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Synergestic effect of Tio_2 with Nanoparticles exihibiting Photocatalytic and Antimicrobial activity

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Abstract

The elements present on the earth surface are hard, nonporous in daily life are now receiving greater attention for their potential function in mitigating the transmission of various nosocomial maladies. In our article work, we have revealed the photo killing consequence when 1% silver-doped Titanium dioxide TiO_2 employed. However, synthesis of the nanoparticles by liquid impregnation approach later were studied using different instruments such as X-ray diffraction (XRD), Transmission Electron Microscopy (TEM), Energy Dispersive Spectroscopy (EDS), and Scanning Electron Microscopy (SEM). Nonetheless, synergistic actions of Ag-TiO_2 nanoparticle coatings when applied on glass along with venetian blind surfaces were found to be effectual in producing loss of viability of two bacteria Pseudomonas aeruginosa which is a gram negative bacteria and gram positive bacteria was Bacillus subtilis on illumination under normal light around the visible spectrum range. The bacteria lost its viability through photocatalytic mechanism. Thus, our article has provided broad insights on synergistic action of nanoparticles when applied on surfaces could be helpful in mitigating the bacteria and hence employment of such nanoparticles in preparation of medical, pharmaceutical and other facilities could act as potential in exhibiting as bactericidal agent.

Several literature articles on nanoparticles has clearly depicted that the significance of Nano sized material in combating bacteria through different process[6,11,31,35,37]. Mainly, the nanoparticles has the ability to obliterate the cell wall plus peptidoglycan layer. The other importance of nanoparticles is emancipation of toxic ions which further damages the protons efflux bombs and alters the charge inside and outside of the membrane. Finally,

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the formation of reactive oxygen species (ROS) which degrades cell wall DNA, RNA, plus proteins. The synergistic combination of nanoparticles with silver-TiO_2 robustly results in formation of ROS, which is the critical antibacterial agent to fight against the bacterium.

The most magnanimous metal nanoparticles, such as silver nanoparticles (AgNPs), can bout effectually against both Gram-negative and Gram-positive bacteria [16,25,43,47]. Amidst, many elements the titanium dioxide (TiO_2) has been extensively considered in our article because of its stable chemical nature along with petite toxicity and greater photo-catalytic activity[5]. On amalgamation of TiO_2 with other generous metals ions having bactericidal activity along with enhanced photo-electrochemical responses to mitigate rejoining of the photo generated charge carriers[10,48]. Moreover, our article has depicted the significance of Ag+TiO_2 which efficiently eradicates various pathogenic microorganisms from surfaces of water and air[20,33,53,55].

Nevertheless, the combination of Ag with other noble metal ions enhances the formation of semiconducting oxides which has become the major assuring method to damage the cell wall of bacteria by destruction of the peptidoglycan layer[8,13,27,51,52]. The hole made by the Ag@TiO_2 hybridization is at present the chief upsurging topic for all scientist for preventing the growth of bacteria and several articles were also released online with regard to nanoparticles significance[46]. Thus, we have provided a broad window about the role of silver ions in connexion with TiO_2 which significantly enhanced their antibacterial activity, demonstrated against the gram positive Staphylococcus aureus and commonly employed *Escherichia coli* which is gram negative bacteria.

Structure of Silver-TiO_2 nanoparticles :

The silver is in colloidal form and when nanoparticle is mixed with its component is termed Nanosilver which has been extensively used for more than 150 years and has revealed to possess biocidal activity[30]. Early from 1954, the ancient Egypt and Rome has shown distinctive evidence of usage of nanoparticles which can result in various organic and inorganic complexes. Although, the most stable oxidation states are +0 and +1, sometimes can exist in others such as +2, +3 also. The chief precursor in the formation of silver nanoparticles is silver nitrate. There exists different shapes of Nanosilver starting formspherical shapes, rods, wires and in triangular forms. The nanoparticles are also coated with citrate, polymer, peptide and sugars. The size of the nanoparticles also varies from few nanometres up to 100 nm are depicted in figure-1.

Mechanism of Antibacterial action of $AgTiO_2$ nanoparticles :

Synergistic effect of $AgTiO_2$ nanoparticle is exhibited after binding to the bacterial cell wall and subsequently instigated degradation of cell membrane due to release of nanoparticles inside the cell which caused interference of biomolecules[34]. The major factor to be considered before the release of nanoparticles is that it has to be coated. These synergistic molecules can hinder the DNA replication process which refrains the proliferation. According to Wu and Long[50] the silver ions have ability to intermingle with phosphorus-containing compounds and hinder with DNA replication activities.Moreover, the synergistic action of both Ag-TiO_2 play a key role in the antimicrobial mechanism and generates Reactive oxygen species (ROS) inside and outside of the cell which results in degradation of membrane and oozing of intracellular materials. Although, various literatures have demonstrated the significance of nanocomposite importance against antimicrobial activity[3,12,28]. The figure-2 explains the synergism activity of nanocomposite *i.e* Ag-TiO_2 combination resulted in bactericidal action. However, the bacterial killing capacity was initiated based upon size features of the Ag-TiO_2 coatings. Moreover, the extension of light spectrum towards the visible region triggered the bactericidal activity due to silver ions which has ability to trap the TiO_2 band gap and exerted its effect[39].

The Biocompatibility of Ag-TiO_2 complex :

Modern expedition in advancements of science and technology for new developments in medical field includes nanomaterials which are found to be effective tools to combat any maladies from tumor or virus, bacteria, to several other microbial pathogens[4,7,17,53]. Although, various nanomaterials based products have been extensively used for packaging of food items especially silver, grapheme, titanium dioxide and carbon most frequently used. Nonetheless, nanotechnology have been also utilized for preparation of various medical applications such as detection of pathogen, eradication of tumor, regeneration of tissues, engineering of tissues and magnetic resonance imaging[14,21,36,40,41]. However, synthetic silver alone or co-amalgamation of Ag/TiO_2 nanoparticles have been exclusively constructed by various techniques due to its broad efficiency along with biocompatibility in many science and technology related fields.

Application of Nanoparticles in several fields :

The occurrences of silver nanoparticles are common from centuries. Nonetheless, Glover *et al.*[15] revealed about the nature of metallic silver and depicted that at certain environmental conditions, only will liberate silver nanoparticles. Liu *et al.*[23] demonstrated mode of transport of nanosilver within the body and out of body compartments. These, nano devices can be applied in numerous fields of science such as biomedical, pharmaceutical and food industry (Shown in Figure-3). The characteristics of these nano sized particles are inorganic in nature with simple or complex nature[24,26,29]. The usage of NPs have drawn greater attention from each and every branch of medicine as they are capable to deliver drugs at optimum dosage range in required time period ensuing augmented therapeutic efficiency of the drugs, thereby lessening side effects and augmented patient outcome[2].

Photo-catalytic reaction of bacteria :

Saha *et al.*,[38] demonstrated that by liquid impregnation method the potential of silver doped titanium dioxide has greater effect against Pseudomonas and bacillus species. Both gram negative and gram positive bacteria were tested for bacterial viability, Ag-TiO_2 when mixed with bacterial slurry on exposure to fluorescent light reduced the viability of the organisms through photcatalysis. Ag-TiO_2

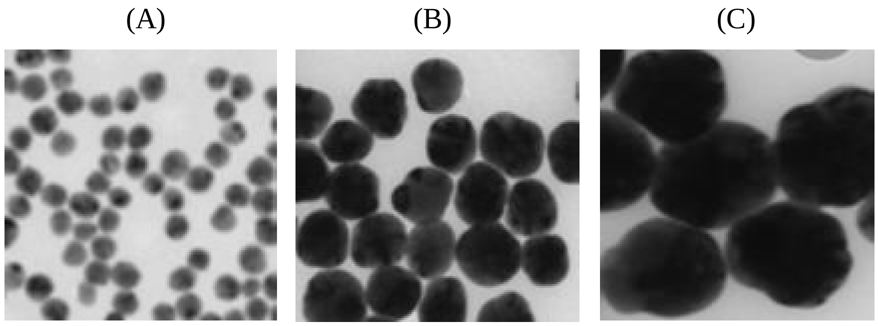

Figure-1: Size, Shape of Silver nanoparticles with diameter ranging from a) 20nm b) 60nm and c) 100nm (Transmission Electron Microscope images)

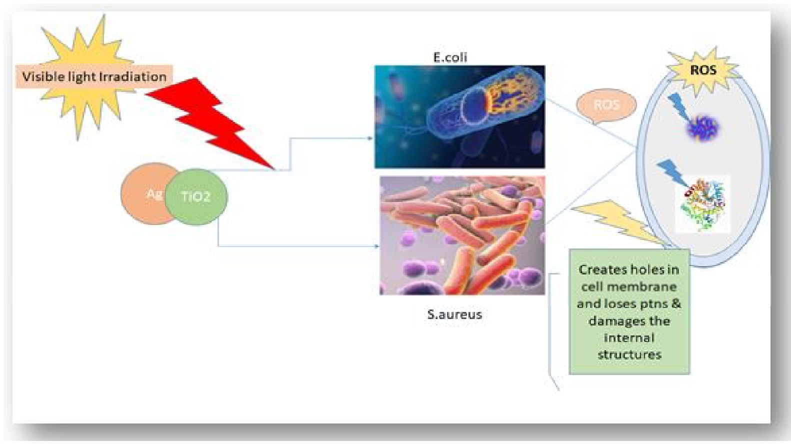

Figure-2: Photocatalytic mechanism to inactivate the growth of bacterium

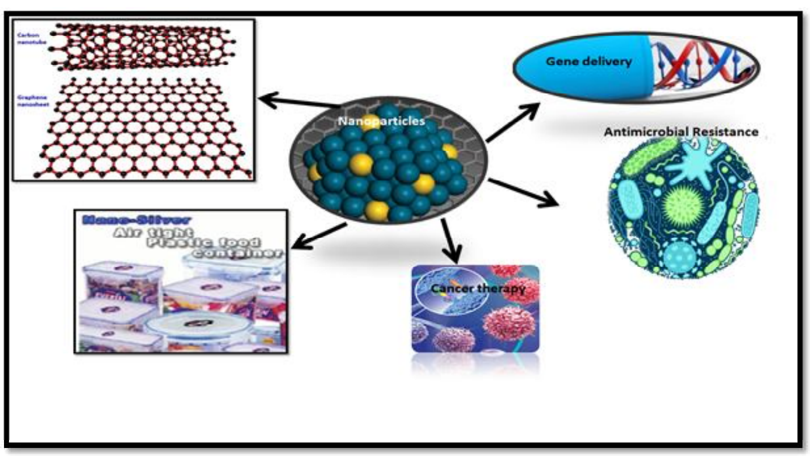

Figure-3: Applications of nanoparticles in various fields of science & technology nanoparticles have revealed antibacterial actions and displayed inhibitory behavior to bacterial growth on *P. aeruginosa* (Gram-negative bacteria) and *B. subtilis* (Gram-positive bacteria) in the presence of light. Thus, doping of silver in titanium nanoparticles resulted in enhanced visible absorption[42].

Nature of Sliver nanoparticles :

The nature of silver nanoparticles is complex and is very difficult to analyse due to its complexity in aqueous solutions The behavior of silver nanoparticles is difficult to analyse due to the complex chemistry of silver in aqueous solutions[1,9,22]. The shapes, sizes, coatings of nanoparticles differ and they possess improved ionic strength, dissolved oxygen concentration, humidity in environment and temperature which influences their stability[45]. Li *et al.*[19] depicted the mode of action of silver nanoparticles:

(1) The nanoparticles get adhered on to the surface of bacteria with further modifying the properties in membrane. Although, nanoparticles are very small size but exhibit strong impact on the surface of microorganisms[49].
(2) The major role of silver nanoparticles is it has the capability to penetrate inside the bacterial cell wall and result in DNA damage.
(3) The antimicrobial mechanism of silver ions mainly helps in interaction of Ag^+ ions with sulphur containing proteins present in bacterial cell wall and exhibits resistance[18,32].

In our current article, we have portrayed the significance of Ag-TiO_2 nanoparticles by a novel and simple liquid impregnation approach. The co-amalgamation of nanoparticles revealed promising outcomes on both bacteria *P. aeruginosa* and *B. subtilis*. Moreover, Ag-TiO_2 formulations on coated glass and coated venetian blind revealed approximately 95% of antibacterial efficiency. Through, photocatalytic reaction the silver doped titanium dioxide exhibited promising effects and can be applied in several fields such as medicine, pharmaceutical, food packaging industry, hospitals etc. to refrain the spread of infections. Further, research need to be concentrated on this field with broad applications in other fields.

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References :

1. Adams, N.W.H. and J.R. Kramer (1999). *Environ. Toxicol. Chem., 18*: 2667–2673.
2. Alexis, F., E. Pridgen, L.K. Molnar and O.C. Farokhzad (2008). *Mol. Pharm. 5:* 505–515. http://dx.doi.org/10.1021/

mp800051m.

3. Ashkarran A.A., S.M. Aghigh, M. Kavianipour, and N.J. Farahani (2011). *Curr Appl Phys. 11:* 1048–1055. doi: 10.1016/j.cap.2011.01.042.
4. Baghbani-arani, F., R. Movagharnia, A. Sharifian, S. Salehi, S. A. S. Shandiz, and S. Shandiz, (2017) *Journal of Photochemistry and Photobiology B: Biology*, vol. *173:* pp. 640–649.
5. Banerjee A.N., (2011) *Nanotechnology, Science and Applications, 4*(1): 35–65.
6. BECON. Nanoscience and Nanotechnology Symposium Report; National Institutes of Health Bioengineering Consortium: Bethesda, MD, USA, June 2000. Available online:http://www.uta.edu/rfmems/060515NSFNUE/Info/biomed/nanotechsympreport.pdf (accessed on 10 June 2019).
7. Cao, H., X. Liu, F. Meng, and P. K. Chu (2011) *Biomaterials, 32*(3): pp. 693– 705.
8. Chang, Y., J. Xu, Y. Zhang, S. Ma, L. Xin, L. Zhu, and C. Xu, (2009) *J. Phys. Chem. C, 113:* 18761–18767. [Cross Ref].
9. Chappell, M.A., L.F. Miller, A.J. George, B.A. Pettway, C.L. Price, B.E. Porter, A.J. Bednar, J.M. Seiter, A.J. Kennedy and J.A. Steevens (2011) *Chemosphere, 84:* 1108–1116.
10. Cozzoli, P. D., R. Comparelli, E. Fanizza, M. L. Curri, A. Agostiano, and D. Laub (2004) *Journal of the American Chemical Society 126*(12): 3868–3879.
11. Dey, S., V. Bakthavatchalu, M.T. Tseng, P. Wu, R.L. Florence, E.A. Grulke, R.A. Yokel, S.K. Dhar, H.S. Yang, and Y. Chen, *et al.* (2008) *Carcinogenesis, 29:* 1920–1929. [CrossRef] [PubMed].
12. Esfandiari N., A. Simchi, and R. Bagheri (2014). *J Biomed Mater Res A. 102:* 2625–2635. doi: 10.1002/jbm.a.v102.8.
13. Fageria, P.S. Gangopadhyay and S. Pande, (2014) Synthesis of ZnO/Au and ZnO/Ag nanoparticles and their photocatalytic application using UV and visible light. *RSC Adv., 4:* 24962–24972. [CrossRef].
14. Faiz, M.B., R. Amal, and C.P. Marquis *et al.*, (2018) *Nanotoxicology, 12*(3): 263–273.
15. Glover, R.D., J.M. Miller and J.E. Hutchison (2011) *ACS Nano, 5*: 8950–8957.
16. Huang, H.H., X.P. Ni, G.L. Loy, C.H. Chew, K.L. Tan, F.C. Loh, J.F. Deng, and G.Q. Xu (1996) *Langmuir, 12 :* 909–912. [CrossRef].
17. Lee, S.J., M. Heo, D. Lee, *et al.*, (2018) *Applied Surface Science, 432:* 317–323.
18. Levy, S.B. (1998) *Sci. Am., 3:* 32–39.
19. Li, Q., S. Mahendra, D.Y. Lyon, L. Brunet, M.V. Liga, D. Li and P.J.J. Alvarez, (2008) *Water Res., 42:* 4591–4602.
20. Liga, M. V., E. L. Bryant, V. L. Colvin, and Q. Li, (2011) Water Research, *45*(2): 535–544. .
21. Llorens, A., E. Lloret, P.A. Picouet, R. Trbojevich, and A. Fernandez, (2012) "Metallic-based micro and nanocomposites in food contact materials and active food packaging," *Trends in Food Science & Technology, 24*(1): 19–29.
22. Liu, J., and R.H. Hurt (2010) *Environ. Sci. Technol. 44:* 2169–2175.
23. Liu, J., Z. Wang, F.D. Liu, A.B. Kane, and R.H. Hurt (2012) *ACS Nano, 6:* 9887–9899.
24. Loureiro, A., N.G. Azoia, A.C. Gomes, and A. Cavaco-Paulo (2016). *Curr. Pharm. Des. 22:* 1371–1390.
25. Marambio-Jones, C., and E.M.V. Hoek, (2010) *J. Nanopart. Res., 12:* 1531–1551. [CrossRef].

26. Martis, E., R. Badve, and M. Degwekar (2012). *Chron. Young Sci. 3:* 68. http://dx.doi.org/10.4103/2229-5186.94320.
27. Mohapatra, S., T.A. Nguyen, and P. Nguyen-Tri (2018) Noble Metal-Metal Oxide Hybrid Nanoparticles: Fundamentals and Applications; Elsevier: Amsterdam, The Netherlands, Volume 1.
28. Motlagh A.L., S. Bastani, and M.M. Hashemi (2014). *Prog Org Coat. 77:* 502–511. doi: 10.1016/j.porgcoat.2013.11.014.
29. Nikalje, A.P. (2015). *Med Chem 5:* http://dx.doi.org/10.4172/2161-0444.1000247.
30. Nowack, B., H.F. Krug, and M. Height, (2010) *Environ. Sci. Technol. , 45:* 1177–1183.
31. Oesterling, E., N. Chopra, V. Gavalas, X. Arzuaga, E.J. Lim, R. Sultana, D.A. Butterfield, L. Bachas, and B. Hennig (2008) *Toxicol. Lett., 178:* 160–166. [CrossRef] [PubMed]
32. Ovington, L.G. (2004) *Ostomy Wound Mag., 50*: 1–10.
33. Paz Y., (2010) "Application of TiO_2 photocatalysis for air treatment: Patents' overview," *Applied Catalysis B: Environmental, 99*(3-4): 448–460.
34. Prakash J., P. Kumar, R.A. Harris, C. Swart, J.H. Neethling, A.J. Van Vuuren, and H.C. Swart (2016) *Nanotechnology. 27:* 355707–355726. doi: 10.1088/0957-4484/27/35/355707.
35. Rai, V.R., and A.J. Bai (2011) Nanoparticles and their potential application as antimicrobials. In Science against microbial pathogens: Communicating current research and technological advances, *Formatex, Microbiology Series No.3;* Méndez-Vilas, A., Ed.; Elsevier: Badajoz, Spain, Volume 1, pp. 97–209.
36. Rajendran, N.K., S. S. D. Kumar, N. N. Houreld, and H. Abrahamse (2018) *Journal of Drug Delivery Science and Technology, 44:* 421–430.
37. Rtimi, S., V. Nadtochenko, I. Khmel, S. Konstantinidis, N. Britun, and J. Kiwi, (2019) *Appl. Sur. Sci., 467:* 749–752. [CrossRef].
38. Saha, S., J. M. Wang, and A. Pal (2012) *Separation and Purification Technology, 89:* 147–159.
39. Santos, C.L., A.J.R. Albuquerque, F.C. Sampaio and D. Keyson (2013) Nanomaterials with Antimicrobial Properties: Applications in Health Sciences. In Microbial Pathogens and Strategies for Combating Them: Science, Technology and Education; Méndez-Vilas, A., Ed.; Formatex: Badajoz, Spain.
40. Salata, O. (2004) *Journal of Nanobiotechnology, 2*(1): 3.
41. Sarkar, S., A.D. Jana, S.K. Samanta, and G. Mostafa, (2007) *Polyhedron, 26*(15): 4419–4426.
42. Seery, M.K., R. George, P. Floris, and S.C. Pillai, (2007) *Journal of Photochemistry and Photobiology 189*(2-3): 258–263.
43. Shenashen, M.A., S.A. El-Safty and E.A. Elshehy (2014) *Part. Syst. Charact., 31:* 293–316. [CrossRef].
44. Standard and White LED Basics and Operation. Available online: https://www.maximintegrated.com/en/ app-notes/index.mvp/id/3070 (accessed on 10 June 2019).
45. Suresh, A.K., D. Pelletier, W. Wang, J.L. Morrell-Falvey, B. Gu, and M.J. Doktycz, (2012) *Langmuir, 28*: 2727–2735.
46. Tri, P.N., T.A. Nguyen, T.H. Nguyen, and P. Carriere, (2019) Antibacterial Behavior

of Hybrid Nanoparticles (Chapter 7). In Noble Metal-Metal Oxide Hybrid Nanoparticles: Fundamentals and Applications; Mohapatra, S., Nguyen, T.H., Nguyen-Tri, P., Eds.; Elsevier: Amsterdam, The Netherlands, pp. 141–155. [Cross Ref].

47. Weir, E., A. Lawlor, A. Whelan, and F. Regan, (2008) *Analyst, 133:* 835–845. [Cross Ref] [Pub Med].
48. Wilker, M. B., K.J. Schnitzenbaumer, and G. Dukovic, (2012) *Israel Journal of Chemistry, 52*(11-12): 1002–1015.
49. Wong, K.K.Y. and X. Liu (2010) *Med. Chem. Commun., 1:* 125–131.
50. Wu D. and M. Long (2011) *ACS Appl Mater Interfaces 3:* 4770–4774. doi:10.1021/am201251d.
51. Xu, C., P. Chen, J. Liu, H. Yin, X. Gao, and X. Mei (2016) *J. Alloy. Compd., 679:* 463–469. [CrossRef].
52. Xu, F., J. Mei, M. Zheng, D. Bai, D. Wu, Z. Gao, and K. Jiang, (2017) *J. Alloy. Compd., 693,* 1124–1132. [CrossRef].
53. Yang, F.C., K.H. Wu, J.W. Huang, D.N. Horng, C.F. Liang, and M.K. Hu, (2012) *Materials Science and Engineering: C, 32*(5): 1062–1067.
54. Yang, X. H., H. T. Fu, X. C. Wang, J. L. Yang, X. C. Jiang, and A. B. Yu, (2014) *Journal of Nanoparticle Research, 16:* 2526.
55. Zhao, L., P. K. Chu, Y. Zhang, and Z. Wu, (2009) *Journal of Biomedical Materials Research Part B: Applied Biomaterials, 91*(1): 470–480.