feuerstein et al., 2004). The evaluation of three different wavelengths, such as 425, 525, and 625 nm corresponding to blue, green, and red LED irradiation against the Porphyromonasgingivalis, Staphylococcus aureus, and E.coli. The irradiation of light at the wavelength of 425nm and 525nm for 0-24hrs exhibited the reduced viability of Porphyromonasgingivalis and E.coli than staphylococcus aureus. The result also stated no bactericidal effect at a wavelength of 625nm (Kim et al., 2013). The irradiation of LED at the wavelength of 450, 470, and 620 nm against the planktonic Legionella rubrilucens showed 5 log reduction at 450nm by the dose of 300 J cm^2 in 470nm; the blue light of 500 J cm^2 exhibited comparable reduction. But there was no inactivation observed by irradiation of red light even at 500 J cm^2 (Schmidt et al., 2019). The illumination of the LED array at 405nm for the time interval of 5, 10, and 20 minutes showed inactivation of the monolayer biofilm of E.coli effectively as well as rapidly. The light exposure for 10 minutes showed a stepwise reduction of 2.52log10 in E.coli biofilm (McKenzie et al., 2013).

The TSA plated 18 strains of Salmonella enterica were subjected to the illumination of the LED at a wavelength of 405 ± five at a temperature of 4°C. The most susceptible to LED illumination was showed by S.entericaserovarenteritidis (ATCC 13076) whereas, S.entericaserovarsaintpaul ATCC 9712 was the most resistant. These studies also reported that the antimicrobial activity of the LED at the wavelength of 405 ± 5 was due to the loss of membrane function and the oxidation of DNA (Kim et al., 2017). The foodborne pathogens such

as Lactobacillus Plantarum, Staphylococcus aureus, and Vibrio para hemolytic were subjected to the illumination of the LED at 405,460 and 520 nm. The results showed the inactivation ($P<0.05$) in the Vibrio para hemolytic at 405 and 460nm. But, the illumination of the LED exhibited less susceptibility for Lactobacillus Plantarum and Staphylococcus aureus. So, the excellent anti-microbial activity of LED illumination was observed at 405nm wavelength (Kumar et al., 2016). The food borne pathogens such as E.coli 0157:H7, Salmonella typhimurium, and Listeria monocytogeneswere suspended in trypticase soy broth. It was illuminated at 461, and 521nm LED to evaluate the antibacterial effects at different pH values (4.5,6.0,7.3,8.0, and 9.5) at 15°C. The illumination of the LED at 461nm was more prominent in inactivating the pathogens than 521nm LED. The result also suggested the 461nm LED can be used to preserve food in acidic and alkaline conditions (Ghate et al., 2015). The study conducted by Endarko et al., (2012) demonstrated that 405 ± 5nm light exhibited effective inactivation of food borne pathogen Listeria monocytogenes and also showed similar kinetics in other Listeria species. The high susceptibility of inactivation via irradiation of the 405nm LED was showed by E.coli, Salmonella enteritidis, and Shigellasonnei.

The study conducted by MacLean et al., (2009) to determine the inactivation of nosocomial pathogens comprises gram-positive and negative bacteria via the irradiation of 405nm LED array. The result reported the inactivation of both gram-positive and negative bacteria along within Methicillin-Resistant Staphylococcus aureus by the illumination of a narrow spectrum of 405 nm visible light from the LED source without pre-treatment of any chemicals. The highest inactivation level was exhibited by Staphylococcus, Streptococcus, and Clostridium strains whereas, Enterococcus faecalis was appeared to inactivate after the longer exposure time. Hence, a longer exposure time was required by gram-negative bacteria to exhibit significant inactivation than the gram-positive bacteria.

The antimicrobial blue light illuminated at the wavelength of 400 nm from the LED source was effective against the 34 different nosocomial wound pathogens, including Pseudomonas aeruginosa, Escherichia coli, Staphylococcus aureus, Enterococcus faecium, Klebsiella pneumonia, Acinetobacterbaumannii, Enterobacter cloacae, Stenotrophomonasmaltophilia, and Elizabethkingiameningoseptica. The decrease in colony-stimulating unit by a>5-log10 in viability occurred in all bacterial strains after 15 to 30 min of exposure of LED light at 54 J/cm^2 -108 J/cm^2 (Halstead et al., 2016).

Anti-Fungal Effects

The photodynamic inactivation studies carried out with 12 isolates of Trichophytonrubrum, at 630 nm LED light along with toluidine blue as a photosensitizer by Baltazar et al., (2013). The illumination of 630 nm LED light at 48 J/cm^2 and ten mg/L of toluidine blue have inhibited more than 98% of fungal growth (Baltazar et al., 2013). A chlorin derivative (TONS 504) and the irradiation of 660 nm LED light demonstrated the antifungal activity against the Fusariumsolani and Aspergillusfumigatus. The optimal conditions for complete photodynamic inactivation for Fusariumsolani were one mg/L of TONS 504 and 30 J/cm^2 of LED illumination. But, the Aspergillusfumigatus showed a partial inhibition with 10mg/L of TONS 504 and 20 or 30 J/cm^2 of LED irradiation (Sueoka et al., 2019). The fungicidal effect of the 405 nm LED array against Botrytis cinerea shows the significant spore reduction in detached tomato leaves. The remarkable inhibition of mycelium growth was exhibited after irradiation of light at a wavelength at 405 nm and 415 nm (Imada et al., 2014).

Anti-Viral Effects

The photodynamic antimicrobial chemotherapy against the ACV (acyclovir) -sensitive and -resistant Herpes Simplex Virus type 1 (HSV-1) revealed that TONS 504 at the concentration of 10 mg/L and LED light illumination of specific wavelength 660 nm at 10 to 30 J/cm^2 have completely eradicated both viruses (Latief et al., 2015). The photodynamic inactivation carried out with curcumin as a photosensitizer and LED light reduced the titers of norovirus surrogates such as feline calicivirus and murine norovirus (Randazzo et al., 2016).

Conclusion

Hence, the above evidence has shed light on the Photodynamic inactivation of LED as a lighting source for inhibiting micro-organisms such as bacteria, fungi, and viruses. There are a wide number of antibiotics as well as chemical substances are used to eradicate harmful micro-organisms. The increased usage of antibiotics and chemical agents led to the development of resistance and resulted in numerous detrimental effects in humans. The illumination of LED light at a specific narrow wavelength employs Photodynamic Inactivation to exhibit antimicrobial activity to eradicate the disease-causing pathogens. The LEDs can also be employed as an effective source for sterilization to eliminate microbes even present in the medical equipment, food substances, healthcare environments, etc., rather than using chemicals. So, the Antimicrobial Photodynamic inactivation is a promising alternative approach to cure various life-threatening diseases via eliminating the harmful pathogens without causing the development.

References

Ahemen, I., et al. "A Review of Solid State White Light Emitting Diode and Its Potentials for Replacing Conventional Lighting Technologies in Developing Countries." *Applied Physics Research,* vol. 6, no. 2, 2014, pp. 95-108.

Awad, Mariam M., et al. "Important Cellular Targets for Antimicrobial Photodynamic Therapy." *Applied Microbiology and Cell Physiology*, vol. 100, 2016.

Baltazar, Ludmila de Matos, et al. "Photodynamic Inhibition of Trichophytonrubrum: in Vitro Activity and the Role of Oxidative and Nitrosative Bursts in Fungal Death." *Journal of Antimicrobial Chemotherapy,* Vol. 68, no. 2, 2013, pp. 354-361.

Bourget, C. Michael. "An Introduction to Light-emitting Diodes." *HortScience*, vol. 43, no. 7, 2008, pp. 1944-1946.

Branas, Christian, et al. "Solid-state Lighting: A System Review." *IEEE Industrial Electronics Magazine,* vol. 7, no. 4, 2013, pp. 6-14.

D'Souza, Craig, et al. "Application of Light-Emitting Diodes in Food Production, Postharvest Preservation, and Microbiological Food Safety." *Comprehensive Reviews in Food Science and Food Safety,* vol. 14, no. 6, 2015, pp. 719-740.

Endarko, Endarko, et al. "High-Intensity 405 nm Light Inactivation of *Listeria monocytogenes*." *Photochemistry and photobiology,* vol. 88, no. 5, 2012, pp. 1280-1286.

Feuerstein, Osnat, et al. "Phototoxic Effect of Visible Light on Porphyromonasgingivalis and Fusobacteriumnucleatum: An *In Vitro* Study." *Photochemistry and Photobiology,* vol. 80, no. 3, 2004, pp. 412-415.

Fila, Grzegorz, et al. "Blue Light Treatment of *Pseudomonas aeruginosa*: Strong Bactericidal Activity, Synergism with Antibiotics and Inactivation of Virulence Factors." *Virulence,* vol. 8, no. 6, 2017, pp. 938-958.

Gayral, Bruno. "LEDs for Lighting: Basic Physics and Prospects for Energy Savings." *Comptes Rendus Physique*, vol. 18, no. 7-8, 2017, pp. 453-461.

Ghate, Vinayak, et al. "Enhancing the Antibacterial Effect of 461 and 521 nm Light Emitting Diodes on Selected Foodborne Pathogens in Trypticase Soy Broth by Acidic and Alkaline pH Conditions." *Food Microbiology,* vol. 48, 2015, pp. 49-57.

Ghorbani, Jaber, et al. "Photosensitizers in Antibacterial Photodynamic Therapy: An Overview." *Laser therapy,* vol. 27, no. 4, 2018, pp. 293-302.

Grinholc, Mariusz, et al. "Fine-tuning rec*A* Expression in *Staphylococcus aureus* for Antimicrobial Photoinactivation: Importance of Photo-induced DNA Damage in the Photoinactivation Mechanism." *Applied Microbiology and Biotechnology*, vol. 99, 2015, pp. 9161-9176.

Gwynne, Peter J., and Maurice P. Gallagher. "Light as a Broad-Spectrum Antimicrobial." *Frontiers in Microbiology*, 2018.

Halstead, Fenella D., et al. "Antibacterial Activity of Blue Light against Nosocomial Wound Pathogens Growing Planktonically and as Mature Biofilms." *Applied and Environmental Microbiology*, vol. 82, 2016, pp. 4006-4016.

Hamblin, Michael R. "Antimicrobial Photodynamic Inactivation: A Bright New Technique to Kill Resistant Microbes." *Current opinion in microbiology*, vol. 33, 2016, pp. 67-73.

Imada, K., et al. "Antifungal Effect of 405-nm Light on B Otrytiscinerea." *Letters in Applied Microbiology*, vol. 59, 2014, pp. 670-676.

Jori, Giulio, et al. "Antimicrobial Photodynamic Therapy: Basic Principles." *Photodynamic Inactivation of Microbial Pathogens: Medical and Environmental Applications*, 2011, pp. 1-18.

Kim, Min-Jeong, and Hyun-Gyun Yuk. "Antibacterial Mechanism of 405-Nanometer Light-Emitting Diode against *Salmonella* at Refrigeration Temperature." *Applied and Environmental Microbiology*, vol. 83, no. 5, 2017.

Kim, SangWoo, et al. "In Vitro Bactericidal Effects of 625, 525, and 425 nm Wavelength (Red, Green, and Blue) Light-Emitting Diode Irradiation." *Photomedicine and Laser Surgery*, vol. 31, no. 11, 2013, pp. 554-562.

Kumar, A., et al. "Antibacterial Efficacy of 405, 460 and 520 nm Light Emitting Diodes on *Lactobacillus plantarum*, *Staphylococcus aureus* and *Vibrio parahaemolyticus*." *Journal of Applied Microbiology*, vol. 120, no. 1, 2016, pp. 49-56.

Latief, Miftahul Akhyar, et al. "Inactivation of Acyclovir-Sensitive and-Resistant Strains of Herpes Simplex Virus Type 1 in Vitro by Photodynamic Antimicrobial Chemotherapy." *Molecular Vision,* vol. 21, 2015, pp. 532-537.

Lavi, Ronit, et al. "ESR Detection of $^1O_2$ Reveals Enhanced Redox Activity in Illuminated Cell Cultures." *Free Radical Research,* vol. 38, no. 9, 2004, pp. 893-902.

Lin, Jiaqi, et al. "Several Biological Benefits of the Low Color Temperature Light-Emitting Diodes based Normal Indoor Lighting Source." *Scientific Reports*, vol. 9, 2019.

Lipovsky, Anat, et al. "Sensitivity of *Staphylococcus aureus* Strains to Broadband Visible Light." *Photochemistry and Photobiology*, vol. 85, no. 1, 2009, pp. 255-260.

Maclean, Michelle, et al. "Inactivation of Bacterial Pathogens Following Exposure to Light from a 405-Nanometer Light-Emitting Diode Array." *Applied and Environmental Microbiology,* vol. 75, 2009, pp. 1932-1937.

Manaia, Célia M. "Assessing the Risk of Antibiotic Resistance Transmission from the Environment to Humans: Non-Direct Proportionality between Abundance and Risk." *Trends in Microbiology*, vol. 25, no. 3, 2017, pp. 173-181.

McKenzie, Karen, et al. "Photoinactivation of Bacteria Attached to Glass and Acrylic Surfaces by 405 nm Light: Potential Application for Biofilm Decontamination." *Photochemistry and photobiology*, vol. 89, no. 4, 2013, pp. 927-935.

Pattison, P. M., et al. "Light-emitting Diode Technology Status and Directions: Opportunities for Horticultural Lighting." *International Symposium on Light in Horticulture,* 2016, pp. 413-426.

Perdahci, C., et al. "A Comparative Study of Fluorescent and LED Lighting in Industrial Facilities." *7th International Conference on Clean and Green Energy (ICCGE 2018)*, 2018.

Preetha, S.S., and Rita Narayanan. "Factors Influencing the Development of Microbes in Food." *Shanlax International Journal of Arts, Science and Humanities*, vol. 7, no. 3, 2020, pp. 57-77.

Prussin, Aaron J., et al. "Total Concentrations of Virus and Bacteria in indoor and outdoor Air." *Environmental Science & Technology Letters*, vol. 2, no. 4, 2015, pp. 84-88.

Randazzo, W., et al. "Curcumin-Mediated Photodynamic Inactivation of Norovirus Surrogates." *Food and Environmental Virology*, vol. 8, 2016, pp. 244-250.

Ryskova, Lenka, et al. "Photodynamic Antimicrobial Therapy." *Open Life Sciences,* vol. 5, no. 4, 2010, pp. 400-406.

Schmid, Julian, et al. "Antimicrobial Effect of Visible Light-Photoinactivation of *Legionella rubrilucens* by Irradiation at 450, 470, and 620 nm." *Antibiotics,* vol. 8, no. 4, 2019.

Setlhare, Gaofetoge, et al. "Identification of Airborne Microbiota in Selected Areas in a Health-Care Setting in South Africa." *BMC Microbiology,* vol. 14, 2014.

Smijs, Threes G.M., et al. "Preclinical Studies with 5, 10, 15-Tris (4-Methylpyridinium)-20-phenyl-[21*H*, 23*H*]-Porphine Trichloride for the Photodynamic Treatment of Superficial Mycoses Caused by *Trichophyton rubrum*." *Photochemistry and photobiology*, vol. 85, no. 3, 2009, pp. 733-739.

Soh, Mei Yu, et al. "Review of High Efficiency Integrated LED Lighting." *12th International Conference on Power Electronics and Drive Systems (PEDS)*, 2017.

Soni, Narendra B., and P. Devendra. "The Transition to Led Illumination: A Case Study on Energy Conservation." *Journal of Theoretical & Applied Information Technology,* vol. 4, no. 11, 2008, pp. 1083-1087.

Sueoka, Kentaro, et al. "Antifungal Efficacy of Photodynamic Therapy with TONS 504 for Pathogenic Filamentous Fungi." *Lasers in Medical Science*, vol. 34, 2019, pp. 743-747.

Usacheva, Marina N., et al. "Comparison of the Methylene Blue and Toluidine Blue Photobactericidal Efficacy against Gram-Positive and Gram-Negative Microorganisms." *Lasers in Surgery and Medicine*, vol. 29, no. 2, 2001, pp. 165-173.

Weisbuch, Claude. "Historical Perspective on the Physics of Artificial Lighting." *Comptes Rendus Physique*, vol. 19, no. 3, 2018, pp. 89-112.

Yeh, Naichia, and Jen-Ping Chung. "High-brightness LEDs - Energy Efficient Lighting Sources and their Potential in Indoor Plant Cultivation." *Renewable and Sustainable Energy Reviews,* vol. 13, no. 8, 2009, pp. 2175-2180.

Author Details

T. Purushothaman, *Head, Department of Biotechnology and Research, Shri Nehru Maha Vidyalaya College of Arts and Science, Coimbatore Tamil Nadu, India,* ***Email ID****: purushonlines@gmail.com.*

K. Irfana Mol, *Department of Biotechnology and Research, Shri Nehru Maha Vidyalaya College of Arts and Science, Coimbatore, Tamil Nadu, India,* ***Email ID****: irfana.kn27@gmail.com.*