

Improving the stability of the football ball by adding nanocomposites into polymer layer

Huayun Tian and Lu Li*

Department of Physical Education, Wuhan University of Technology, Wuhan 430076, Hubei, China

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Abstract. Nanotechnology, the science of manipulating matter at the nanoscale, offers remarkable opportunities for innovation across various fields. Nanomaterials, which form the cornerstone of advanced materials, drive forward new ideas and groundbreaking applications. In the textile industry, traditional antibacterial and antifungal garments are typically treated with chemical compounds to inhibit bacterial growth. However, these treatments often lack durability, losing effectiveness after multiple washes. To address this limitation, the application of green nanotechnology in developing high-performance textiles emerges as a promising solution. This study explores the integration of nanocomposites into the polymer layers of footballs to enhance their stability and performance. By embedding nanoparticles within the polymer matrix, the durability and resilience of the footballs are significantly improved, leading to better control and performance on the field. This innovative approach not only extends the lifespan of the footballs but also provides economic advantages by reducing the frequency of replacements. Additionally, the enhanced stability contributes to a more consistent and reliable playing experience, promoting improved safety and performance for athletes.

Keywords: durability; football stability; nanocomposites; nanotechnology; performance enhancement; polymer layers

1. Introduction

Throughout history, people, especially scientists, believed that matter could be broken down into small enough pieces to become indestructible particles (Modreanu 2022). The Greek philosopher Democritus was the first to use the word atom in the indivisible sense to describe the particles that make up matter (Plastina 2022). In 1959, Richard Feynman published an article about the future possibilities of nanotechnology. Despite the positions held by many until then, Richard. P. Feynman is known as the founder of this science (Modreanu 2022, Srivastava *et al.* 2022). In nanotechnology, materials and elements are decreased to 1 and 100 nanometers (Ashfaq *et al.* 2022). In this case, the materials show extraordinary and unique properties and characteristics used in various science branches (Khan *et al.* 2022b). Nanotechnology is known for its potential to increase energy consumption efficiency, help clean the environment, solve health problems, and even help people's daily life (Okeke *et al.* 2022). This technology can significantly reduce costs. Nanotechnology products are smaller, cheaper, lighter, and at the same time more practical, and more importantly, less energy and raw materials have been operated in their production (Kaushik 2022). Although the natural world contains many nanometer-scale structures, such as vital molecules in the human body and dietary components, it has only become possible to systematically and deliberately alter molecules in the past quarter century (Basu and Dhasmana 2022).

Nanotechnology in its many forms has the potential to make a tremendous influence on society. In general, the use of nanotechnology will benefit both people and organizations. (Govarthanan *et al.* 2022). New materials with unique features at the nanoscale level are used in these applications (Esparham *et al.* 2021, Guo *et al.* 2021, Wang *et al.* 2021, Zhao and Yu 2021, Zhong and Liang 2022). The electronics and optoelectronics industries, the food and energy technology sectors, the medical product manufacturing industry, and a wide range of pharmaceuticals, drug delivery systems, diagnostics, and medical technology are just a few of the many industries that have embraced nanotechnology with open arms (Khan *et al.* 2022a). Materials at scales of about nanometers show different physical properties than the normal state (Egwu *et al.* 2022). This is because the atoms and molecules of materials on the nanoscale have more freedom of action, affecting their chemical properties and, as a result, their physical properties (Joudeh and Linke 2022). Structures of nanomaterials expose more surfaces to bond with other nanoparticles. Nanoparticles have different ways of interacting with each other (Bunmahotama *et al.* 2022). Depending on their attractive or repellent interaction forces, they can remain free or join jointly. Nanoparticles suspended in gas tend to stick together more than liquids (Chen 2023). Nanoparticles cannot be seen with conventional light microscopes due to the wavelength range of visible light in the region of 400-700 nm and require electron microscopes or laser microscopes (Zavašnik *et al.* 2021). Therefore, nanoparticle dispersions in bright environments can be transparent, while larger particles are usually opaque. They scatter some or all of the visible light that falls on them (Kuroiwa and Tatsuma 2020).

*Corresponding author, Ph.D.,
E-mail: l04201212@163.com

A Composite is a combination macroscopically made of several distinct materials so that these components can be easily distinguished (Biswal *et al.* 2020). The nanocomposite is also the same composite, with the difference that one or more of its components have dimensions less than 100 nanometers (Sadeghpour *et al.* 2022). Each nanocomposite consists of two phases. The first phase is a crystal structure, a base or matrix made of polymer, metal, or ceramic (Zhang *et al.* 2020b, Huang *et al.* 2024, Wei *et al.* 2024, Wu *et al.* 2024). The second phase is nanometer-scale particles distributed inside the first phase as reinforcement (Musil and Vlček 2001). Nanoparticles used in nanocomposites increase the flexibility, the barrier to the entry and exit of gases, and the moisture and thermal stability of the polymers formed from them (Müller *et al.* 2017).

The sensor can detect the existence of a stimulus or its changes and react to it (Rensink 2000). Nanosensors are inherently more diminutive and more sensitive than other sensors (Hangarter *et al.* 2013). Also, they have the capacity that their cost price is lower than the cost price of sensors in the market. Nanosensors react to environmental changes, temperature, humidity, oxygen levels, and microbial and pathogenic factors (Patel *et al.* 2020, Mohammadpour and Naghib 2021).

Rehabilitation refers to a series of therapeutic treatments designed to improve a patient's functional capacity after an injury or illness and to lessen the impact of that condition on daily life (Waddell and Burton 2005). In many rehabilitation processes, the injury, problem, and disease are not entirely fixed, and the goal of rehabilitation is not necessarily a complete cure (Seo and Mooney 2022). The methods available in rehabilitation may cause a complete cure for the person. When it is impossible to cure or eliminate a disease or problems complications, ultimately, rehabilitation can provide the highest quality of life and individual, muscular, joint, and mental-psychological performance (Janssen *et al.* 2021, Campagnini *et al.* 2022). Rehabilitation programs depend on the disease and problem and the referring person, as a result, rehabilitation treatment programs may differ from one person to another. Rehabilitation treatments are conducted for hospitalized and discharged patients in the clinic and at home (Prabawa *et al.* 2022, van Haastregt *et al.* 2022).

Titanium dioxide nanoparticles are one of the most widely used semi-conducting nanoparticles with special hydrophilic, photocatalytic, ultraviolet light absorbing, and antibacterial properties and are widely used in the manufacture of polymer nanocomposites (Sunny *et al.* 2022, Younis *et al.* 2022). All the properties of titanium dioxide are found in titanium dioxide nanoparticles, but since nanoscale materials have high reactivity, these materials also have higher efficiency in nanoscale. Each of them has a central feature and a unique characteristic (D *et al.* 2022). This characteristic of antibacterial nanoparticles is the photocatalytic and superhydrophobic properties of these particles, which makes titanium nanoparticles different from other antibacterial nanomaterials (Anbumani *et al.* 2022). Also, other optical and electrical properties, low prices, chemical stability, and non-toxic and green

products have been used in various industries (Ali *et al.* 2022b). Researchers must manufacture ecologically acceptable nanoparticles without the use of hazardous and dangerous compounds utilizing synthesis techniques (Ding and She 2021, Cuong Bui 2022, Soltanieh *et al.* 2022, Wu *et al.* 2022). Various chemical and physical methods used to manufacture nanoparticles may cause environmental contamination, including chemical and physical pollution. Utilizing enzymes, microorganisms, and plant extracts, scientists have made significant attempts to produce nanomaterials in a manner that is ecologically benign. In recent years, along with genetic engineering and the manufacture of pest-resistant transgenic plants, the biosafety and low environmental risk of nanometal synthesis using plant extracts has caught the attention of researchers. Plant extracts include reducing agents that, when exposed to metal salts, convert them into metal ions. Using plant extracts to synthesize nanoparticles is also straightforward, inexpensive, and ecologically benign. (Shiva Samhitha *et al.* 2022, Xing *et al.* 2023).

Chitosan, a natural polysaccharide, is similar to the structure of cellulose and is obtained from the deacetylation of chitin. Chitin is the second most abundant biopolymer after cellulose, made by many living organisms (Zhang *et al.* 2017, Yang *et al.* 2020, Su *et al.* 2023, Jiang *et al.* 2024). This substance is the main component of the cell wall of fungi, the exoskeleton of arthropods such as crabs, shrimps, and insects. Among the properties of chitosan are: biocompatibility, biodegradable, non-toxic, surface absorption on surfaces, heat stability, and anti-bacterial properties. Furthermore, the low cost makes it suitable for various scientific and engineering processes (Ali *et al.* 2022a, Wang and Zhuang 2022).

Urinary and fecal incontinence is a common disease in men and women that can happen at any age. Performing sports rehabilitation exercises for urinary incontinence is one of the ways to treat this condition (Nambiar *et al.* 2022). Bacteria can enter the urinary system outside the body and cause infections and inflammation. This condition causes urinary tract infections (Bull *et al.* 2022). The following bacteria usually cause urinary tract infections: *Escherichia coli*, *Proteus mirabilis*, and *Enterococcus faecalis*. Infections and cysts in the end parts of the reproductive and urinary tracts almost always occur due to the pathogen entering from their exit holes located in the lower parts of these tracts. Therefore, the infection will spread from lower to higher parts (Prasada Rao *et al.* 2022).

Nanotechnology has revolutionized various industries by enabling the manipulation of matter at the nanoscale, offering unique opportunities for innovation and advancement (Xia *et al.* 2019, Zhang *et al.* 2020a, Pang *et al.* 2022). In the field of sports equipment, particularly footballs, stability and performance are critical factors that can be significantly enhanced through the incorporation of nanocomposites. Traditional methods of enhancing the durability and performance of footballs have relied on chemical treatments, which often lack long-term resilience and effectiveness. These conventional approaches are insufficient in addressing the persistent issue of wear and tear, leading to frequent replacements and increased costs.

Moreover, they fail to offer adequate antimicrobial properties, which are essential for maintaining hygiene and safety in sports environments (Omid *et al.* 2013, Azimi *et al.* 2016, Ghadiri *et al.* 2016a, b, c, Shafiei *et al.* 2016, 2017, Mousavi *et al.* 2017).

To bridge these gaps, this study explores the integration of chitosan and titanium dioxide (TiO₂) nanocomposites into the polymer layers of footballs. This approach leverages the remarkable antimicrobial properties of chitosan and the stability and longevity of TiO₂ nanoparticles. The novelty of this work lies in the combination of these nanomaterials to create a composite that not only enhances the mechanical properties of the footballs but also provides significant antimicrobial benefits. By inhibiting bacterial growth and increasing the durability of the footballs, this innovative solution addresses both the performance and safety concerns associated with traditional footballs. The application of green nanotechnology in this context represents a promising advancement in sports equipment design, paving the way for more reliable, durable, and hygienic footballs.

2. Materials and equipment

The list of materials and equipment used for the green synthesis of titanium dioxide nanoparticles for the synthesis of chitosan nanocomposite and to investigate the antibacterial effect of this nanocomposite as a bacteria sensor in diapers is shown in Table 1.

3. Test method

3.1 Preparation of TiO₂ nanoparticles

The leaf extract of *Lawsonia inermis* was employed in the production of titanium dioxide nanoparticles. The leaf samples were cleaned with distilled water and dried for two weeks at room temperature and in the shade. Then the dried leaves were powdered using a grinder. The 200 grams of powder prepared from *Lawsonia inermis* leaves were mixed with 500 ml of deionized water and placed on a heater with a temperature of 60° C for 15 minutes to boil. After cooling, it was passed through the Whatman filter paper. Then the prepared aqueous extract was placed in an oven with a temperature of 60° C to dry. To synthesize titanium dioxide nanoparticles, 2 grams of extract powder was mixed in 100 milliliters of deionized water and placed on a heater with a temperature of 70 °C. Then the appropriate amount of titanium isopropoxide was added drop by drop and kept for 20 minutes. The solution was kept at 60° C for 100 minutes. The colored solution was centrifuged at 4000 rpm for 40 minutes. The synthesized nanoparticles were separated and dried in an oven at 70 °C. The dried samples were placed in the oven at 300 °C for 4 hours. Identification of the type of bonds and chemical composition in the synthesized titanium dioxide nanoparticles was analyzed by Fourier-transform infrared spectroscopy and the shape and size of nanoparticles using SEM photography.

Table 1 List of materials and equipment

Materials	Equipment
Lawsonia inermis leaf	Heater
Distilled water	Oven
NaOH	Whatman filter paper
Chitosan	Centrifuge
Acetic acid	Scanning electron microscope (SEM)
	Incubator
Titanium isopropoxide	Fourier-transform infrared spectroscopy (FT-IR)
	Ultraviolet-Visible spectroscopy (UV-Vis)
	Ultrasonic

3.2 Preparation of chitosan

First, one gram of chitosan was dissolved in fifty milliliters of distilled water, then one milliliter of acetic acid was added and the mixture was stirred for twenty-four hours. This solution was diluted to a level of 100 ml with distilled water after 24 hours, and then the pH was corrected to 5 using NaOH (0.5 M). Then, concentrations of 0.5, 1, 3, and 5 mg/ml were produced for testing with this solution. Acetic acid was used to dissolve chitosan in this step (Qi *et al.* 2024, Wang *et al.* 2022, Jia *et al.* 2023, Zhang *et al.* 2023a, b, c, Yan *et al.* 2024).

3.3 Preparation of chitosan-titanium dioxide nanocomposite

For the nanocomposite preparation, concentrations of chitosan solution and titanium dioxide solution that had the most excellent antibacterial effect were selected. The green method added a certain amount of titanium dioxide nanoparticles to chitosan. In the end, the solution is poured into a container, and after drying, a white film is formed as a chitosan-TiO₂ nanocomposite.

3.4 Antibacterial activity of titanium dioxide nanoparticles and chitosan

Using the diffusion technique, the antibacterial activity of produced titanium dioxide nanoparticles against Gram-negative and Gram-positive bacteria was investigated (Ebrahimi *et al.* 2017, Ehyaei *et al.* 2017, Ghadiri *et al.* 2017a, b, c, Shivanian *et al.* 2017, Shahabinejad *et al.* 2018, Shafiei *et al.* 2020). All bacterial strains were cultivated in a linear fashion and incubated for 24 hours at 35 degrees Celsius. Bacteria were cultured on the plate. In each plate, three wells were created at certain time intervals, and different concentrations of titanium dioxide nanoparticles made from *Lawsonia inermis* leaves were prepared separately in deionized water. After sonication, using a sampler, about 10 microliters of Each well was injected. The diameter of non-growing halos was measured after 24 hours of incubation at 35°C, and the non-growing halos were less resistant to titanium dioxide nanoparticles.

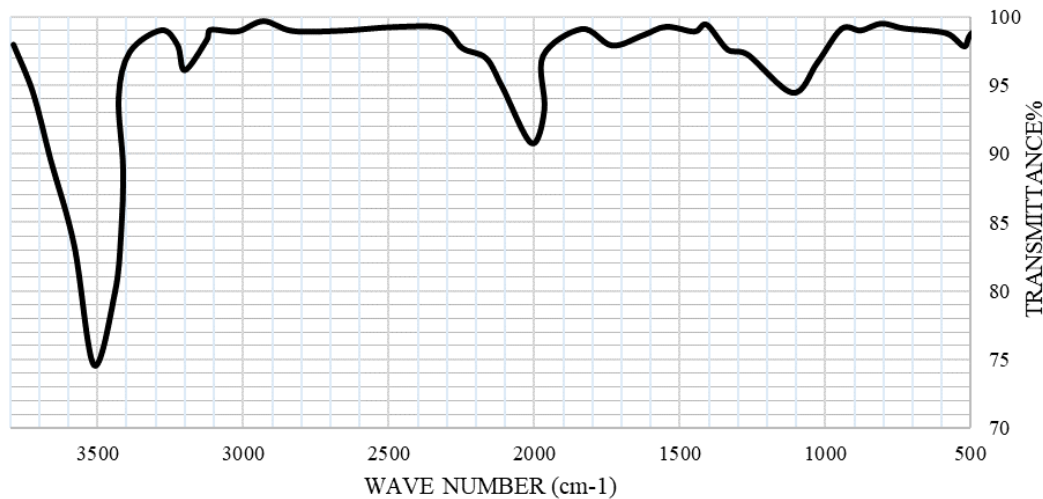


Fig. 1 FTIR spectroscopy of TiO_2

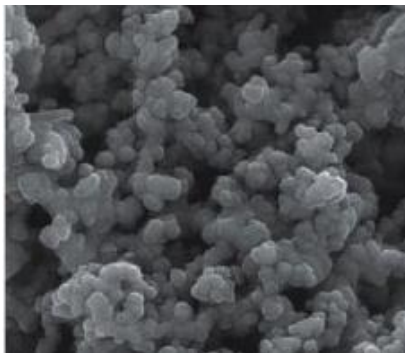


Fig. 2 SEM image of TiO_2 nanoparticles

Staphylococcus bacteria and Escherichia coli bacteria were tested in this work. These conditions were also used to investigate the antibacterial effect of prepared chitosan.

3.5 Preparation of diapers containing chitosan- TiO_2 nanocomposite

Immersion coating involves immersing a substrate (diapers) in a coating material (nanocomposite) at a constant rate. It is a process used to create high-volume products such as coated fabrics and coatings in the biomedical field. This coating method can provide a uniform, high-quality film even in bulky and complex forms.

First, the diaper cover was placed in the designed solution of chitosan- TiO_2 nanocomposite and subjected to ultrasound for 40 minutes. Then it was washed with distilled water to coagulate the nanocomposite on the fabric and placed at 150°C for 5 minutes. In order to investigate the effect of the nanocomposite, visible-ultraviolet spectroscopy was performed.

4. Results and discussion

4.1 FTIR spectroscopy

The results of FTIR spectroscopy of titanium dioxide of

the synthesized sample are shown in Fig. 1. The FTIR spectrometer has measured vibrations in the range of wavelengths from 450 to 4000 cm^{-1} . The large peak observed in the 3400 to 3600 cm^{-1} region is related to the stretching vibration of the hydroxyl (OH) group attached to Ti. The peak observed in 1700 cm^{-1} is related to the vibration of the carbonyl group. The shoulders are seen at 500 and 650 cm^{-1} , and generally, the peaks below 810 cm^{-1} are related to the stretching vibrations of bands such as Ti-O and -Ti-. The mentioned bands in the FTIR spectrum indicate Ti presence in the structure of nanoparticles and the formation of TiO_2 nanoparticles.

4.2 Image of SEM

The results of scanning electron microscopy showed the spherical shape of the synthesized titanium dioxide nanoparticles. As shown in Fig. 2, the nanoparticles have spherical particles with dimensions of about 230 nm , formed from the aggregation of TiO_2 nanoparticles with relatively the same size and around 22 nm . The size of titanium dioxide nanoparticles depends on the reaction temperature, the extracts concentration, the titanium solutions concentration, and the duration of the reaction.

4.3 UV absorption

UV absorption test was performed on chitosan solution, TiO_2 , and chitosan- TiO_2 nanocomposite (Fig. 3). (Maximum wavelength) λ_{max} for chitosan, TiO_2 , and their nanocomposite, respectively, was equal to 210 , 290 , and 210 nm . The wavelength with the maximum absorption is the same for chitosan and chitosan- TiO_2 nanocomposite, and the absorption of nanocomposite is lower than chitosan. This indicates that these two materials have reacted well together.

4.4 Antibacterial activity

First, the antimicrobial effect of chitosan nanoparticles and TiO_2 nanoparticles with different concentrations was

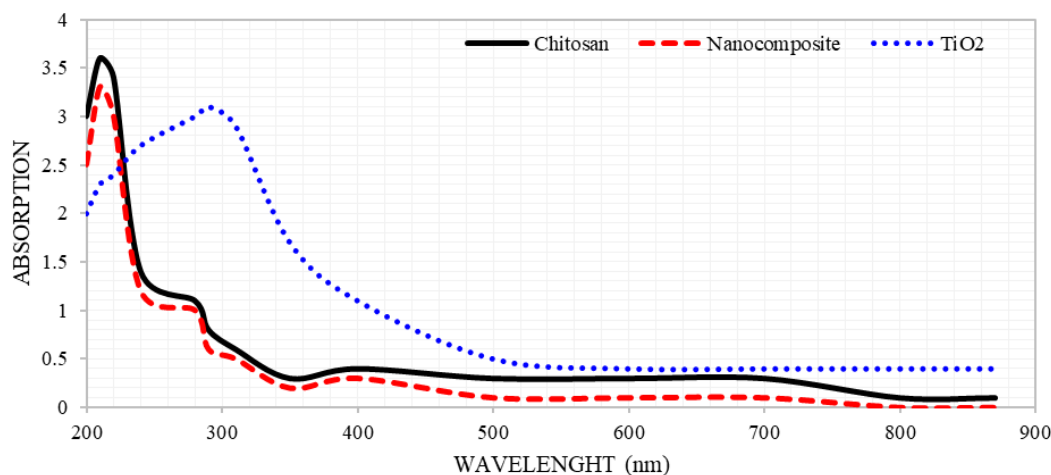


Fig. 3 UV-VIS absorption for chitosan solution, TiO₂ and nanocomposite

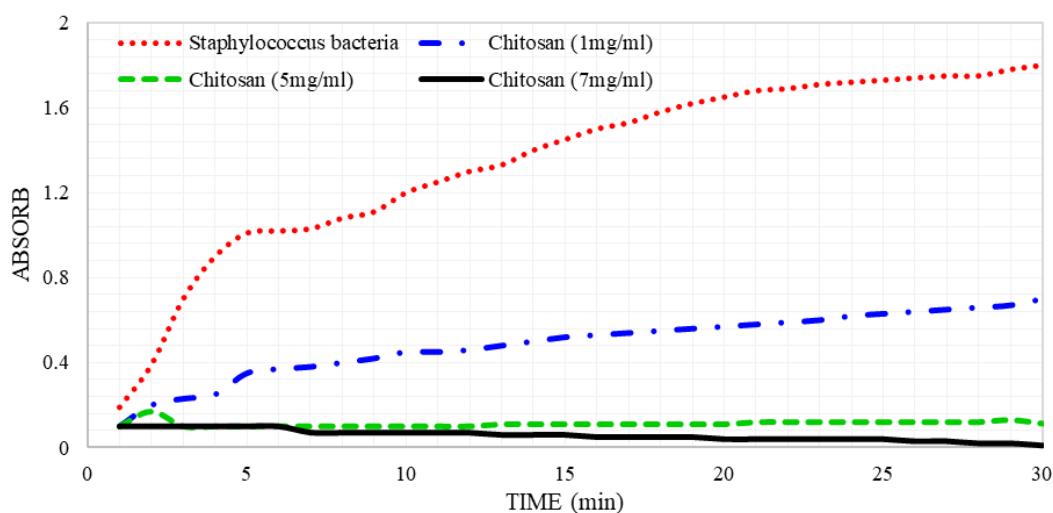


Fig. 4 Effect of chitosan nanoparticles on Staphylococcus bacteria in liquid culture medium

investigated separately in both solid culture medium and liquid culture medium. The antimicrobial effect of chitosan at concentrations of 0.5, 1, 5, and 7 mg/ml was investigated in liquid and solid culture media, and the results are as follows:

In the solid culture medium, it was observed that the concentration of 5 mg/ml had the best effect in inhibiting the growth of bacteria on both Staphylococcus and Escherichia coli bacteria. In the liquid culture medium, the bacterial growth process for both Escherichia coli and Staphylococcus bacteria was investigated and measured separately in the presence of chitosan nanoparticles with different concentrations. The results obtained are shown in Figs. 4 and 5. By increasing the concentration of chitosan nanoparticles, the activity of Staphylococcus bacteria decreases further, that is, there is a direct relationship between the number of nanoparticles consumed and the decrease in the activity of this bacteria.

Over time, it was found that the concentration of 7 mg/ml of chitosan nanoparticles had the most significant inhibitory effect on Staphylococcus compared to other

concentrations of this nanoparticle.

Increasing the concentration of chitosan nanoparticles also decreases the activity of Escherichia coli bacteria. Here, too, there is a direct relationship between the dosage of nanoparticles and the decrease in the activity of this bacterium. Over time, the concentration of 8 mg/ml of chitosan nanoparticles compared to the concentrations of 1 and 5 mg/ml of this nanoparticle has the most inhibitory effect on Escherichia coli bacteria.

The antimicrobial effect of TiO₂ in concentrations of 0.5, 2 and 4% were investigated in liquid and solid culture media, and the results are as follows:

In the solid culture medium, it was observed that the concentration of 4% had the best effect in inhibiting the growth of bacteria on both Staphylococcus and Escherichia coli bacteria. With the increase in the amount of TiO₂ nanoparticles, the diameter of the halo formed by the bacteria becomes smaller, and it shows a substantial decrease in the activity of these bacteria, that there is a direct relationship between the number of nanoparticles consumed and the reduction of bacterial activity.

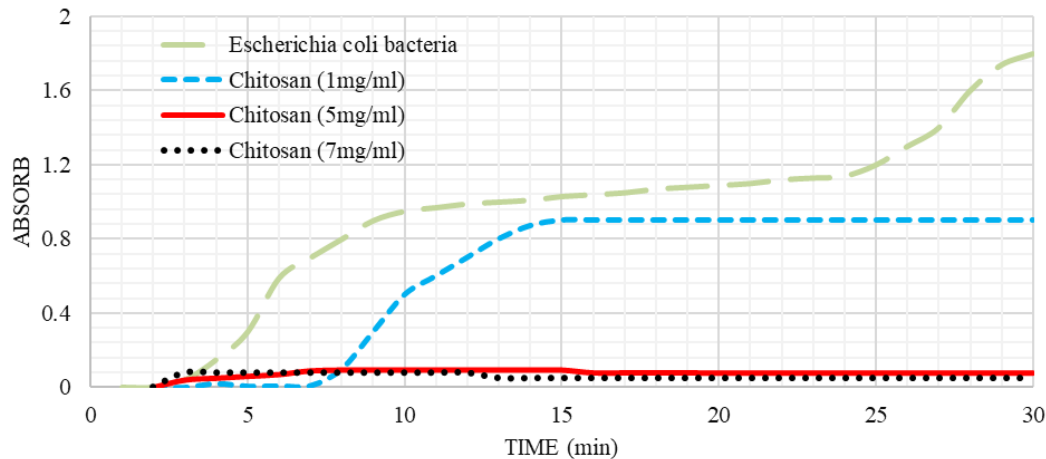


Fig. 5 Effect of chitosan nanoparticles on Escherichia coli bacteria in liquid culture medium

4.5 Investigating the effect of nanocomposite in solid and liquid culture medium

The upper cover of the garment containing nanocomposite synthesized in solid culture medium for both types of bacteria after 24 hours of placing two bacteria on the culture medium, it was observed that the cover without nanocomposite is a suitable environment for the growth of bacteria. For both types of bacteria, but in clothes containing nanocomposite, no bacteria grow, and the environment is free of bacteria. In the liquid culture medium, the effect of chitosan-TiO₂ nanocomposite was investigated. The effect of nanocomposite in preventing the growth of bacteria can be seen in Fig. 6. The anti-bacterial effect of nanocomposite is excellent, and the bacteria have not had a chance to grow. These graphs show the investigation of the antimicrobial effect in the liquid culture medium. Their optical density has changed by comparing the change in the transparency of the solutions in front of the control solution. As a result, the absorption will change. These Figs. show that the light density of the liquid culture medium in the presence of bacteria and nanocomposite is equal to the light density of the control medium, which has no bacteria from the beginning. So, the conclusion that can be drawn is that in the presence of chitosan-TiO₂ nanocomposite, no microbes have grown, and this nanocomposite has prevented the growth of bacteria.

5. Conclusions

In this study, the integration of nanocomposites into the polymer layers of footballs has been explored to enhance their stability and performance. The incorporation of nanoparticles within the polymer matrix was found to significantly improve the durability and resilience of the footballs, thus offering a more consistent and reliable playing experience. This innovative approach is not only expected to extend the lifespan of the footballs but also to provide economic benefits by reducing the frequency of replacements.

The green nanocomposite, comprising chitosan and

titanium dioxide (TiO₂), was demonstrated to possess remarkable antimicrobial properties, rendering it suitable for improving the stability and performance of footballs. Chitosan, a polycationic compound derived from chitin, effectively interacts with negatively charged substances, thereby enhancing the structural integrity of the polymer layers. Its solubility in acidic environments and ability to bond with biological surfaces further contribute to its effectiveness in various applications.

Titanium dioxide nanoparticles, known for their stability, longevity, and resistance to various microbes, play a crucial role in the enhanced performance of the footballs. These nanoparticles exhibit photocatalytic properties, making them valuable in self-cleaning surfaces and antimicrobial materials. The chitosan-TiO₂ nanocomposite was found to effectively inhibit bacterial growth, ensuring that the footballs remain free from harmful germs, thereby promoting a safer playing environment.

Given the demonstrated antimicrobial properties and the potential for enhancing football performance, the application of chitosan-TiO₂ nanocomposites is considered highly promising. This approach is expected to not only improve the stability and durability of footballs but also to contribute to a safer and more reliable sports experience. The findings of this study are anticipated to pave the way for future innovations in sports equipment, leveraging the benefits of nanotechnology to enhance performance and safety.

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