Green Synthesis of Zirconium Oxide Nanoparticles and their Effect on Inhibition Growth of Bacteria

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Abstract— Nanotechnology begins with the characterization, production, and possible uses of a wide range of nanoscale materials. Because of their high surface-to-volume ratio and other essential features, nanomaterials have served as a platform for researchers in a variety of domains throughout the last few decades. In the field of nanobiotechnology, the fabrication of environmentally friendly and reliable nanoparticles is important. Among nanoparticles, zirconium nanoparticles are biocompatible and possess distinct mechanical, electrical, and optical properties that attract the attention of many researchers. Zirconium nanoparticles receive many diverse biomedical applications due to their distinctive antibacterial, anti-oxidant, anti-cancer and anti-fungal properties. In recent decades, an environmentally friendly and safe approach has been developed to produce nanoparticles avoiding dangerous by-products. One of these safe methods is the bio-green approach. Pollution and diseases resulting from bacterial infections are major issues that can be solved completely or partially using nanotechnology. Many bacterial species are pathogenic to humans and other organisms, and some of them are resistant to drugs, so continuous research is required to address this problem. In this review, zirconium oxide and its antibacterial applications are studied.

Keywords— Zirconium Oxide Nanoparticles, anti-bacterial growth, nano-particles, green synthesis, Ecofriendly nanoparticles

I. INTRODUCTION

Nanomaterials are in high demand and are being manufactured in a variety of fields, including aerospace, biopharmaceuticals, sensors, catalysis, cosmetics, healthcare, mechanics, electrochemistry, energy, agriculture, electronics, and synthetic materials. Chemistry, food technology, optics and optical equipment, pharmaceuticals, and textile manufacturing [1,2]. Infectious disorders produced by microorganisms in general, and bacteria in particular, are among the most common in the world, killing millions of people each year [3]. Archaeologists have discovered fossilized bacteria dating back over 3 billion years, making bacteria the oldest and most ubiquitous living species on Earth [4]. Many bacterial species are capable of producing diseases in people and other organisms because they have a multitude of chemical or genetic properties that can serve as disease-causing agents. Virulence factors, which enable the bacterial cell to hurt the host by manufacturing toxins and a variety of other enzymes [5], Excessive and frequent antibiotic use has resulted in the creation of resistant generations and strains. Bacterial resistance is a global issue [6]. As a result, research is focusing on finding alternatives to antibiotics, such as nanoparticles made from certain metals and their oxides, which have emerged as a promising alternative in recent years. [7] Some materials' nanoparticles have distinct physical and chemical properties when compared to their natural size, which qualifies them to enter many fields, starting with electronics and not ending with the medical field [8]. Many metals and minerals that are designated as harmless for microorganisms in their natural form revealed considerable toxicity at the nanoscale level due to the increased specific surface area. and increased reactivity of these particles. [9 ,10]. Many metal oxides have exceptional antibacterial properties, including ZnO, TiO_2, Fe_2O_3, CuO, ZrO_2, etc. [11, 12]. Among the transition metal oxide nanoparticles, ZrO_2 NPs have attracted significant research interest due to their electrical, thermal, catalytic, sensing, optical, mechanical, and biocompatible properties. ZrO2 NPs, one of the transition metal oxide nanoparticles, have garnered a lot of attention from researchers because of their mechanical, optical, electrical, thermal, catalytic, sensing, and biocompatible characteristics [13, 14]. Zirconium dioxide (ZrO_2) is a mineral oxide that has many uses. In medical fields, the use of zirconium oxide nanoparticles (ZrO_2) (Nano-ZrO_2) is rapidly increasing [15, 16]. Zirconium oxide (ZrO_2) is emerging as a very interesting and promising nanomaterial in the world of metallurgy [17].

II. NANOTECHNOLOGY

Nanotechnology is the focus of attention, and many countries in the world are betting on it, as it is very small and promises a qualitative breakthrough in all fields of science [18]. Nanotechnology is defined as the engineering, manufacturing, characterization, and use of materials and tools on a scale of 100 nanometers or less [19]. It is also considered a broad and developed field that depends on the study of nanoscience and related sciences, as this technology includes the manufacture of many devices, structures, and systems that consist of very small units, with the availability of technological capabilities in producing nanoparticles and controlling their internal structure through rearranging the

Received: 24-6-2024
Revised: 3-8-2024
Published: 6-8-2024

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molecules and atoms that make up the nanoparticles. Particles for the purpose of obtaining special and useful products used in various scientific applications [20, 21]. Nanoparticles are atomic or molecular aggregates ranging in size from 1 to 100 nanometers. They have a number of distinguishing characteristics, including a large surface area, high surface energy, and high quantum confinement [22]. Nanoparticles possess unique capabilities for electrical, magnetic, and chemical catalysis. It is also distinguished by great stability, minimal reactivity, biocompatibility, and a low level of toxicity. They are available in a variety of forms, making them widely usable in many disciplines of biomedicine, including cancer detection and therapy. Other diseases, pharmaceutical production, and gene delivery. Certain metal nanoparticles exhibit antiviral, antibacterial, antifungal, and anticancer effects [23].

III. Green Synthesis of Nano-Particles

Utilizing environmentally friendly techniques to create metal oxide nanoparticles is a key topic of current research in the field of nanobiotechnology. The fact that this process is safe makes it superior to both the chemical and physical methods. e, easy to use, fast, and cost-effective and can also produce a wide range of materials. nanoparticles easily. NPs and also using this approach does not require any requirements of energy, pressure, temperature increase and toxic chemicals [24, 25]. The use of physical and chemical methods has several downsides, including the release of a highly poisonous chemical into the environment, which is hazardous to the ecosystem, time-consuming, expansive, and energy-intensive. To address these challenges, environmentally friendly nanoparticle preparation technologies are already available. Compared to the old approach, the green-mediated approach offers many advantages, which are biocompatible, environmentally friendly, and more exciting [26, 27] .In this method, plants are used by using different parts of plants to prepare nanoparticles. In addition, fungus, bacteria, algae, and other biological compounds, including egg albumen and starch, are utilized as capping, reducing, and oxidizing agents [27, 28]. In general, there are two approaches. There are two main methods for nanoparticle assembly, which are top-down and bottom-up [29]. The first method involves turning bulk materials into thinner crystals through physical techniques. This necessitates the use of enormous mechanical energy sources like grinding and ionic breaching [30]. As a result, the top-down technique has numerous unavoidable shortcomings, including secondary impressions or intermediates that alter the physicochemical properties and surface chemistry of the generated nanoparticles [31]. Importantly, top-down techniques do not typically yield nano-sized particles. Meanwhile, particle production is the process of forming building blocks from very small particles such as atoms or molecules and then combining them together. In this method, nanostructured particles can be created purposely under the control of manufacturing circumstances [32]. Physical (such as vapor decomposition, plasma irradiation, ultrasonization), chemical (such as sol-gel, co-precipitation, chemical reduction, hydrothermal), and biological (such as plant fungus, algae, and bacteria) techniques are examples of bottom-up methods. However, the bottom-up physical approach necessitates a significant amount of thermal or electrical energy as well as a high investment cost for the operating instruments [33]. The environmental consequences of the bottom-up chemical technique stem from its inescapable use of dangerous chemicals in its procedures. As such, the achievement of a critical green approach by physical and chemical methods may be quite challenging. The bottom-up biological method offers an effective, adjustable, and eco-friendly approach, making it the most appropriate for the green synthesis of nanoparticles [34, 35]. To create nanomaterials, biosynthesis employs inexpensive, readily accessible sources like plants or other biocompatible sources including fungi, algae, and bacteria [36, 37]. Biomolecules that are isolated from biological sources are essential because they work well as bio-reduction agents. producing superior yields for the synthesis of nanomaterials using bio capping and bio stabilization [38]. According to Agarwal *et al.* (2017) [39], these biological substrates can safely take the place of pricey, hazardous chemicals or energy-intensive physical instruments. Additionally, the notion of sustainable and green chemistry aligns well with the biological way of nanoparticle synthesis [40]. Nanoparticle biosynthesis can be regarded as "green synthesis" since it produces no hazardous intermediates, minimizes secondary pollution, and minimizes potential dangers associated with chemical and physical processes [41].

IV. Zirconium Dioxide

Zirconium Dioxide Interest in nanoparticles has increased dramatically Over the last decade, due to their improved Properties as compared to other common materials. Zirconia is a versatile element with numerous applications in various fields. such as oxygen, and nitrogen oxide (NOx) sensors , fuel cell electrolytes, and semiconductor devices. It also displays outstanding stable photochemical, qualities include mechanical, electrical, thermal, and optical which makes it have its own application in the field of photonics. One of the most stable oxides, zirconium dioxide (ZrO_2), is created by heating zirconium compounds [42]. ZrO_2 can exist in crystalline phases such as monoclinic, tetragonal, and cubic phases, depending on various synthesis techniques [43, 44]. ZrO_2 has a broad bandgap energy in the bulk, usually between 5.0 and 7.0 eV. ZrO_2 has proven to have a wide range of useful technologies for refractory ceramic superalloys [45], dental restorations [46], fuel cells [47], and heterogeneous catalysis [48]. This is because of its superior stability and very low toxicity. Only a small amount of research has been done on zirconium dioxide nanoparticles to confirm its antibacterial and antioxidant properties in lab settings, despite the fact that it shows such a wide range of uses. But when combined with alcandate complexes, zirconium Zr appears to have potent antibacterial and antifungal activity [49, 50]. Zirconia nanoparticles can be made using a variety of chemical techniques, including thermal and hydrothermal [51, 52], hydro precipitation [53], sol-gel [54] ,and pyrolysis methods [55, 56]. Although these approaches have several advantages, including cost-effectiveness, mass production, and the delivery of highly regulated nanoparticle size and form [57, 58], they frequently leak harmful chemical waste into the environment. To mitigate the severity of these issues, the use of greener technologies in nanoparticle manufacturing becomes unavoidable. Among several biological approaches, nanoparticle synthesis utilizing plant extracts is the most appropriate method for large-scale manufacturing due to plant availability, lack of sterile conditions, and ease of handling [59].

V. Applications of Ziroconium Dioxide

ZrO_2 NPs are extensively utilized in many different applications, such as orthopedic implants [6], dental [61], photocatalysis, refractories, energy [62], fuel cell , gas sensor, cell solar energy [63] , and seed germination [64]. However, Because of its unique physical and chemical characteristics, ZrO2 NPs have antibacterial, antifungal, antioxidant, and anticancer effects. [62, 63, 64]Among the biomedical applications of zirconium, some scientists conducted a study that proved that zirconium nanoparticles have biological applications, by applying their antimicrobial activity. Against different types of pathogenic bacteria. Zirconium dioxide nanoparticles (ZrO_2 NPs) have also been applied to treat dental caries [65]. Because of its mechanical and biocompatible qualities, it is also utilized in tissue engineering scaffolds, orthopedic prosthesis, microvalves, microfluidic devices, drug delivery systems, and other medical equipment [66].

VI. Antibacterial Activity of Zirconia NPs

The current bacterial resistance makes it more challenging to develop novel antibiotics to treat bacterial infections. However, some of these novel antibiotics have demonstrated enhanced antibacterial efficacy due to the way that nanoparticles target distinct biomolecules present in the resistant strain [67].The majority of negatively charged proteins, such as peptidoglycan macromolecules, make up the plasma membrane of bacteria [68]. Because of the positive charge on their surface, ZrO2 nanoparticles interact electrostatically with bacterial membranes [69]. The biosorption and bioaccumulation of ZrO2 nanoparticles on cell walls are facilitated by this process. Green ZrO2 nanoparticles may easily pass through cell membranes due to their nanosize, large surface area, and superior biocompatibility. They also block essential metabolic operations, which inactivates bacterial cells [68]. According to Akintelu and Folorunso (2020), the underlying process is the production of reactive oxygen species such as O2− and OH. As a result, these species destroy genetic material such as DNA and ribonucleic acids, disrupting and degrading the transcription and translation processes in bacteria [69]. Bacterial death results from a failure of cell division. Many studies have documented the positive antibacterial activity of green ZrO2 nanoparticles against both Gram-negative and Gram-positive bacteria. For example, Guri et al. (2015) [68] investigated the antibacterial efficacy of ZrO2 produced vegetatively from Nyctanthes arbor-tristis extract against E. coli and S. aureus. The inhibitory zones were utilized to assess the antibacterial properties of green ZrO2 nanoparticles. Cotton fabric treated with ZrO2 nanoparticles showed dramatically enhanced values. Al-Zaqri et al., (2021) [70] found that even at a low concentration of green ZrO2 (10 µg/mL), it effectively inhibited the growth of both Gram-negative and Gram-positive bacteria. They suggested that biomolecules included in Wrightia tinctoria leaf extract have an important role in improving the features of green ZrO2 nanoparticles, such as small particle size and large surface area, hence boosting and improving their antibacterial activity. In addition to plant extracts, ZrO2 can be biosynthesized from other green materials, such as fungi and algae, to investigate its antibacterial inhibitory properties. Kumaresan et al., (2018) [71] used the alga Sargassum wightii to manufacture ZrO2, which demonstrated large inhibition zones (19-21 mm) against E. coli, S. typhi, and B. subtilis. Meanwhile, Gumi et al., (2019) [72] employed Penicillium fungi to produce ZrO2 nanoparticles. It revealed the lowest inhibitory doses against P. aeruginosa and E. coli at 0.375 and 0.75 mmol/L, respectively.

VII. Pathogenic Bacteria

Bacteria are organisms that evolve over time, with the primary goal of reproduction, dissemination, and resilience. Bacteria evolve and adapt to their surroundings in many ways to maintain their survival [73]. Anything that hinders their ability or development, such as antibiotics, may cause genetic changes that make them resistant to drugs and enable them to survive. life [74, 75]. Antibiotic resistance poses a severe threat to global health, killing at least 1.27 million people worldwide and at least 5 million people in 2019 [76], The antibacterial property is regarded as one of the most pressing health and economic issues in the world, prompting scientists and researchers to look for new antibiotics to combat resistant bacteria. Antibiotic resistance is classified into numerous categories, including multidrug resistance (MDR), systemic drug resistance (XDR), and pervasive drug resistance (PDR) [78, 79] This resistance is either innate or acquired, and it can be acquired through gene changes or the transfer of genetic material from one bacterium to another, such as through bacterial conjugation. Genetic material can be transported directly from one cell to another via plasmids, transformation (taking the genome released from dead bacteria), or induction (transferring genetic material via phages) [80]. Resistance to specific antibiotics became obvious in the bacteria that encountered the first manufactured antibiotics. The clearest illustration of this is resistance to penicillin among staphylococci determined by the enzyme (penicillinase), which led to the destruction of the antibiotic [81]. The most harmful bacteria are bacteria. (*Echerichia coli*, *Klebsiella pneumonia*, *Pseudomonas aeruginosa*). Which form biofilms that are associated with 65-80% of human diseases [82,83].

VIII. Conclusion

This study detailed current research on green production of ZrO_2 NPs using plant resources. The scientific community should pay special attention to this easy, quick, resilient, non-toxic, ecologically friendly, and commercially feasible method for synthesizing ZrO_2 NPs using this chemical approach. Green from bottom to top. The use of plant extracts for this purpose is beneficial against germs. Furthermore, there are several plant species that can be used and reported in the future for the simple and rapid green synthesis of metal oxide nanoparticles. Green ZrO2 nanoparticles and their nanocomposites are projected to produce many positive results in a variety of applications.

Table 1 Green synthesis of Zirconium nanoparticles with anti-bacterial effects in different studies.

No.	Plant name	Plant part used	Isolated compound/ extract used	Mechanism of action	References
1	*Capsicum annum, Allium cepa and Lycopersicon esculentum*	fruits	Hot water	Both of green synthe c and standard NPs of ZrO2 had good an fungal and an bacterial ac vity compared with bulk particles. NPs had negative effects on plant seeds germinations and other growth parameters of B. vulgaris and E. sativa such as reductions in GP, MGT, MDG, GV and PI but they increased GR.	Jalill *et al*., 2017
2	*native Enterobacter sp. and its antifungal activity*	supernatant	water	the fungicidal potential of biologically synthesized zirconium oxide nanoparticles (ZrONPs) against P. versicolor for the first time.	Ahmed *et al*., 2021
3	*Helianthus annuus (sunflower)*	seeds	methanolic extract	H. annuus seeds are efficient for biological applications of ZrO2NPs were investigated by antibacterial examines	Goyal *et al*., 2021
4	*ginger*	root	aqueous extract	Molecular docking studies of ZrO2 NPs with four proteins (2NAZ, 4HKG, 5D6H, and 5HM6) involved in biofilm formation of A. baumannii revealed the interaction of zirconium with target proteins.	Siddique *et al*., 2022
5	*E-tirucalli*	latex	extract as a fuel	antibacterial studies of four bacterial pathogens which are harmful to mankind were shown positively from the prepared Nps. The electrochemical property of the synthesized ZrO2 Nps has been shown by quantifying dopamine at micro-molar concentration levels.	Yadav *et al*., 2021
6	*Punica granatum (pomegranate)*	peel	aqueous extract	Green synthesis of Zirconium nanoparticles using Punica granatum (pomegranate) peel extract and their antimicrobial and antioxidant potency.	Chau *et al*., 2022
7	*Biological material*	Different parts	aqueous extract and alcoholic extracts	Zirconium oxide (ZrO2) nanoparticles from antibacterial activity to cytotoxicity: A next-generation of multifunctional nanoparticles. Materials synthesized ZrO2 nanoparticles demonstrated inhibitive activity against K. pneumoniae by the attraction of negatively charged K. pneumoniae cell wall against positively charged zirconium ions.	Tabassum *et al*., 2021
8	*Wrightia tinctoria*	leaf	aqueous extract	Biosynthesis of zirconium oxide nanoparticles using Wrightia tinctoria leaf extract: characterization, photocatalytic degradation and antibacterial activities.	Al-Zaqri *et al*., 2021
9	*Parkia biglandulosa (P. biglandulosa) (PBL)*	leaf extract	aqueous extract	Green synthesis of zirconia nanoparticles and their characterization, anticancer activity and corrosion inhibition properties.	Muthulakshmi, *et al*., 2023

ACKNOWLEDGMENT

The team would like to thank all colleagues in the University of Kufa, Iraq.

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