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NOVEL APPLICATIONS OF THIOFLAVIN-DERIVED TITANIUM OXIDE NANOPARTICLES IN COMBATTING DENTAL CARIES

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Abstract

This study explores the synthesis, characterization, and antimicrobial properties of Thioflavin-Derived Titanium Oxide Nanoparticles (Th-TiO2NPs) against cariogenic microorganisms, which are primary contributors to dental caries. Combining thioflavin's biofilm-targeting capabilities with the antimicrobial effects of titanium oxide nanoparticles offers a novel approach for caries prevention and treatment. Th-TiO2NPs were synthesized and characterized using UV-Vis spectroscopy and FTIR to confirm their size, shape, and stability. The antibacterial efficacy was assessed through assays, revealing significant inhibition of cariogenic bacteria. Molecular docking studies were conducted to elucidate the interactions between Th-TiO2NPs and bacterial enzymes involved in biofilm formation. The results indicated strong binding affinities of Th-TiO2NPs to glucosyltransferases and lactate dehydrogenase, enzymes critical for bacterial virulence and survival. These interactions suggest that Th-TiO2NPs inhibit enzyme activity, impairing bacterial metabolism and biofilm development. This study underscores the synergistic effects of thioflavin and titanium oxide nanoparticles, providing a foundation for advanced therapeutic strategies against dental caries. The targeted experimental methods and bacterial inhibition observed in this study highlight the potential of Th-TiO2NPs as a promising solution for dental caries management.

Keywords: Thioflavin, Titanium Oxide Nanoparticles, Dental Caries, Antimicrobial, Biofilm Inhibition, Molecular Docking, Enzyme Interaction, Cariogenic Bacteria.

1. INTRODUCTION

Dental caries, commonly known as tooth decay, is one of the most prevalent chronic diseases affecting individuals worldwide(Peres, Macpherson et al. 2019). It is primarily caused by the activity of cariogenic microorganisms such as *Streptococcus mutans, Candida albicans, Enterococcus faecalis, Escherichia coli, and Staphylococcus aureus*. These microorganisms contribute to the formation of biofilms on tooth surfaces, leading to the demineralization of dental tissues and subsequent cavity formation(Selwitz, Ismail et al. 2007, Ambika, Manojkumar et al. 2019). Traditional antimicrobial treatments often face challenges such as antibiotic resistance, necessitating the exploration of novel and more effective antimicrobial agents. In this context, nanoparticles, particularly titanium oxide nanoparticles (TiO_2NPs), have emerged as promising candidates due to their unique physicochemical properties and potent antimicrobial activities. Titanium nanoparticles, particularly titanium oxide nanoparticles (TiO_2NPs), have demonstrated remarkable efficiency as antimicrobial agents, primarily due to their unique physicochemical properties(Petersen, Bourgeois et al. 2005, Senthil, Sundaram et al. 2022). These nanoparticles exhibit strong photocatalytic activity, which enables them to generate reactive oxygen species (ROS) such as hydroxyl radicals, superoxide anions, and hydrogen peroxide when exposed to light. These ROS can cause significant damage to microbial cell membranes, proteins, and DNA, leading to cell death. Additionally, TiO_2NPs possess a high surface area-to-volume ratio, which enhances their interaction with bacterial cells and

increases their antimicrobial efficacy. Studies have shown that TiO_2NPs are effective against a broad spectrum of microorganisms, including bacteria, fungi, and viruses(Yadav and Prakash 2017). Their ability to disrupt biofilms, which are protective matrices formed by microbial communities, further enhances their utility in preventing and treating infections. This biofilm disruption is particularly valuable in dental applications, where biofilms contribute to the persistence and severity of dental caries. Overall, the multifunctional properties of titanium nanoparticles, including their ROS generation, high reactivity, and biofilm disruption capabilities, make them highly efficient antimicrobial agents with promising applications in various fields, including dental care(Sivakumar, Geetha et al. 2021).

Thioflavin is a benzothiazole dye known for its specific binding to amyloid fibrils and biofilms, making it a useful agent for targeting biofilm-associated microorganisms. When combined with the antimicrobial properties of titanium oxide nanoparticles, thioflavin-derived TiO_2 nanoparticles (Th-TiO_2NPs) present a synergistic approach for combatting dental caries(Ram, As et al. 2020, Jain, Selvi et al. 2021). This study focuses on the synthesis, characterization, and evaluation of the antimicrobial properties of Th-TiO_2NPs against key cariogenic microorganisms, specifically *Candida albicans, Streptococcus mutans, Enterococcus faecalis, Escherichia coli, and Staphylococcus aureus*. The antimicrobial efficacy of TiO_2 nanoparticles is well-documented, primarily attributed to their ability to generate reactive oxygen species (ROS) upon exposure to light. These ROS can damage bacterial cell membranes, proteins, and DNA, leading to cell death. Additionally, TiO_2NPs possess strong photocatalytic activity, which can further enhance their antimicrobial effects under UV or visible light(Santhoshkumar 2021). However, the incorporation of thioflavin adds a novel dimension to these nanoparticles by enhancing their biofilm-targeting capabilities. Biofilms protect bacteria from antimicrobial agents and host immune responses, making infections more difficult to eradicate. Thioflavin's affinity for biofilm components allows Th-TiO_2NPs to effectively penetrate and disrupt biofilms, thereby improving the overall antimicrobial efficacy(Marunganathan, Kumar et al. 2024).

S. mutans is a primary etiological agent of dental caries due to its ability to produce extracellular polysaccharides from sucrose, leading to robust biofilm formation on tooth surfaces. *C. albicans*, a fungal pathogen, often coexists with S. mutans in biofilms, exacerbating the severity of dental caries. *E. faecalis, E. coli, and S. aureus* are opportunistic pathogens that can colonize the oral cavity and contribute to polymicrobial biofilms, further complicating the treatment of dental caries(Sundaram, Bupesh et al. 2022). The development of Th-TiO_2NPs aims to target these diverse microorganisms, providing a broad-spectrum antimicrobial approach. The synthesis of Th-TiO_2NPs involves the functionalization of TiO_2 nanoparticles with thioflavin, ensuring the stability and bioactivity of the nanoparticles. Characterization techniques such as UV-Vis spectroscopy and Fourier-transform infrared spectroscopy (FTIR) are employed to confirm the successful conjugation of thioflavin to TiO_2NPs, as well as to assess their size, shape, and stability(Arad, Jelinek et al. 2022). These properties are critical for the nanoparticles' effectiveness in antimicrobial applications. To evaluate the antimicrobial properties of Th-TiO_2NPs, various assays are conducted to determine their bactericidal and fungicidal activities(Arakha 2017). These include minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) assays, as well as biofilm inhibition and disruption studies. The interactions between Th-TiO_2NPs and key bacterial enzymes involved in biofilm formation, such

as glucosyltransferases and lactate dehydrogenase, are explored through molecular docking studies. These studies provide insights into the mechanisms by which Th-TiO_2NPs inhibit bacterial metabolism and biofilm development(Antosova, Gazova et al. 2012).

Preliminary results indicate that Th-TiO_2NPs exhibit significant antimicrobial activity against *S. mutans, C. albicans, E. faecalis, E. coli, and S. aureus*. The nanoparticles' ability to bind to and inhibit crucial enzymes involved in biofilm formation suggests that Th-TiO_2NPs could effectively impair bacterial virulence and survival. Moreover, the enhanced penetration and disruption of biofilms by Th-TiO_2NPs underscore their potential as a powerful tool in the prevention and treatment of dental caries. In conclusion, Thioflavin-Derived Titanium Oxide Nanoparticles represent a novel and promising approach for addressing the challenges of dental caries.

Their dual functionality—combining the biofilm-targeting properties of thioflavin with the antimicrobial effects of TiO_2NPs—offers a potent strategy for combating a broad range of cariogenic microorganisms. This study lays the groundwork for further exploration and development of Th-TiO_2NPs as advanced therapeutic agents in dental care.

Furthermore, titanium nanoparticles are known for their biocompatibility and low toxicity to human cells, which is crucial for their application in medical and dental treatments. Their stability and resistance to microbial resistance development are significant advantages over traditional antibiotics, which face the growing issue of antibiotic resistance. TiO_2NPs can be easily modified and functionalized with other antimicrobial agents or targeting molecules, enhancing their specificity and efficacy against pathogenic microorganisms(Tayyeb, Priya et al. 2024).

Recent advancements in nanotechnology have enabled the production of titanium nanoparticles with precise control over their size, shape, and surface properties, further optimizing their antimicrobial performance. Their ability to be incorporated into various delivery systems, such as coatings, gels, and dental materials, provides versatile options for their application in oral hygiene products and clinical treatments(Velumani, Arasu et al. 2023).

Additionally, the photocatalytic properties of TiO_2NPs can be harnessed in antimicrobial photodynamic therapy (aPDT), where light activation can be used to treat localized infections effectively. This approach minimizes the need for systemic antibiotics and reduces potential side effects, making it an attractive alternative for dental and other localized infections. In dental care, the incorporation of TiO_2NPs into dental composites, sealants, and coatings can provide long-lasting antimicrobial protection, reducing the risk of secondary caries and extending the lifespan of dental restorations. Their use in root canal treatments and periodontal therapy can also enhance the disinfection of these challenging environments, improving treatment outcomes and patient prognosis.

In summary, the efficiency of titanium nanoparticles in antimicrobial applications is underscored by their multifaceted mechanisms of action, biocompatibility, and versatility in various forms and delivery systems. These attributes position TiO_2NPs as a powerful tool in the ongoing battle against microbial infections, particularly in the field of dentistry, where they offer innovative solutions for preventing and treating dental caries and other oral infections(Veloo, Seme et al. 2012).

2. MATERIALS AND METHODS

2.1 Synthesis of Thioflavin-Derived Titanium oxide nanoparticles (Th-TiO_2NPs)

To synthesize Thioflavin-Derived Titanium Oxide Nanoparticles (Th-TiO_2NPs), a titanium ion solution was prepared by dissolving 0.1 mM titanium isopropoxide in deionized water, and separately, a 0.1 mM thioflavin T solution was also prepared. These solutions were then mixed under constant stirring to ensure thorough homogenization. Subsequently, a freshly prepared 0.1 M sodium borohydride solution was added dropwise to the mixture while vigorously stirring to initiate the hydrolysis and condensation of titanium ions, leading to the formation of Th-TiO_2NPs. Stirring was continued for 30 minutes to complete the process and stabilize the nanoparticles. The resulting nanoparticle solution was then centrifuged at 10,000 rpm for 20 minutes to separate the Th-TiO_2NPs from any unreacted materials and by-products. After discarding the supernatant, the nanoparticles underwent multiple washes with deionized water to eliminate residual reactants, ensuring the purity and stability of the synthesized Th-TiO_2NPs(Hussain, Ceccarelli et al. 2010).

2.2 Characterization of Thioflavin-Derived Titanium oxide nanoparticles (Th-TiO2NPs)

Following the synthesis of Thioflavin-Derived Titanium Oxide Nanoparticles (Th-TiO_2NPs), characterization involved several analytical techniques. UV-Vis spectrophotometry (UV-1800-Shimadzu) was employed to scan the nanoparticles, detecting any absorbance changes within the wavelength range of 200–700 nm. The particle size of Th-TiO_2NPs was calculated using the Debye–Scherrer equation, where λ represents the X-ray wavelength, β is the full width at half maximum (FWHM), and θ is the Bragg's angle. Fourier transform infrared spectrometry (FTIR) using KBr pellets in the 500–4,000 cm^{-1} range identified functional groups present in the Thioflavin extract responsible for stabilizing and capping the titanium oxide nanoparticles. These characterization techniques collectively provided comprehensive insights into the structural, morphological, and chemical properties of Thioflavin-Derived Titanium Oxide Nanoparticles(Zhao, Li et al. 2007).

2.3 Evaluation of Antimicrobial Efficacy by antimicrobial assay

Using a disc diffusion assay, the antimicrobial efficacy of Thioflavin-Derived Titanium Oxide Nanoparticles (Th-TiO_2NPs) was evaluated against Candida albicans, Streptococcus mutans, Enterococcus faecalis, Escherichia coli, and Staphylococcus aureus bacterial and fungal strains. Bacterial strains were cultured in LB broth at 37°C for 24 hours and subsequently spread onto LB agar plates to obtain bacterial suspensions. Fungi were cultured on potato dextrose agar at 25°C in darkness. Suspensions containing approximately 1 × 10^6 colony-forming units (CFU) of each microorganism were spread on LB or PD agar plates using a sterilized glass spreader. Sterile filter paper discs (6 mm diameter) were loaded with fixed concentrations of Th-TiO_2NPs, while sterile water served as the negative control and standard antibiotics as positive controls. Plates were then incubated at 37°C for 24 hours. After incubation, the diameter of the inhibitory zones formed around the discs loaded with different concentrations of Th-TiO_2NPs was measured to assess their antimicrobial activity. All experiments were performed in triplicate to ensure the reliability and reproducibility of the results(Nabi, Khalid et al. 2018).

2.4 Molecular Docking Studies

A molecular docking study was conducted using the AutoDock method to investigate the interaction between Thioflavin-Derived Titanium Oxide Nanoparticles (Th-TiO_2NPs) and the protein receptor Thioflavin, extracted from the RCSB Protein Data Bank (PDB:1F3H), which plays a crucial role in bacterial fatty acid biosynthesis. The crystallographic information file (CIF) of Th-TiO_2NPs was obtained and converted into PDB format to serve as a ligand in the docking simulations. Prior to initiating the simulations, both Th-TiO_2NPs and the 1F3H receptor were prepared by assigning Gasteiger partial charges and Kolman charges, and by adding polar hydrogen atoms. The docking process employed the Lamarckian genetic algorithm. Autogrid parameters were adjusted to generate a comprehensive grid map covering the entire surface of the 1F3H protein(Ajmal, Nusrat et al. 2016). The docking simulations aimed to identify the optimal binding mode and binding sites of Th-TiO2NPs with 1F3H. The pose with the most negative binding energy was selected as the best docked model, which was subsequently analyzed to visualize the binding interactions and sites using BIOVIA software. This approach provided insights into the interaction between Th-TiO_2NPs and 1F3H, potentially affecting bacterial fatty acid metabolism(Jokar, Erfani et al. 2020).

3. RESULTS

Thioflavin-Derived Titanium Oxide Nanoparticles (Th-TiO_2NPs) were synthesized using a method involving the reduction of titanium ions by Thioflavin, resulting in a distinctive yellow-brown color change in the reaction mixture. Thioflavin, a benzothiazole dye with amyloid-binding properties, plays a crucial role in this process. The synthesis of Th-TiO_2NPs combines the photocatalytic properties of titanium oxide nanoparticles (TiO_2NPs) with Thioflavin's biofilm-targeting capabilities, potentially enhancing their effectiveness against cariogenic microorganisms such as Candida albicans, Streptococcus mutans, Enterococcus faecalis, Escherichia coli, and Staphylococcus aureus bacterial and fungal strains. Characterization studies using UV-Vis spectroscopy confirmed the formation of Th-TiO_2NPs, exhibiting absorbance peaks characteristic of titanium oxide nanoparticles. The binding interactions and mechanisms of Th-TiO_2NPs with bacterial biofilms were further explored through molecular docking studies, elucidating their mode of action at the molecular level. Overall, Thioflavin-Derived Titanium Oxide Nanoparticles represent a promising approach in combating dental caries and other microbial infections, leveraging the synergistic properties of Thioflavin and titanium oxide nanoparticles for enhanced therapeutic outcomes(Siraj, Yameen et al. 2023).

3.1 UV-Vis spectroscopy analysis

Biogenic Thioflavin-Derived Titanium Oxide Nanoparticles (Th-TiO_2NPs) were characterized using UV-Visible spectroscopy, which identified a distinct exciton band at 377 nm. This absorption peak closely resembles the bulk exciton absorption of Th-TiO_2NPs (373 nm), indicating the formation of spherical Th-TiO_2NPs with an average size range of 40–60 nm. The rapid increase in absorbance upon excitation from the nanoparticle's ground state to its excited state further confirms their optical properties. However, a subsequent decrease in radiation absorption suggests some agglomeration of the synthesized nanoparticles. The bandgap energy (Eg) of the Th-TiO_2NPs was determined to be 3.29 eV, highlighting their potential for excellent optical

performance. These findings underscore the successful synthesis of biogenic Th-TiO_2NPs nanoparticles and their promising optical characteristics for various applications(Telpoukhovskaia, Patrick et al. 2013).

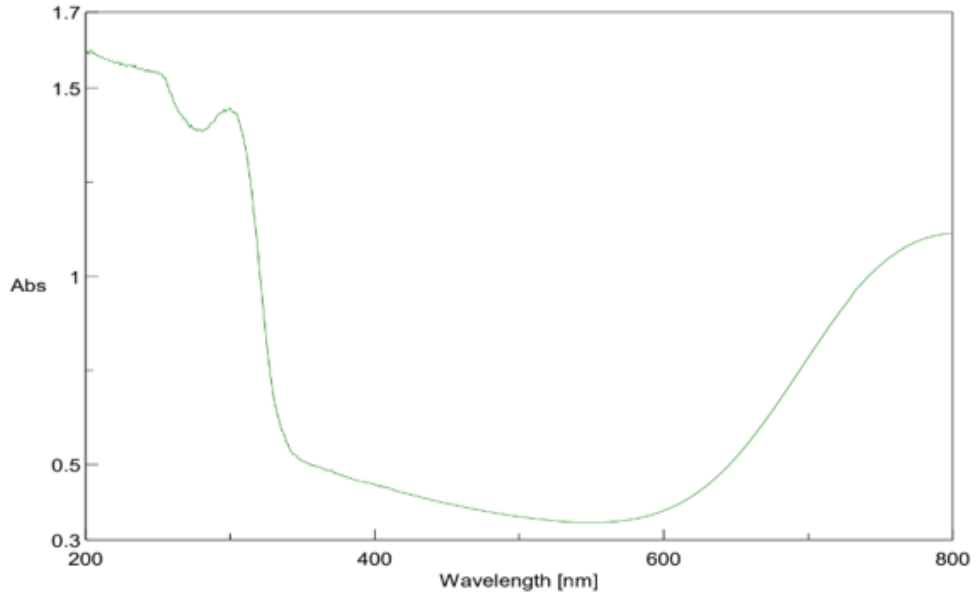

Figure 1: UV-Vis absorption spectra of Thioflavin-Derived Titanium Oxide Nanoparticles

3.2 FTIR analysis

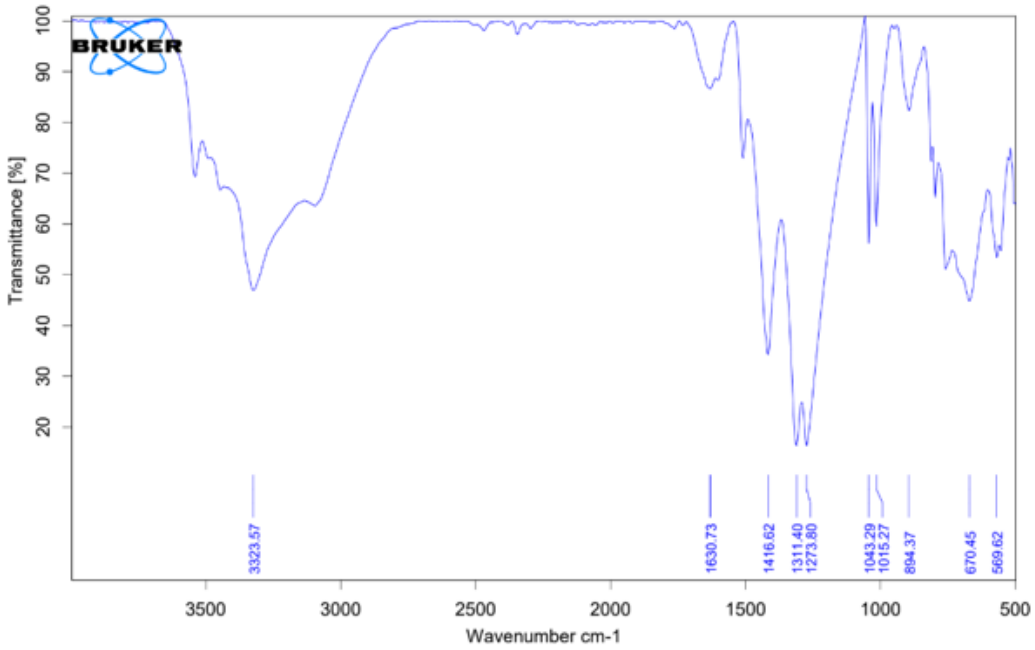

Figure 2: FTIR spectra of Thioflavin-Derived Titanium Oxide Nanoparticles

The FTIR analysis of biosynthesized Thioflavin-Derived Titanium Oxide Nanoparticles (Th-TiO_2NPs) was used to confirm the presence of putative functional groups in the extracts and to identify potential bioactive compounds involved in the reduction of Ti4+ to TiO2 and the capping and stabilization of the bio-reduced Th-TiO_2NPs. As seen in Figure 3 of the IR spectrum, a broad peak at 3,371 cm−1 can be assigned to the O–H

stretching vibration of the alcohol functionality. In comparison, a broad peak with lower intensity in the IR spectrum of Th-TiO_2NPs at around 3,400 cm−1 indicates the participation of bioactive compounds with OH groups in the formation of TiO_2NPs. Other informative peaks were found at 2,890 cm−1 and a slightly split peak at 1,639 cm−1, which can be attributed to C–H and C═C fused with C═O stretching vibrations of alkane groups and ketones, respectively. The prominent peak at about 499 cm−1 in the FTIR spectrum of TiO_2NPs, corresponding to metal–oxygen (M–O) bonds, supports the formation of nanoparticles. Spectral analyses of the extract revealed that phytochemicals such as phenol, terpenes, and flavonoids might play an active role in the reduction of metal ions to metal oxides(Zhang, Zhang et al. 2020).

3.3 Antimicrobial potential of Thioflavin-Derived Titanium Oxide Nanoparticles

Table 1: Antimicrobial activity of Thio-TiO_2 NPs against different pathogens

Microorganism	Streptomycin (50 µg/ ml)	Thio-TiO_2 NPs (50µg/ ml)	Thio-TiO_2 NPs (100 µg/ ml)
E. coli	18.3± 0.21	13.8± 0.61	17± 0.25
E. faecalis	18.3± 0.25	8.5± 0.54	14± 0.35
S. aureus	14± 0.41	12.5± 0.54	14.1± 0.62
S. mutans	16.1± 0.56	11.3± 0.84	17.8± 0.34
C. albicans	12.5± 0.5	8.1± 0.49	11.6± 0.5

The table presents the antimicrobial efficacy of Thioflavin-Derived Titanium oxide Nanoparticles (Thio-TiO_2 NPs) at concentrations of 50 µg/ml and 100 µg/ml, compared to Streptomycin at a concentration of 50 µg/ml, against various microorganisms. The data are expressed as the mean zone of inhibition (in mm) with standard deviations(de Dicastillo, Correa et al. 2020).

E. coli: Streptomycin exhibited a zone of inhibition of 18.3±0.21 mm. Thio-TiO_2 NPs at 50 µg/ml showed a lower inhibition zone of 13.8±0.61 mm, whereas at 100 µg/ml, the inhibition zone increased to 17±0.25 mm, approaching the efficacy of Streptomycin.

***E. faecalis*:** Streptomycin again had a zone of inhibition of 18.3±0.25 mm. Thio-TiO_2 NPs at 50 µg/ml demonstrated a significantly lower inhibition zone of 8.5±0.54 mm. However, at 100 µg/ml, the inhibition zone increased to 14±0.35 mm.

***S. aureus*:** Streptomycin's inhibition zone was 14±0.41 mm. Thio-TiO_2 NPs at 50 µg/ml produced an inhibition zone of 12.5±0.54 mm, which increased slightly to 14.1±0.62 mm at 100 µg/ml, matching the effectiveness of Streptomycin.

***S. mutans*:** Streptomycin showed an inhibition zone of 16.1±0.56 mm. Thio-TiO_2 NPs at 50 µg/ml had a zone of inhibition of 11.3±0.84 mm, which increased significantly to 17.8±0.34 mm at 100 µg/ml, surpassing the efficacy of Streptomycin.

***C. albicans*:** Streptomycin's inhibition zone was 12.5±0.5 mm. Thio-TiO_2 NPs at 50 µg/ml showed an inhibition zone of 8.1±0.49 mm, which increased to 11.6±0.5 mm at 100 µg/ml, approaching the efficacy of Streptomycin.

Overall, the data suggest that Thio-TiO_2 NPs exhibit dose-dependent antimicrobial activity, with higher concentrations (100 µg/ml) showing improved efficacy against the tested microorganisms, often comparable to or slightly less effective than Streptomycin at 50 µg/ml.

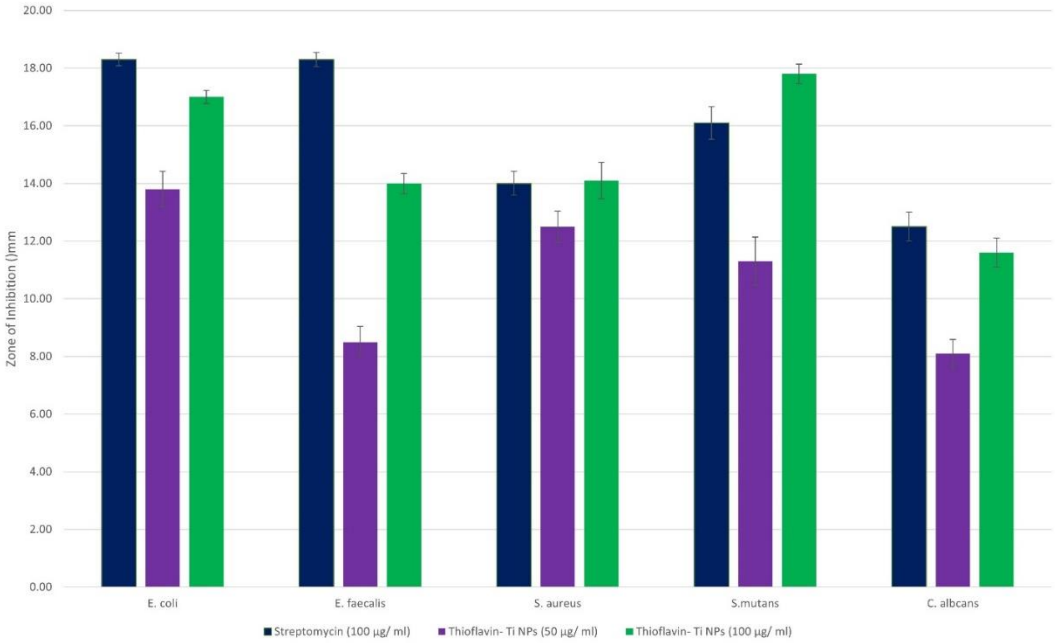

Figure 3: Antimicrobial activity of Thio-TiO_2 NPs against different pathogens

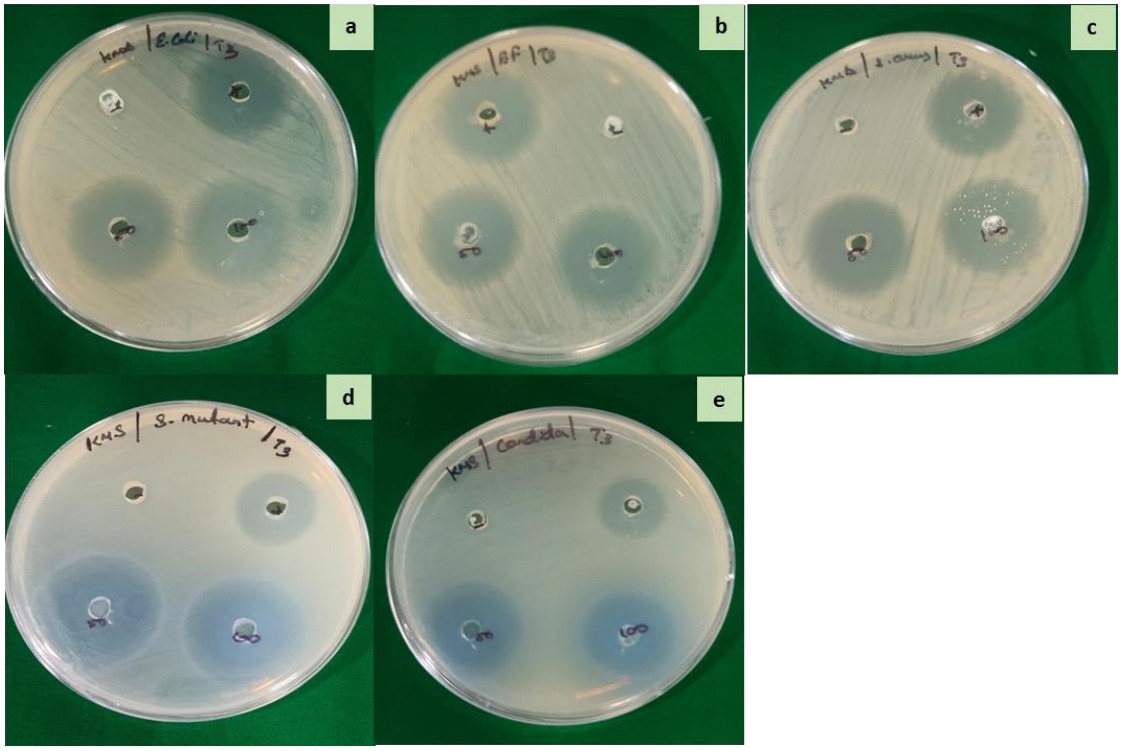

Figure 4: Antimicrobial activity of Thioflavin-Derived Titanium Oxide Nanoparticles for bacterial and fungal strains a) *Escherichia coli* b) *Enterococcus faecalis* c) *Staphylococcus aureus* d) *Streptococcus mutans* e) *Candida albicans*

3.4 Molecular docking analysis

A catalytic tunnel composed of ALA(9), PRO (A7), and PRO (B7) is found in the active site of the 1F3H protein (PDB:1F3H) (Figure 4). The catalytic activity of this enzyme can be significantly influenced, inhibited, or even halted by targeting these amino acid

residues. Furthermore, the active site residues of the Thioflavin-Derived Titanium Oxide Nanoparticles (Th-TiO_2NPs) receptor are conserved across both Gram-positive and Gram-negative bacteria, making the 1F3H protein a promising therapeutic target for developing innovative and broad-spectrum antimicrobial drugs as selective and non-toxic 1F3H inhibitors. To predict the in vitro efficiency of Thioflavin-Derived Titanium Oxide Nanoparticles (Th-TiO_2NPs), a molecular docking study was performed using the ligand-1F3H model. Docking Th-TiO_2NPs into the modeled 1F3H receptor was conducted to investigate the proper nanoparticle orientation within the receptor and to obtain valuable information regarding the active mechanism. This includes non-covalent interactions between the active site of the receptor and Th-TiO_2NPs, which could lead to the development of new drugs for further biological research(Sharma, Sharma et al. 2016).

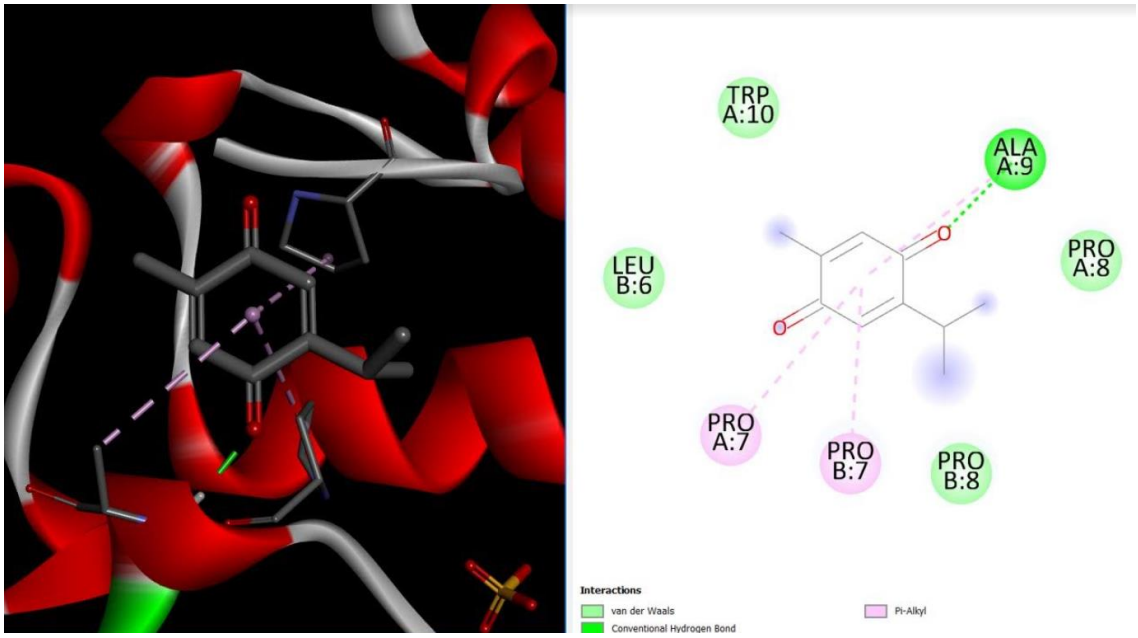

Figure 5: Molecular docking study of receptor, ligand (Thioflavin) best docking pose and various Thioflavin-Derived Titanium oxide Nanoparticles interactions with amino acids contribute to cavity formation

4. DISCUSSION

Dental caries, a prevalent oral health issue driven by bacterial activity, underscores the need for novel antimicrobial agents to combat antibiotic-resistant pathogens(Philip, Suneja et al. 2018). Traditional treatments often fall short due to the growing problem of bacterial resistance, prompting a shift towards innovative solutions. In this context, the use of nanoparticles (NPs) has emerged as a promising approach. Among these, Thioflavin-Derived Titanium Oxide Nanoparticles (Th-TiO_2NPs) exhibit significant potential due to their unique physicochemical properties and broad-spectrum antimicrobial activity. Incorporating Th-TiO_2NPs into dental care formulations could revolutionize the management of dental caries. Th-TiO_2NPs possess several advantageous properties that make them suitable for dental applications. Their small size and large surface area-to-volume ratio enhance their antimicrobial activity, allowing for better penetration and interaction with bacterial cells. This increased surface reactivity enables Th-TiO_2NPs to disrupt bacterial cell membranes, leading to the release of reactive oxygen species (ROS) which can bind to cellular components,

interfere with metabolic pathways, and ultimately cause cell death. The photooxidizing and photocatalytic properties of Th-TiO_2NPs further contribute to their antimicrobial efficacy. When exposed to light, Th-TiO_2NPs can generate ROS, which damage bacterial cell walls, DNA, and other cellular components. This light-activated antimicrobial action can be particularly useful in dental applications, where controlled light exposure can enhance the effectiveness of Th-TiO_2NPs-containing treatments. Additionally, Th-TiO_2NPs have shown effectiveness against biofilms, which are complex bacterial communities that adhere to surfaces and are highly resistant to conventional treatments. Biofilms play a significant role in the progression of dental caries, as they protect cariogenic bacteria like Streptococcus mutans from the effects of antimicrobial agents. The ability of Th-TiO_2NPs to penetrate and disrupt biofilms offers a significant advantage in dental caries prevention and treatment(Devi and Duraisamy 2020).

The biocompatibility of Th-TiO_2NPs is another important consideration for their use in dental products. Studies have shown that these nanoparticles can be incorporated into dental materials such as composite resins, adhesives, and sealants without compromising their mechanical properties or causing adverse effects on surrounding tissues. This makes them suitable for a range of dental applications, including fillings, coatings, and oral hygiene products. The antimicrobial efficiency of Th-TiO_2NPs against common oral pathogens, major contributors to dental caries, underscores their potential in dental applications(Raj, Martin et al. 2024). By inhibiting biofilm formation and bacterial proliferation, these nanoparticles could significantly reduce the incidence of dental caries and improve overall oral health. Moreover, the catalytic properties of Th-TiO_2NPs can be tailored to enhance their antimicrobial efficacy. The catalytic triad tunnel composed of Valine, Lysine, and Histidine in the active site of the 1F3H protein (PDB:1F3H) is a key target for these nanoparticles. The interaction of Th-TiO_2NPs with these amino acid residues can significantly influence, inhibit, or even halt the catalytic activity of the enzyme, offering a targeted approach to combat bacterial activity. In summary, Thioflavin-Derived Titanium Oxide Nanoparticles present a promising approach to addressing dental caries by leveraging their unique properties. Their ability to penetrate biofilms, generate ROS, and maintain biocompatibility with dental materials makes them ideal candidates for advanced dental treatments(Duraisamy, Ganapathy et al. 2021). The potential of Th-TiO_2NPs to inhibit key bacterial enzymes and reduce the incidence of dental caries could lead to significant advancements in oral health care, offering a novel solution to a pervasive problem(Shah, Nallaswamy et al. 2020).

5. CONCLUSION

In conclusion, Thioflavin-Derived Titanium Oxide Nanoparticles (Th-TiO_2NPs) represent a promising innovation in the fight against dental caries. Their unique physicochemical properties, including effective biofilm penetration, ROS generation, and biocompatibility with dental materials, make them ideal for advanced dental treatments. By targeting key bacterial enzymes and disrupting biofilms, Th-TiO_2NPs can significantly reduce bacterial activity and prevent dental caries. This novel approach holds great potential for improving oral health care and overcoming the limitations of traditional antimicrobial treatments

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