

RESEARCH ARTICLE

Fe-Ag-V Ternary Oxide Nanoparticles Synthesized from *Ganoderma lucidum* Extract: Antioxidant and Antibacterial Proficiency in Focus

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ABSTRACT

The synthesis of novel nanomaterials stands as a significant focus of scientific inquiry in nanotechnology. This study synthesized Fe-Ag-V ternary oxide nanoparticles sourced from *Ganoderma lucidum* extract. The eco-friendly synthesis process involves several steps, including dissolving PVP polymer in *Ganoderma lucidum* extract, introducing metal salts, Gum Arabic, maturation, gel formation, drying, and culminating in calcination. The resulting nanoparticles, comprising iron, silver, and vanadium, exhibit distinct structural and compositional features. Characterization methods like Dynamic Light Scattering (DLS), Scanning Electron Microscopy (SEM) imaging and Fourier Transform Infrared (FTIR) Spectroscopy analysis provide a thorough understanding. The nanoparticles have a polydispersity index (PDI) of 0.581 and an average particle size of 42 nm, indicating their nanoscale properties. The presence of important elements such as vanadium, iron, and silver were ascertained by Energy Dispersive X-ray Spectroscopy (EDX). A face-centred cubic (FCC) crystal structure, with an average crystallite size of around 15.6 nm was revealed by the X-ray Diffraction (XRD). These structural characteristics suggest potential uses in catalysis, sensors, and drug delivery systems. The Ferric Reducing Ability of Plasma (FRAP) assay demonstrated significant antioxidant activity, achieving an R2 value of 0.9974. Effective antibacterial properties were observed against pathogenic bacteria, with MIC values that ranged from 1.25 to 5.0 mg/ml, as determined by MIC and MBC evaluations. In summary, *Ganoderma lucidum*-mediated ternary oxide nanoparticles exhibit a unique composition, structural integrity, and functional attributes. Their eco-friendly synthesis, combined with remarkable antioxidant and antibacterial efficacy, positions them as promising candidates for various applications, offering innovative and sustainable solutions.

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INTRODUCTION

In today's swiftly evolving nanotechnology landscape, the creation and utilization of cutting-edge nanomaterials stand at the forefront of scientific exploration [1-2]. Researchers are delving into the synthesis of these materials, manipulating

structures at the nanoscale to unlock unique properties and propel advancements across diverse fields [3-5]. The precision in crafting nanomaterials opens doors to groundbreaking applications in medicine, electronics, energy, and environmental solutions [6-8]. This dynamic frontier fosters interdisciplinary collaboration, with experts from various fields converging to harness the

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potential of nanotechnology [9-10]. In essence, nanotechnology is not just a realm of scientific curiosity; it's a driving force shaping the future of technology and offering practical solutions to global challenges [11-12]. Among these, ternary oxide nanoparticles have emerged as a promising class of materials, demonstrating unique properties and versatile applications [13-15]. This investigation looked into the fascinating realm of nanoscience, specifically focusing on the synthesis of ternary oxide nanoparticles derived from *Ganoderma lucidum* extract and unravelling their exceptional antioxidant and antibacterial prowess.

Ganoderma lucidum, commonly known as the *reishi* mushroom, has been a subject of extensive research due to its rich repertoire of bioactive compounds [12]. The integration of this natural source into the synthesis of ternary oxide nanoparticles adds a layer of eco-friendliness and sustainability to the process [16-20]. As we delve into the intricacies of this synthesis, it becomes evident that harnessing the potential of *Ganoderma lucidum* extract offers not only an innovative approach but also a bridge between traditional knowledge and cutting-edge nanotechnology.

The preparation stages involved a meticulous combination of elements, where the choice of precursor materials and reaction conditions plays a pivotal role in determining the characteristics of the resulting nanoparticles [21-23]. Ternary oxide nanoparticles, composed of three different elements, exhibit a unique array of physicochemical properties [24-26], which, when coupled with the biocompatible nature of *Ganoderma lucidum* extract, opens avenues for diverse utilizations in environmental remediation, catalysis and medicine [24].

One of the most compelling aspects of the synthesized nanoparticles lies in their antioxidant proficiency. Antioxidants play a critical part in the neutralization of reactive oxygen species (ROS) within biological systems, thereby mitigating oxidative stress and its associated consequences [25-30]. The inclusion of *Ganoderma lucidum* extract in the nanoparticle synthesis process adds a natural and sustainable aspect to their functionality [12, 24]. Furthermore, the antibacterial efficacy of these nanoparticles adds a therapeutic dimension to their repertoire [24]. In an era where antibiotic resistance poses a global threat, the development of effective antibacterial agents is of paramount importance [31-33]. The investigation into the

antibacterial potential of *Ganoderma lucidum*-derived ternary oxide nanoparticles sheds light on their ability to combat microbial pathogens, hinting at a potential breakthrough in the field of antibacterial nanomaterials.

In light of the foregoing, this study focused on synthesizing, characterizing, and investigating the antioxidant and antibacterial properties of Fe-Ag-V ternary oxide nanoparticles derived from *Ganoderma lucidum* extract.

MATERIALS AND METHODS

Chemicals

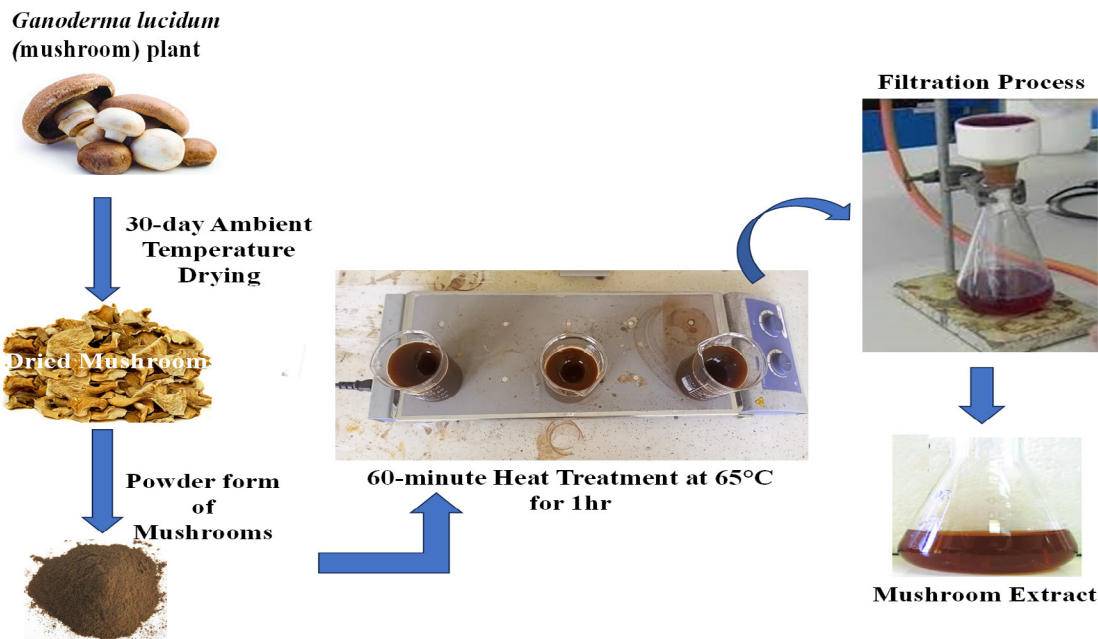
The study utilized analytical grade chemicals, all of which were procured from Sigma-Aldrich. This comprehensive range of chemicals included iron sulfate hexahydrate ($\text{FeSO}_4 \cdot 6\text{H}_2\text{O}$), Gum Arabic, silver nitrate (AgNO_3), Tripyridyl-s-triazine (TPTZ), vanadium metavanadate, polyvinylpyrrolidone (PVP), iron chloride hexahydrate ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$), and acetate buffer. It is important to note that these chemicals were used in their original state without undergoing additional purification steps. This decision was made to maintain the integrity of the experimental process and ensure the consistency of results.

Preparation of Plantain Peel Extract

The preparation of plantain peel extract followed the procedure outlined by Uwidia *et al.* (2024) [12]. To prepare the plantain peel extract, 10 g of dry and cleaned plantain peels broken down into powdered form along with 200 ml of distilled water were introduced into a beaker. Heating of the mixture at 60°C was carried out for half an hour with periodic stirring. After cooling to room temperature, it was filtered, and the resulting filtrate was refrigerated. Scheme 1 illustrates the process of preparing *Ganoderma Lucidum* (Mushroom) Plant Extract.

Green Synthesis of *Ganoderma lucidum* plant-based Ternary Oxides of Fe-Ag-V Nanoparticles

The procedure for synthesizing Fe-Ag-V nanoparticles using *Ganoderma lucidum* plant-based ternary oxides closely followed the procedure enumerated by a previous study [34]. The method started with the dissolution of 0.4g of PVP polymer in 180 ml of *Ganoderma lucidum* Extract, which was maintained under consistent blending at 65 °C for roughly 15 minutes. PVP played a crucial role in preventing the undesired accumulation and



Scheme 1. Preparation process of *Ganoderma Lucidum* (Mushroom) Plant Extract

agglomeration of metal oxides by obstructing cation mobility. Concurrently, 1g of each Fe, Ag, and V salts were introduced into the mixture along with 0.09g of gum arabic, likely aiding in stabilizing the emulsion and ensuring uniform dispersion of metal salts. Following the addition of all components, the mixture underwent a maturation period of two days, resulting in the formation of a gel structure. During drying in an oven at 110°C, an unexpected self-propagation phenomenon occurred, leading to the formation of a highly porous product. This porous structure likely resulted from the intricate interactions among the components, forming nanoscale voids within the material. Upon cooling, the dried gel was finely powdered in preparation for the subsequent calcination step. The powder was subjected to elevated temperatures of 500°C for a duration of three hours. This calcination step enhanced the crystallinity of the nanoparticles and removed any remaining organic contaminants, resulting in the formation of pure and well-defined Fe-Ag-V ternary oxides. See Figure 2: Preparation process of PVP-capped Gum Arabic Emulsified *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles.

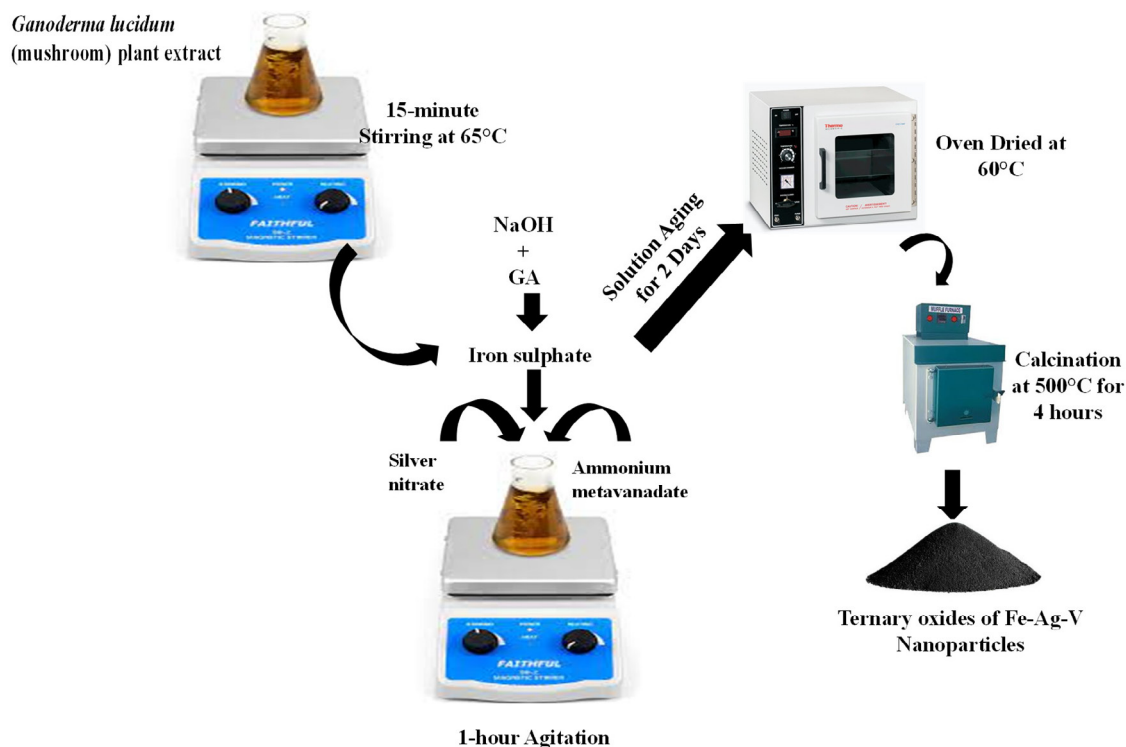
Characterization Techniques

Sophisticated equipments were employed to comprehensively examine the properties of

the synthesized nanoparticles. Morphological characteristics were elucidated through scanning electron microscopy (SEM) imaging using a JEOL-JSM 5600LV instrument. Fourier Transform Infrared (FTIR) Spectroscopy was employed to identify functional groups, analyzing infrared absorption bands within potassium bromide (KBR) pellets. Elemental composition was assessed via Energy Dispersive X-ray Spectroscopy (EDS). The average particle sizes were determined using a Nano-Zetasizer from Malvern Instruments, employing dynamic light scattering (DLS) at 25°C, with a scattering angle of 173 degrees and a wavelength of 633 nm. These combined techniques provided a thorough understanding of the nanoparticles, encompassing their structural properties and surface charge. This comprehensive analysis forms a strong basis for exploring potential applications across various domains. Antimicrobial activity tests were carried out in triplicate for each bacterium, with subsequent recording and analysis of average results.

Antimicrobial Assay Using Iron, Silver, and Vanadium Ternary Oxide Nanoparticles MIC and MBC Determination

The Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentration (MBC) were determined in this investigation using



Scheme 2. Preparation process of PVP-capped Gum Arabic Emulsified *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles

established protocols with slight modifications [35-36]. To evaluate the antibacterial efficacy of the synthesized iron, silver, and vanadium ternary oxide nanoparticles, various bacterial strains, including *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella pneumoniae*, and *Bacillus cereus*, were acquired and authenticated from the Medical Microbiology Laboratory of the University of Benin Teaching Hospital in Benin City, Nigeria. The antimicrobial activity of the nanoparticles was assessed using the standard broth dilution method (CLSI M07-A8). MIC was determined in nutrient broth using serial two-fold dilutions of nanoparticles, ranging from 0.1325 mg/ml to 10 mg/ml, with a bacterial concentration adjusted to 1×10^8 CFU/ml (0.5 McFarland's standard). The positive control consisted of nutrient broth medium with the tested bacterial concentrations, while the negative control contained only inoculated broth. Incubation took place at 37°C for 24 hours. MIC, defined as the lowest concentration inhibiting 99% of microbial growth, was determined by visually assessing turbidity before and after incubation and was confirmed in three sets for the tested bacteria. Following MIC determination, 100 μ l aliquots

from all tubes showing no visible bacterial growth were seeded on Mueller Hinton agar plates without nanoparticle supplementation. The incubation at 37°C of these plates were carried out for 24 hours. MBC, defined as the lowest concentration of the antimicrobial agent that kills 99.9% of the initial bacterial population, was determined by the presence or absence of bacterial growth on agar plates before and after incubation. Ciprofloxacin served as the positive control in this experiment.

Antioxidant Investigation

Ferric-Reducing Antioxidant Control (FRAP) strategy was used to investigate the in vitro antioxidant properties of the PVP-capped Gum Arabic emulsified ternary oxides of Fe-Ag-V nanoparticles, as sketched out in a past examination by Sharmila *et al.* (2018) [37]. To prepare the FRAP reagent for the assay, a mixture of 0.01 M tripyridyl-s-triazine (TPTZ) solution in 0.04 M HCl, 0.020 M $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$, and 0.3 M acetic acid buffer (pH 3.6) in a ratio of 10:1:1 was prepared. The absorbance of the FRAP reagent is monitored at 593 nm and sustained at a temperature of 37°C. For this assay, the synthesized

metallic-based nanoparticles are dissolved in de-ionized water at varying concentrations between 100 and 500 mg/ml. A solution is prepared by mixing 1.5 ml of the FRAP reagent with 50 ml of the nanoparticle solution, and the absorbance reading is taken after the mixture has been incubated at 37°C in the dark for 10 minutes. The subtraction of the initial blank absorbance reading from the final absorbance reading is used to estimate the FRAP value of the nanoparticles. Known concentrations of ferrous sulfate (FeSO_4) ranging from 0.000125 to 0.02 M are prepared to generate a standard curve. The assay results are reported in moles of ferrous (Fe (II)) equivalent. The FRAP assay assesses the antioxidant potential of the Fe-Ag-V nanoparticles by measuring their ability to reduce the blue ferric tripyridyltriazine complex to its ferrous form. This approach offers critical insights into the antioxidant capacity of the nanoparticles, providing essential information for their potential use in biomedical and other applications.

RESULT AND DISCUSSION

Comparisons between Eco-Friendly Plant Extracts and Conventional Methods

The synthesis of Gum Arabic Emulsified *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles using environmentally friendly *Ganoderma lucidum* plant extracts represents a significant departure from traditional methods. This transition towards sustainable nanotechnology practices is underpinned by the unique characteristics of eco-friendly synthesis, providing insight into the benefits and implications of employing *Ganoderma lucidum* plant extracts in this complex process.

Eco-friendly synthesis relies on leveraging *Ganoderma lucidum* plant extracts, esteemed for their abundance of bioactive compounds like polyphenols and polysaccharides [37-39]. *Ganoderma lucidum*'s innate attributes as a potent natural reducer and stabilizer facilitate the environmentally conscious production of nanoparticles, eliminating the necessity for toxic chemicals commonly used in traditional methods. Building upon this sustainable approach is the integration of Gum Arabic, a natural polysaccharide derived from *Acacia* trees [40-41]. Gum Arabic acts as an emulsifier, ensuring the even dispersion of metal salts during nanoparticle synthesis. This natural emulsification process further enhances eco-friendliness, as Gum Arabic is biodegradable

and sourced from renewable plant materials [41-43].

Comparing the eco-friendly synthesis to conventional methods reveals a myriad of advantages. Traditional approaches typically involve the use of harsh chemicals, energy-intensive procedures, and the generation of hazardous by-products [44-46]. In contrast, the synthesis based on *Ganoderma lucidum* plant extracts mitigates environmental impact by eliminating toxic elements and reducing energy consumption [47]. This eco-friendly methodology promotes sustainability, resonating with the increasing global focus on green practices in scientific research.

Additionally, the eco-friendly synthesis yields nanoparticles with improved biocompatibility. The lack of toxic residues minimizes ecological repercussions, making the nanoparticles biologically inert [44]. This attribute is crucial for prospective applications in biomedicine, where the compatibility of nanoparticles with biological systems is paramount for therapeutic efficacy [45-47]. The environmentally mindful synthesis not only reduces harm to the ecosystem but also paves the way for novel applications in medicine and beyond.

The Gum Arabic Emulsified *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles synthesized through eco-friendly methods hold promise for diverse applications. The biocompatibility and reduced environmental impact position these nanoparticles for use in targeted drug delivery, catalysis, and antimicrobial applications. The environmentally conscious synthesis paves the way for sustainable advancements in nanotechnology, fostering a balance between technological innovation and ecological responsibility [48-49]. In summary, the detailed synthesis process represents a notable advancement towards sustainable and environmentally conscious nanotechnology, demonstrating the promise of green nanotechnology in aligning scientific advancements with environmental stewardship.

The Rationale for Selecting Ganoderma lucidum (Mushroom) Plant Extracts in the synthesis of Ternary Oxides of Fe-Ag-V Nanoparticles

The decision to employ *Ganoderma lucidum* (Mushroom) plant extracts in the synthesis of Ternary Oxides of Fe-Ag-V Nanoparticles stems from the unique qualities inherent in this mushroom species. Recognized as the Reishi

mushroom, *Ganoderma lucidum* holds a rich history in traditional medicine and has attracted modern scientific attention due to its diverse array of bioactive compounds [50]. Notably, *Ganoderma lucidum* stands out for its abundance of polysaccharides, polyphenols, and flavonoids [51-52], which confer antioxidant, anti-inflammatory, and immunomodulatory properties. Incorporating *Ganoderma lucidum* extracts into nanoparticle synthesis aims to capitalize on these inherent medicinal qualities for potential applications in nanotechnology [53-54].

One notable advantage of *Ganoderma lucidum* extracts lies in their natural capacity as reducing and stabilizing agents. The collaborative action of polyphenols and polysaccharides present in the mushroom facilitates the reduction of metal ions during nanoparticle synthesis while simultaneously stabilizing the resulting nanoparticles [53-54]. This dual functionality promotes an environmentally friendly and sustainable synthesis process, obviating the need for harsh chemicals typically used in conventional methods [55]. Utilizing plant extracts aligns with the growing emphasis on sustainability and eco-friendliness in scientific research, with *Ganoderma lucidum* serving as a naturally abundant resource that fits within the paradigm of sustainable practices [50-53]. Furthermore, the biocompatibility of bioactive compounds derived from the mushroom renders them suitable for potential biomedical applications where compatibility with biological systems is crucial [55].

The diverse assortment of bioactive compounds found in *Ganoderma lucidum* extracts lends versatility to the synthesized nanoparticles. With potential applications ranging from drug delivery to catalysis and antimicrobial activities, these nanoparticles exhibit a broad spectrum of functionalities [54-56]. The therapeutic potential inherent in the mushroom extracts enhances the overall value of the synthesized nanoparticles, positioning them as promising candidates in biomedical and nanotechnological fields [50]. Moreover, the decision to incorporate *Ganoderma lucidum* extracts in nanoparticle synthesis reflects an integration of traditional wisdom with modern scientific methodologies [57-58]. Historically, the mushroom has been utilized in East Asia for its health benefits, and integrating these traditional insights into nanoparticle synthesis signifies a convergence of ancient knowledge with

contemporary nanotechnology [59].

In summary, the selection of *Ganoderma lucidum* (Mushroom) plant extracts for synthesizing Ternary Oxides of Fe-Ag-V Nanoparticles is driven by the mushroom's abundant bioactive composition, natural reducing and stabilizing capabilities, sustainability, biocompatibility, versatility, therapeutic potential, and the fusion of traditional wisdom with modern scientific practices. This strategic decision underscores the potential of nature-inspired approaches in advancing nanotechnology for diverse applications.

Potential Mechanism of the Use of Ganoderma lucidum Plant Extract in Synthesizing Ternary Oxides of Fe-Ag-V Nanoparticles

The potential mechanism underlying the use of *Ganoderma lucidum* plant extract in synthesizing Ternary Oxides of Fe-Ag-V Nanoparticles involves a complex interplay of bioactive compounds present in the mushroom. This mechanism is intricately linked to the unique properties of *Ganoderma lucidum* extracts, particularly their roles as reducing agents and stabilizers in the nanoparticle synthesis process.

Ganoderma lucidum is rich in bioactive compounds, including polyphenols and polysaccharides, which exhibit strong reducing capabilities [50]. During the synthesis of Ternary Oxides of Fe-Ag-V Nanoparticles, these bioactive compounds act as electron donors, facilitating the reduction of metal ions such as iron (Fe), silver (Ag), and vanadium (V) to form nanoparticles. The redox reactions initiated by the bioactive compounds contribute to the conversion of metal ions into their respective metallic forms, laying the foundation for nanoparticle formation [60-61].

Simultaneously, the bioactive compounds in *Ganoderma lucidum* extracts play a crucial role in stabilizing the newly formed nanoparticles. The polyphenols and polysaccharides act as capping agents, binding to the surfaces of the nanoparticles [57, 61]. This capping effect prevents the agglomeration or unwanted aggregation of nanoparticles, ensuring their uniform dispersion and stability [61]. The stabilizing function of these compounds is essential for preventing the particles from undergoing undesired transformations or clustering during the synthesis process [62-63].

The potential mechanism is further enhanced by the synergistic effects of the various bioactive compounds present in *Ganoderma lucidum*

extracts. The combination of polyphenols, known for their antioxidant properties, and polysaccharides, recognized for their stabilizing effects, creates a favourable environment for controlled nanoparticle synthesis [64-65]. This synergy contributes to the overall efficiency of the synthesis process and influences the characteristics of the resulting nanoparticles [65]. One notable aspect of this potential mechanism is its alignment with green and sustainable synthesis principles. The use of natural reducing and stabilizing agents from *Ganoderma lucidum* extracts eliminates the need for toxic or environmentally harmful chemicals, making the process eco-friendly [66-67-68]. This aspect is particularly significant in the context of contemporary nanotechnology, where sustainable and environmentally conscious practices are increasingly prioritized.

In summary, the potential mechanism of using *Ganoderma lucidum* plant extract in synthesizing Ternary Oxides of Fe-Ag-V Nanoparticles revolves around the unique properties of the mushroom's bioactive compounds. The reducing capabilities of polyphenols and polysaccharides initiate the formation of nanoparticles, while their stabilizing effects ensure uniform dispersion. The synergistic interplay of these compounds contributes to the overall efficiency of the synthesis process, emphasizing a green and sustainable approach in nanoparticle fabrication.

Elemental Composition of the Synthesized Nanoparticles

Figure 1 presents a visual representation of the elemental composition of the synthesized

Ternary Oxides of Fe-Ag-V Nanoparticles. The analysis of the synthesized Ternary Oxides of Fe-Ag-V Nanoparticles, conducted through Energy Dispersive X-ray Spectroscopy (EDS), provided insights into the elemental composition of the nanoparticles. The predominant elements identified in the composition include oxygen (O), silver (Ag), and vanadium (V), indicative of the desired ternary oxide structure. However, additional elements, namely carbon (C), sulfur (S), and potassium (K), were also detected, albeit in varying proportions.

The mean values for each element offer an overview of their average presence within the nanoparticle structure. Carbon, with a mean value of 6.13%, exhibits a moderate contribution, while oxygen and silver constitute significant portions with mean values of 36.05% and 27.8%, respectively. Sulfur and potassium contribute mean values of 5.76% and 1.26%, respectively, and vanadium and iron complete the elemental makeup with mean values of 14.52% and 8.48%. Examining the standard deviations provides insights into the variability of elemental content across different spectra. For instance, the standard deviation of carbon at 2.43% suggests a moderate degree of fluctuation in its concentration. The range of values (min to max) further emphasizes the diversity within the dataset. Carbon, for instance, ranges from 3.12% to 8.97%, showcasing the extent of variation observed.

The presence of impurities, such as carbon, sulfur, and potassium, is intrinsic to the synthesis process and may arise from precursor materials or reagents. While these impurities are present, their levels appear relatively low and within an

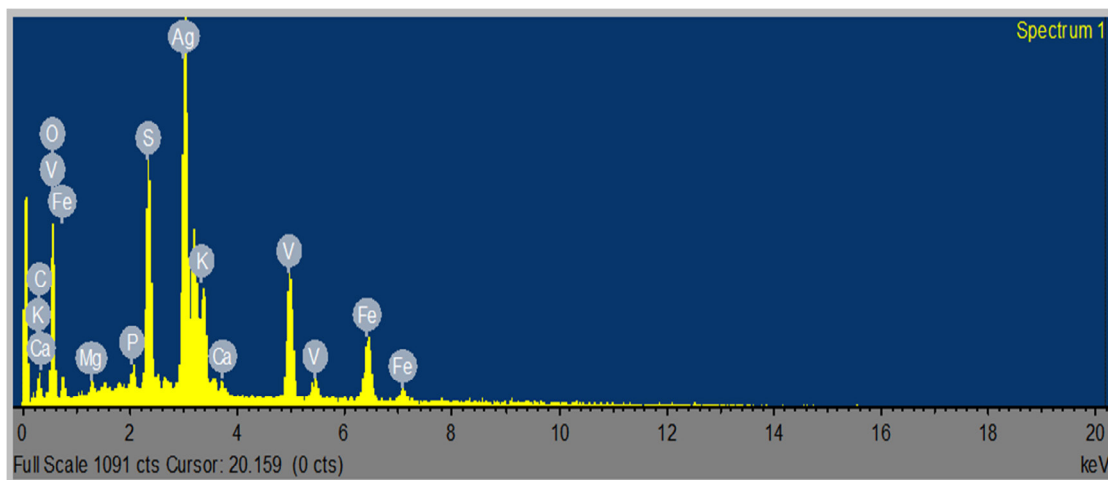


Fig. 1. Elemental composition of the synthesized Ternary Oxides of Fe-Ag-V Nanoparticles

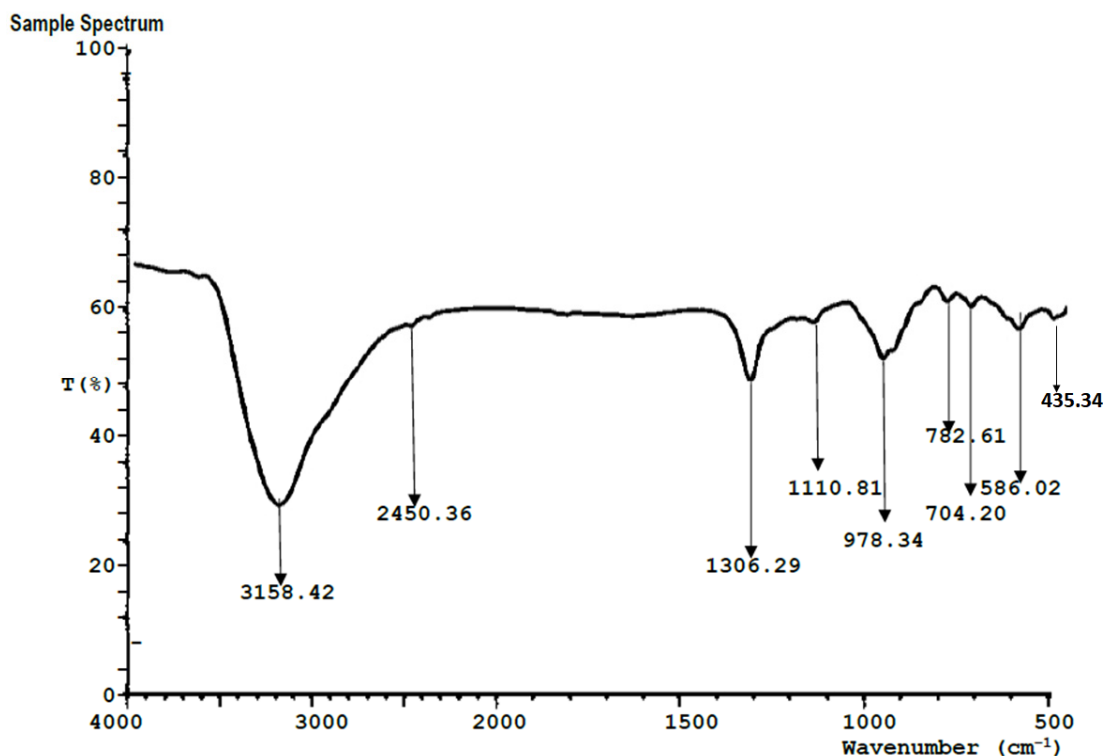


Fig. 2. FTIR of ternary oxide nanoparticles of iron, silver, and vanadium from extracts of *Ganoderma lucidum* Extract.

acceptable range. The standard deviation values and the range of elemental concentrations reflect some heterogeneity in the nanoparticle samples, which is not uncommon in nanomaterial synthesis.

In the context of the potential interference with antioxidant and antibacterial properties, the significance of these impurities depends on their concentrations and specific chemical nature. Generally, minor impurities may not markedly interfere with the intended properties of the nanoparticles.

Functional Group Characteristics

In Figure 2, the functional group characteristics of the iron, silver, and vanadium ternary oxide nanoparticles synthesized with *Ganoderma lucidum* extract are depicted. The Fourier Transform Infrared (FTIR) spectrum featured in the figure serves as a critical analytical tool, offering insights into the intricate structure of the nanoparticles. Notably, a significant peak at 3158.42 cm^{-1} indicates the stretching vibrations of hydroxyl groups (-OH), which are associated with flavonoids and phenolic compounds present in the plant extracts. These hydroxyl groups play

a crucial role in the reduction and stabilization of the nanoparticles, highlighting the involvement of natural compounds in the synthesis process.

Furthermore, a conspicuous peak at 2450.36 cm^{-1} denotes the elongated vibrations of methylene (-CH) groups, suggesting the existence of organic constituents sourced from mushroom extracts, guava leaves, and plantain peel within the nanoparticles. Additionally, a peak observed at 1306.29 cm^{-1} , attributable to C=C stretching vibrations, serves as evidence of the presence of double bonds within organic molecules. This particular peak accentuates the array of organic elements assimilated into the nanoparticles.

The presence of iron in the nanoparticles is indicated by a peak at 625.61 cm^{-1} , characteristic of metal-oxygen (M-O) bonds found in iron oxide. Vanadium's inclusion is confirmed by peaks at 1110.81 cm^{-1} , 978.34 cm^{-1} , 782.61 cm^{-1} , and 704.20 cm^{-1} , corresponding to vanadium-oxygen (V-O) bonds. These peaks clearly demonstrate the incorporation of vanadium oxide into the nanoparticles, enhancing their functionality. Additionally, peaks at 586.02 cm^{-1} and 435.34 cm^{-1} , indicative of silver oxide, confirm the presence

Results

Z-Average (d.nm): 41.98	Peak 1: 123.2	% Intensity: 59.7	St Dev (d.n...) 138.3
Pdl: 0.581	Peak 2: 2.320	16.7	1.607
Intercept: 0.908	Peak 3: 2186	12.4	1231
Result quality Good			

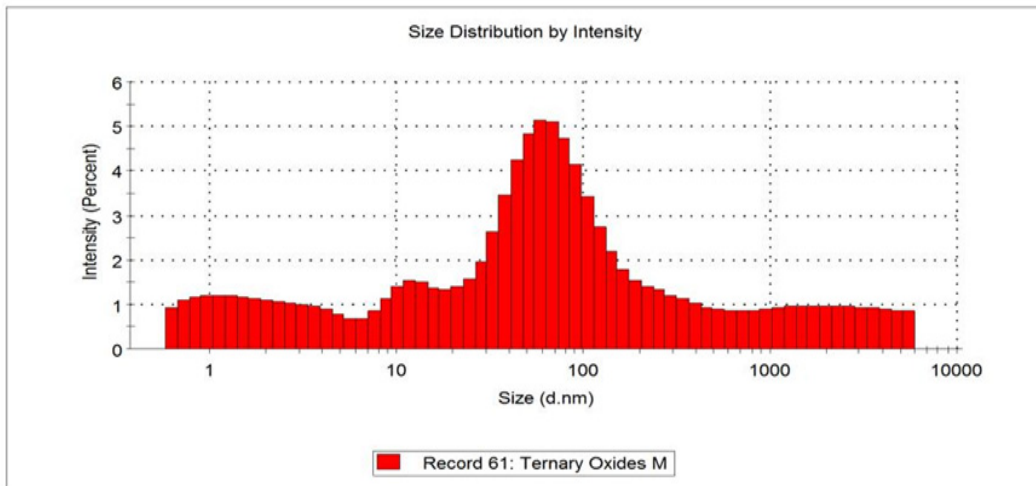


Fig. 3. Dynamic Light Scattering Analysis of PVP-capped Gum Arabic Emulsified *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles

of silver. These findings collectively verify the integration of iron, silver, and vanadium in the synthesized nanoparticles.

Figure 3 depicts the Dynamic Light Scattering (DLS) evaluation of the PVP-capped Gum Arabic Emulsified *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles. This analysis offers critical insights into their uniformity and size distribution. The average nanoparticle diameter is reported as 42 nm, indicating the typical particle size within the sample. Additionally, the polydispersity index (PDI) is noted as 0.581, reflecting the variability in particle sizes within the analyzed nanoparticles.

The reported 42 nm particle diameter implies that the majority of nanoparticles in the sample fall within this size range. Such nanoparticles hold promise for a myriad of utilizations, such as biological interactions and drug delivery, as a result of their improved ability to penetrate biological barriers. The obtained particle diameter is particularly relevant to the nanoparticles' antioxidant properties, as nanoparticles within the 10-100 nm range offer increased surface area-

to-volume ratios, facilitating enhanced interaction with reactive oxygen species (ROS) and potentially improving antioxidant efficacy.

Concerning antibacterial properties, nanoparticle size plays a pivotal role. Nanoparticles around 42 nm can readily interact with bacterial cell membranes, aiding penetration and disrupting membrane integrity, thus enhancing antibacterial effectiveness. The recorded polydispersity index (PDI) of 0.581 indicates some degree of variability in particle sizes within the nanoparticle system, suggesting polydispersity. While a PDI below 0.5 indicates a monodispersed sample, a value above 0.5 suggests polydispersity.

To summarize, the DLS analysis unveils that the PVP-capped Gum Arabic Emulsified *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles exhibit a moderately uniform size distribution with an average particle diameter of 42 nm. These characteristics hold potential for their application in antioxidant and antibacterial activities, although the moderate polydispersity necessitates further exploration into its implications on the nanoparticles' biological activities.

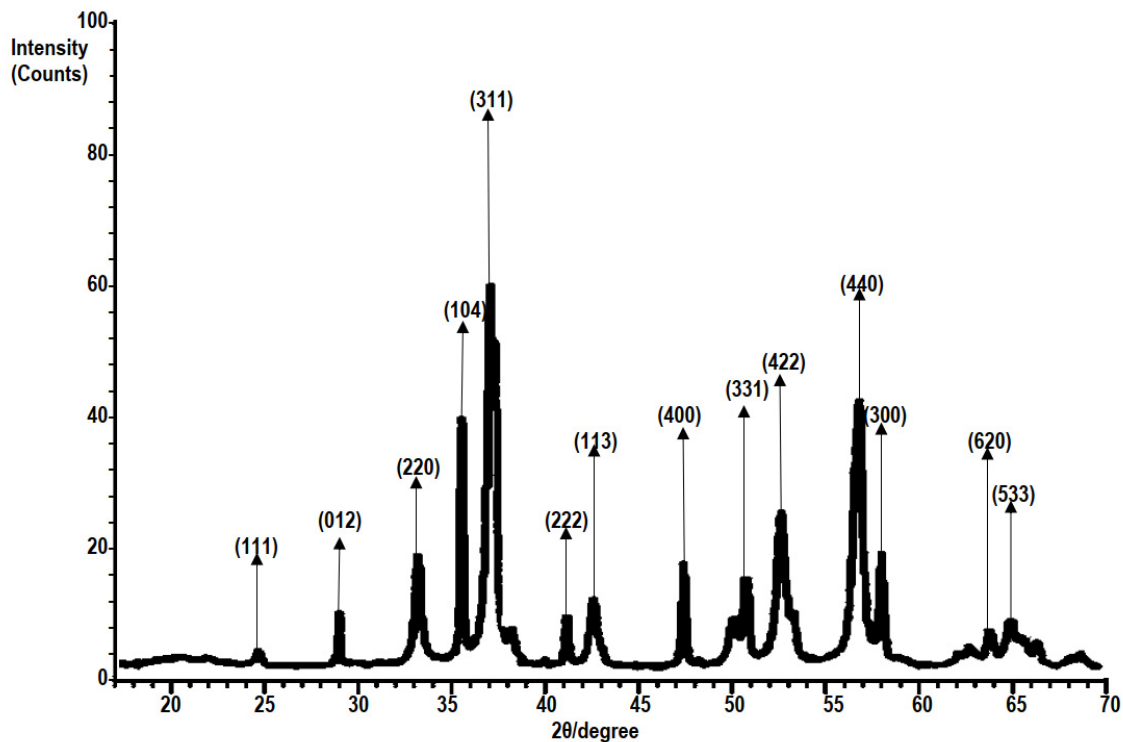


Fig. 4. XRD pattern of *Ganoderma lucidum* (mushroom) plant Extract-Derived Ternary Oxides of Iron, Vanadium, and Silver Nanoparticles.

Structural and Compositional Insights from X-ray Diffraction (XRD) Analysis

In Figure 4, the X-ray diffraction (XRD) pattern illustrates the Iron, Vanadium, and Silver Ternary Oxides of NPs synthesized from mushroom Extract, highlighting the crucial contribution of the plant extract to their synthesis. This XRD analysis investigated the structural characteristics of the nanoparticles, offering significant insights with direct implications for their antioxidant and antibacterial properties.

The distinct peaks detected at 24.72° (111), 29.00° (012), and 34.12° (220) confirmed that the nanoparticles have face-centred cubic (FCC) crystal structure [77]. The pronounced nature of these peaks indicates a heightened crystalline structure with periodic atomic arrangements, enhancing the stability and potential durability of the nanoparticles under diverse conditions [79-80]. The relative intensities of these peaks provide valuable information about specific crystal planes, influencing surface interactions and reactivity. Such crystallographic features play a pivotal role in boosting the nanoparticles' catalytic activities,

directly impacting their potential as antioxidants [80-81]. The confirmation of iron (Fe) presence at peaks 34.12° (220), 37.00° (311), 42.63° , 47.40° (400), and 52.61° (422) aligns with iron oxide's crystallographic planes [1, 26].

In the nanoscale regime, iron oxides often demonstrate catalytic activities, suggesting that these nanoparticles could potentially catalyze reactions relevant to antioxidant processes. The peaks indicating vanadium oxides at (012), (311), (222), and (400) [12, 24] carry electronic properties and catalytic activities that may contribute to the antioxidant features of the nanoparticles [82-83]. Similarly, the sharp peak at 42.63° (113), 24.72° (111), 34.12° (220), and 37.00° (311) confirming the presence of silver (Ag) introduces exceptional antimicrobial properties to the nanoparticles [24-25]. These antimicrobial properties align with the nanoparticles' potential to exhibit antibacterial efficacy.

The determined average crystallite size of approximately 15.6 nm plays a crucial role in influencing the nanoparticles' reactivity, particularly in the context of antioxidant and

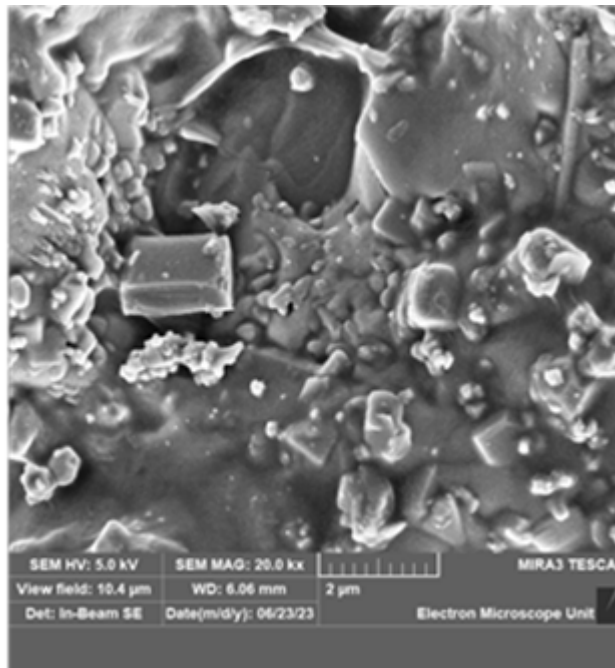


Fig. 5. A detailed Scanning Electron Micrograph (SEM) 2 μ m view of the morphology of *Ganoderma lucidum* (mushroom) Plant Extract-Derived Ternary Oxides of Iron, Vanadium, and Silver Nanoparticles.

antibacterial activities [84-85]. Nanoparticles within this crystallite size range possess an elevated surface area-to-volume ratio, enhancing their interaction with reactive species and bacterial cells [85-86]. This characteristic is pivotal for their potential effectiveness in antioxidant processes and antibacterial applications [85-87].

In summary, the XRD results not only confirm the crystallographic structure of the synthesized ternary oxide nanoparticles but also provide key insights into their potential antioxidant and antibacterial properties. The unique crystallographic orientations and elemental composition highlighted in Figure 4 lay the foundation for further exploration of these nanoparticles' applications in biomedical and antimicrobial contexts.

Morphological Characteristics of the synthesized Nanoparticles

The Scanning Electron Micrograph (SEM) in Figure 4 captures a detailed view of the morphology of *Ganoderma lucidum* (mushroom) plant Extract-Derived Ternary Oxides of Iron, Vanadium, and Silver Nanoparticles. The SEM image reveals a distinctive characteristic: the nanoparticles exhibit a clustered morphology with no clearly defined shape. The observed clustering implies that the

individual nanoparticles are closely packed or agglomerated, forming interconnected structures within the sample. Unlike nanoparticles with well-defined shapes, such as spheres or cubes, the clustered particles depicted in the SEM image lack a uniform geometric structure. Instead, they appear to form irregular aggregates with varying sizes and orientations.

The absence of a definitive shape in the nanoparticles suggests a certain degree of agglomeration or aggregation during the synthesis process. This phenomenon could be influenced by factors such as the concentration of precursor materials, the reaction kinetics, or the specific conditions during nanoparticle formation. The clustered morphology is a common occurrence in nanoparticle synthesis, and it can be influenced by various parameters, including the stabilizing agents used in the process.

While the lack of a distinct shape may present challenges in terms of uniformity, it also introduces a unique aspect to the nanoparticles. The clustered morphology provides a larger surface area with potential active sites for interactions. However, it is important to note that the clustering observed in the SEM image may impact the overall surface accessibility and dispersion of the nanoparticles in applications such as catalysis, sensors, or

biomedical applications.

In the context of antioxidant and antibacterial properties, the clustered morphology could influence the nanoparticles' reactivity and interactions with target molecules or cells [88]. The irregular surfaces and interparticle spaces within the clusters may affect the exposure of active sites, potentially influencing the efficacy of the nanoparticles in scavenging free radicals or interacting with bacterial cells [89-91].

In summary, the SEM image depicting clustered particles with no definite shape provides valuable insights into the morphology of *Ganoderma lucidum* plant Extract-Derived Ternary Oxides of Iron, Vanadium, and Silver Nanoparticles. The observed clustering introduces both challenges and opportunities, emphasizing the need for further investigations to understand and optimize the nanoparticles for specific applications, including

their potential roles in antioxidant and antibacterial contexts.

Antioxidant properties of the Synthesized Ternary Oxides of Fe-Ag-V Nanoparticles

The antioxidant properties of the Ternary Oxides of Fe-Ag-V Nanoparticles, as investigated in this study, are presented in Table 1 and visually depicted in Figure 5. The results showcase the Ferric Reducing Antioxidant Power (FRAP) of the nanoparticles at varying concentrations, providing valuable insights into their ability to reduce ferric ions and, consequently, their antioxidant potential.

Figure 6 illustrates the antioxidant properties of the nanoparticles, presenting a graphical depiction of the FRAP values across various concentrations. This graphical representation facilitates a rapid and intuitive comprehension of the nanoparticles' antioxidant efficacy and how it alters with varying

Table 1. Antimicrobial activity of Ternary Oxide of Fe-Ag-V nanoparticles synthesized from *Ganoderma lucidum* (mushroom) plant extract against *Staphylococcus aureus* (NCTC: 12973)

Nanoparticle/Conc (mg/ml)	0.3125	0.625	1.25	2.50	5.00	10.00	MIC	MBC
Ternary Oxide of Fe-Ag-V NPs	+	+	-	-	-	-	1.25	2.50
Control	-	-	-	-	-	-		

Positive (+) = Turbidity indicating growth
 Negative (-) = No turbidity indicating absence of growth
 Control = ciprofloxacin

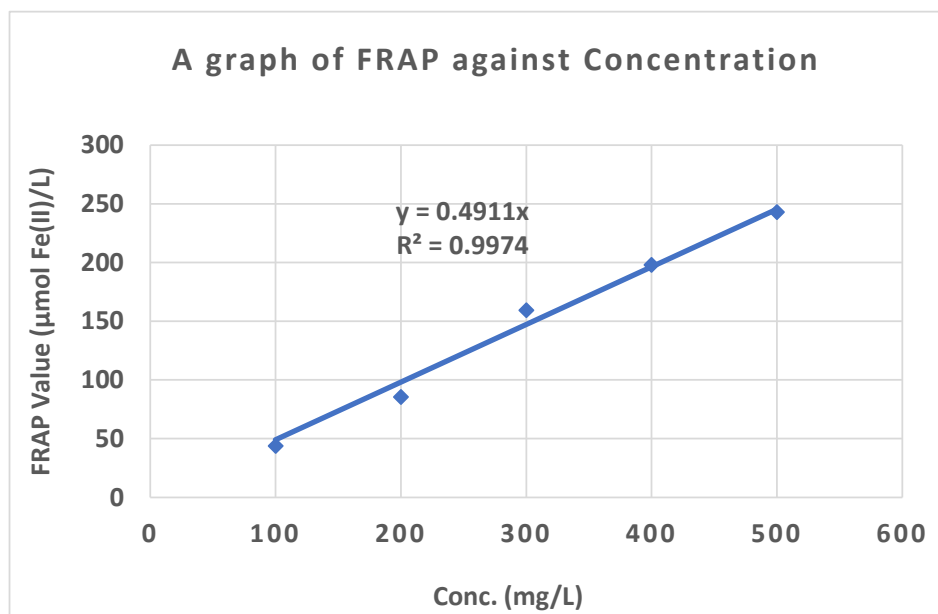


Fig. 6. Antioxidant Properties of Ternary Oxides of Fe-Ag-V Nanoparticles produced in this study.

concentrations. The graph delineates the specifics of the FRAP values of the Ternary Oxides of Fe-Ag-V Nanoparticles at concentrations ranging from 100 mg/ml to 500 mg/ml. The recorded FRAP values signify the concentration of ferric ions reduced by the nanoparticles, quantified in micromoles of Fe (II) per liter ($\mu\text{mol Fe (II)/L}$). The tabulated data underscores a conspicuous concentration-dependent correlation, with higher nanoparticle concentrations demonstrating augmented FRAP values.

The determination of the R^2 value, which stands at an impressive 0.9974, suggests a high degree of correlation between the concentration of Ternary Oxides of Fe-Ag-V Nanoparticles and their antioxidant activity, as measured by FRAP [92-93]. This strong correlation coefficient indicates that the FRAP values can be effectively predicted or explained by the concentration of the nanoparticles [93]. Such a high R^2 value reinforces the reliability and robustness of the data, enhancing the credibility of the study's findings.

In summary, the antioxidant results demonstrate a concentration-dependent antioxidant activity of the Ternary Oxides of Fe-Ag-V Nanoparticles, with the FRAP assay providing a quantitative measure of their reducing power. The high R^2 value further supports the consistency and predictability of the observed antioxidant behaviour. These findings contribute valuable insights into the potential application of these nanoparticles in contexts where antioxidant properties are desired, such as in biomedical and therapeutic applications.

Antibacterial Application of the Synthesized Fe-Ag-V Ternary Oxides NPs

Table 1 details the antimicrobial efficacy of Fe-Ag-V Ternary Oxide NPs, synthesized from *Ganoderma lucidum* extract, against *Staphylococcus aureus* (NCTC: 12973). It shows various concentrations tested, marked as either positive (+)

for bacterial growth or negative (-) for no growth, along with MIC and MBC values.

Concentrations range from 0.3125 mg/ml to 10.00 mg/ml. At lower concentrations (0.3125 mg/ml and 0.625 mg/ml), bacterial growth is evident, marked by (+). In contrast, no growth is observed at 1.25 mg/ml and higher concentrations, marked by (-), indicating effective bacterial inhibition.

The MIC, the lowest concentration that inhibits bacterial growth, is determined to be 1.25 mg/ml. This demonstrates the nanoparticles' capacity to prevent *Staphylococcus aureus* proliferation. The MBC, the lowest concentration required to kill the bacteria, is identified as 2.50 mg/ml. Ciprofloxacin-treated controls show no bacterial growth across all concentrations, validating its strong antibacterial effect and serving as a positive control.

Thus, Table 1 illustrates the substantial antibacterial activity of Fe-Ag-V nanoparticles against *Staphylococcus aureus*. The nanoparticles show a concentration-dependent inhibition and bactericidal effect, with MIC and MBC values highlighting their potential as antimicrobial agents. The comparison with ciprofloxacin further confirms their effectiveness against bacterial infections.

Table 2. Comprehensive Analysis of Antimicrobial Efficacy of Fe-Ag-V Ternary Oxide NPS generated from Guava, Plantain Peel, and Mushroom Extracts Against *Escherichia coli* (NCTC: 12241). At the lowest concentrations evaluated (0.3125 mg/ml and 0.625 mg/ml), marked with a (+), turbidity is observed, indicating growth in bacterial. This turbidity remains noticeable at 1.25 mg/ml. However, at concentrations of 2.50 mg/ml and higher, indicated by a (-), there is no turbidity, indicating no bacterial growth. This pattern is consistent up to the highest tested concentration of 10.00 mg/ml.

The Minimum Inhibitory Concentration (MIC) is identified as 2.50 mg/ml, marking the

Table 2. Antimicrobial Effectiveness of Ternary Oxide of Fe-Ag-V Nanoparticles Synthesized from Blends of Mushroom, Guava, and Plantain Peels against *Escherichia coli* (NCTC: 12241)

Nanoparticle/Conc (mg/ml)	0.3125	0.625	1.25	2.50	5.00	10.00	MIC	MBC
Ternary Oxide of Fe-Ag-V NPs	+	+	+	-	-	-	2.50	5.0
Control	-	-	-	-	-	-		

Positive (+) = Turbidity indicating growth
 Negative (-) = No turbidity indicating absence of growth
 Control = ciprofloxacin



Table 3. Antimicrobial activity of Ternary Oxide of Fe-Ag-V nanoparticles synthesized from *Ganoderma lucidum* (mushroom) plant extract Against *Klebsiella pneumoniae* (NCTC: 13368)

Nanoparticle/Conc (mg/ml)	0.3125	0.625	1.25	2.50	5.00	10.00	MIC	MBC
Ternary Oxide of Fe-Ag-V NPs	+	+	+	+	-	-	5.0	10.00
Control	-	-	-	-	-	-		

Positive (+) = Turbidity indicating growth

Negative (-) = No turbidity indicating absence of growth

Control = ciprofloxacin

smallest concentration of Fe-Ag-V Ternary Oxide nanoparticles necessary to prevent *Escherichia coli* growth. The Minimum Bactericidal Concentration (MBC) is found to be 5.0 mg/ml, which is the minimum nanoparticle concentration required to kill the bacteria. In comparison, the control group treated with ciprofloxacin shows no turbidity at any tested concentration, indicating no bacterial growth. This serves as a control in the positive direction and underscores the effectiveness of ciprofloxacin as an antibacterial agent.

In summary, Table 2 underscores the antimicrobial effectiveness of Fe-Ag-V Ternary Oxide NPs against *Escherichia coli*. The concentration-dependent inhibition of bacterial growth, as evidenced by the MIC and MBC values, establishes the nanoparticles as potential antimicrobial agents. The comparison with the control group further validates their antibacterial efficacy, positioning these NPs as emerging materials for applications in combating infectious diseases.

Table 3 outlined the comprehensive evaluation of the antimicrobial efficacy of Fe-Ag-V Ternary Oxide NPs derived from *Ganoderma lucidum* (mushroom) plant extract against *Klebsiella pneumoniae* (NCTC: 13368). At the lowest concentrations examined (0.3125 mg/ml and 0.625 mg/ml), denoted by (+), turbidity is observed, indicating potential bacterial growth. However, turbidity persists at 1.25 mg/ml and 2.50 mg/ml. Conversely, at concentrations of 5.00 mg/ml and higher, designated by (-), no seen turbidity, indicating that there is no growing bacterial. This trend persists consistently up to the highest concentration tested (10.00 mg/ml).

The Minimum Inhibitory Concentration (MIC), representing the lowest amount of Fe-Ag-V Ternary Oxide nanoparticles required to inhibit *Klebsiella pneumoniae* growth, is established at 5.0 mg/ml. Conversely, the MBC, indicating the lowest nanoparticle concentration capable

of causing bacterial death, is recorded as 10.00 mg/ml. In contrast, the control group treated with ciprofloxacin shows no turbidity at any concentration, verifying the absence of bacterial growth. This acts as a positive control, underscoring the effectiveness of ciprofloxacin as an antibacterial agent.

Thus, the findings presented in Table 3 highlighted the antimicrobial effectiveness of Fe-Ag-V Ternary Oxide NPs against *Klebsiella pneumoniae*. The concentration-dependent inhibition of bacterial growth, as demonstrated by the MIC and MBC values, suggests the potential of these nanoparticles as antimicrobial agents. Additionally, the comparison with the control group reaffirms their antibacterial efficacy, indicating their suitability for combating bacterial infections, particularly those caused by *Klebsiella pneumoniae*.

Table 4 offers a comprehensive evaluation of the antibacterial potency of Fe-Ag-V Ternary Oxide of NPs generated from *Ganoderma lucidum* plant extract against *Bacillus cereus*. At the lowest concentrations examined (0.3125 mg/ml and 0.625 mg/ml), denoted by (+), there is visible turbidity, indicating bacterial growth. This turbidity persists at 1.25 mg/ml, while concentrations of 2.50 mg/ml and above, marked by (-), show no turbidity, indicating that there was no growth in bacterial. This trend continues up to the maximum investigated concentration (10.00 mg/ml).

The Minimum Inhibitory Concentration (MIC), representing the lowest concentration at which the Fe-Ag-V Ternary Oxide NPs inhibits *Bacillus cereus* proliferation, is established at 2.50 mg/ml. In contrast, the MBC, which signifies the lowest nanoparticle concentration capable of causing bacterial death, is identified as 5.0 mg/ml. In comparison, the control group treated with ciprofloxacin shows no turbidity across all concentrations, confirming the absence of bacterial growth and acting as a control in the positive

Table 4. Assessment of Antimicrobial Effectiveness of Ternary Oxide of Fe-Ag-V Nanoparticles Derived from *Ganoderma lucidum* (mushroom) plant extract against *Bacillus cereus*.

Nanoparticle/Conc (mg/ml)	0.3125	0.625	1.25	2.50	5.00	10.00	MIC	MBC
Ternary Oxide of Fe-Ag-V NPs	+	+	+	-	-	-	2.50	5.0
Control	-	-	-	-	-	-		

Positive (+) = Turbidity indicating growth
 Negative (-) = No turbidity indicating absence of growth
 Control = ciprofloxacin

direction.

Table 4 underscores the antimicrobial efficacy of Ternary Oxide of Fe-Ag-V Nanoparticles against *Bacillus cereus*. The concentration-dependent inhibition of bacterial growth, as evidenced by MIC and MBC values, positions the nanoparticles as potential antimicrobial agents. Furthermore, the comparison with the control group validates their antibacterial efficacy, suggesting their promise for combatting bacterial infections, particularly those caused by *Bacillus cereus*.

Potential Antibacterial Mechanism for the use of *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles in eliminating *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella pneumoniae* and *Bacillus cereus*

i. Membrane Disruption

The *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles exhibit a multifaceted antibacterial mechanism, particularly when interacting with distinct bacterial strains such as *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella pneumoniae*, and *Bacillus cereus*. The synergy of iron, silver, and vanadium components in these nanoparticles plays a pivotal role in disrupting bacterial cell membranes, yielding comprehensive antibacterial efficacy.

For *Staphylococcus aureus*, the nanoparticles' iron component may interact with the bacterial cell membrane, disrupting its structural integrity. Concurrently, the silver component can induce increased permeability in the membrane, facilitating the entry of ions and disrupting essential cellular processes. The vanadium component, with its catalytic properties, adds to the oxidative stress on the membrane, collectively resulting in structural damage and compromised functionality [94]. *Escherichia coli* experiences a similar disruption as the iron, silver, and vanadium components collaborate to interfere with the bacterial cell

membrane. Iron may contribute to membrane destabilization, while silver, known for its affinity to bacterial surfaces, enhances permeability [95]. Vanadium's catalytic activity induces oxidative stress, creating a hostile environment for *Escherichia coli*, ultimately leading to membrane disruption [96]. *Klebsiella pneumoniae* encounters the synergistic impact of iron, silver, and vanadium, collectively targeting its cell membrane [97]. The iron component likely destabilizes the membrane, while silver disrupts its integrity, possibly leading to increased permeability [97]. Simultaneously, vanadium's catalytic activity generates oxidative stress, contributing to the overall disruption of *Klebsiella pneumoniae*'s membrane structure [97].

In the case of *Bacillus cereus*, the combination of iron, silver, and vanadium acts collaboratively on the bacterial cell membrane. Iron may induce membrane destabilization, silver enhances permeability, and vanadium contributes to oxidative stress [98-100]. This coordinated assault on the membrane integrity of *Bacillus cereus* results in structural damage, compromising the bacterium's essential functions [98-100].

The collective action of iron, silver, and vanadium in these nanoparticles showcases a tailored approach in targeting bacterial membranes. This synergistic effect ensures a comprehensive disruption of structural integrity, increased permeability, and membrane damage across various bacterial strains, underscoring the nanoparticles' versatility in combating a broad spectrum of pathogens.

ii. Oxidative Stress

In the context of *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella pneumoniae*, and *Bacillus cereus*, the *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles exhibit a potent antibacterial mechanism driven by the catalytic properties of vanadium oxide and the redox activity of iron. This collaborative action induces oxidative

stress within bacterial cells, resulting in a cascade of events that compromise bacterial DNA, proteins, and membranes [101-102].

For *Staphylococcus aureus*, the vanadium oxide's catalytic properties come into play, initiating the generation of reactive oxygen species (ROS). These ROS, coupled with the redox activity of iron, create oxidative stress within the bacterial cell. The ensuing damage affects the integrity of bacterial DNA, disrupts protein structures, and induces membrane impairment, collectively hindering the vital functions of *Staphylococcus aureus* [102-104]. Similarly, *Escherichia coli* experiences the impact of oxidative stress induced by vanadium oxide and iron. The catalytic properties of vanadium oxide led to ROS generation, while the redox activity of iron enhances the oxidative environment within bacterial cells. This oxidative stress inflicts damage on *Escherichia coli*'s DNA, proteins, and membranes, impairing essential cellular processes [105]. *Klebsiella pneumoniae* is not immune to the oxidative assault orchestrated by vanadium oxide and iron [105-106]. The catalytic properties of vanadium oxide contribute to ROS production, while the redox activity of iron intensifies the oxidative stress. The resulting oxidative damage targets *Klebsiella pneumoniae*'s DNA, proteins, and membranes, impeding its ability to thrive and propagate [107-108]. In the case of *Bacillus cereus*, the catalytic properties of vanadium oxide, coupled with the redox activity of iron, induce oxidative stress within the bacterial cell [109-110]. The generation of ROS impacts *Bacillus cereus* at the molecular level, causing damage to DNA, proteins, and membranes. This oxidative onslaught collectively disrupts vital cellular functions in *Bacillus cereus* [109-111].

The collaborative action of vanadium oxide and iron in the nanoparticles exemplifies a targeted approach in inducing oxidative stress across various bacterial strains. This oxidative assault, characterized by ROS generation, ensures a comprehensive and effective antibacterial response by compromising the genetic material, protein structures, and membrane integrity of *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella pneumoniae*, and *Bacillus cereus*.

iii. Metal Ion Release

The *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles employ a comprehensive antibacterial mechanism against

Staphylococcus aureus, *Escherichia coli*, *Klebsiella pneumoniae*, and *Bacillus cereus*. The release of metal ions, encompassing silver, iron, and vanadium, plays a pivotal role in exerting antimicrobial effects by interfering with intracellular processes, disrupting metabolic pathways, and causing damage to cellular structures [112-114].

In the case of *Staphylococcus aureus*, the released metal ions, particularly silver, iron, and vanadium, infiltrate bacterial cells and interfere with intracellular processes. These metal ions disrupt essential metabolic pathways within the bacteria, leading to impaired cellular functions. The collective action of silver, iron, and vanadium ions contributes to the overall antimicrobial activity against *Staphylococcus aureus* [115-116]. *Escherichia coli* experiences a similar impact, where the release of metal ions, including silver, iron, and vanadium, disrupts intracellular processes crucial for bacterial survival. These ions interfere with metabolic pathways, impeding *Escherichia coli*'s ability to function optimally. The combination of silver, iron, and vanadium ions collectively enhances the antibacterial efficacy against *Escherichia coli* [117-118]. *Klebsiella pneumoniae* is also susceptible to the antimicrobial effects of released metal ions. The infiltration of silver, iron, and vanadium ions disrupts intracellular processes, causing disturbances in metabolic pathways [97,119]. The resulting damage compromises the integrity of *Klebsiella pneumoniae*, contributing to the overall antibacterial activity of the nanoparticles [97,119].

In the case of *Bacillus cereus*, the release of metal ions, including silver, iron, and vanadium, interferes with intracellular processes and disrupts metabolic pathways. The impact of these ions extends to causing damage to cellular structures within *Bacillus cereus*, collectively enhancing the antibacterial activity against this bacterial strain [120-121].

The collective action of released metal ions, comprising silver, iron, and vanadium, exemplifies a targeted approach in disrupting intracellular processes across various bacterial strains. This interference with metabolic pathways and damage to cellular structures contribute significantly to the overall antibacterial efficacy of the *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles against *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella pneumoniae*, and *Bacillus cereus*.

iv. Intracellular Interactions

The *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles employ a sophisticated antibacterial mechanism against *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella pneumoniae*, and *Bacillus cereus*. The release of metal ions, especially iron and vanadium, plays a crucial role in interacting with intracellular components, resulting in the disruption of key cellular processes such as DNA replication, protein synthesis, and enzyme activities [122].

In the case of *Staphylococcus aureus*, the released iron and vanadium ions permeate the bacterial cell, interacting with intracellular components. This interaction disrupts the delicate process of DNA replication, compromises protein synthesis, and interferes with crucial enzyme activities [123-124]. The collective impact of these intracellular disruptions contributes significantly to the overall antibacterial effects against *Staphylococcus aureus*. *Escherichia coli* experiences a similar phenomenon, where the released iron and vanadium ions intrude into the bacterial cell and interact with intracellular components [123-124]. This interaction disrupts DNA replication, hinders protein synthesis, and interferes with vital enzyme activities. The consequential disturbances collectively amplify the antibacterial effects against *Escherichia coli* [125]. *Klebsiella pneumoniae* is not immune to the intracellular interactions initiated by the released iron and vanadium ions. These ions penetrate the bacterial cell, disrupting DNA replication, impeding protein synthesis, and interfering with enzyme activities essential for bacterial survival [126 -127]. The cumulative effect of these intracellular disruptions contributes to the overall antibacterial efficacy against *Klebsiella pneumoniae*. Similarly, in the case of *Bacillus cereus*, the released iron and vanadium ions engage with intracellular components, causing disruptions in DNA replication, protein synthesis, and enzyme activities [128]. These intracellular interactions collectively enhance the antibacterial effects against *Bacillus cereus*.

The released iron and vanadium ions showcase a targeted approach in disrupting crucial intracellular processes across various bacterial strains. The disruption of DNA replication, protein synthesis, and enzyme activities forms a cornerstone of the antibacterial mechanism of the *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles against *Staphylococcus*

aureus, *Escherichia coli*, *Klebsiella pneumoniae*, and *Bacillus cereus*.

v. Surface Interaction:

The *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles exhibit a multifaceted antibacterial mechanism against *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella pneumoniae*, and *Bacillus cereus*. The nanoparticles, characterized by their diverse composition of iron, silver, and vanadium, engage in interactions with bacterial surfaces. The incorporation of Gum Arabic and PVP as capping agents further plays a crucial role in ensuring the stable and uniform dispersion of nanoparticles, thereby enhancing their interaction with bacterial cells [57, 126].

In the case of *Staphylococcus aureus*, the nanoparticles, with their unique composition, interact with the bacterial surface. The presence of Gum Arabic and PVP ensures the stable dispersion of nanoparticles, promoting effective contact with *Staphylococcus aureus* cells. *Escherichia coli*, too, experiences the interaction of the nanoparticles with its surface [17, 31]. The diverse composition of iron, silver, and vanadium, coupled with the stabilizing influence of Gum Arabic and PVP, facilitates a stable and uniform dispersion of nanoparticles, enhancing their interaction with *Escherichia coli* cells [32-34]. Similarly, *Klebsiella pneumoniae* encounters the interaction of nanoparticles with its bacterial surface [119, 125]. The presence of Gum Arabic and PVP, acting as capping agents, contributes to the stable dispersion of nanoparticles, optimizing their interaction with *Klebsiella pneumoniae* cells [125]. *Bacillus cereus* is not exempt from the nanoparticle-bacterial surface interaction [120-121]. The diverse composition of iron, silver, and vanadium, combined with the stabilizing effect of Gum Arabic and PVP, ensures a stable dispersion of nanoparticles, fostering effective contact with *Bacillus cereus* cells.

The utilization of Gum Arabic and PVP as capping agents proves instrumental in maintaining the stability and uniform dispersion of the nanoparticles, facilitating enhanced interactions with bacterial surfaces across various strains. This surface interaction, coupled with the diverse composition of iron, silver, and vanadium, collectively contributes to the antibacterial efficacy of the *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles against *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella pneumoniae*, and *Bacillus cereus*.

vi. Synergistic Effects

The *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles deploy a potent antibacterial mechanism against *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella pneumoniae*, and *Bacillus cereus*. The synergistic effects of iron, silver, and vanadium components collectively target various aspects of bacterial physiology, creating a unique combination that enhances the overall antibacterial efficacy of the nanoparticles [129].

For *Staphylococcus aureus*, the synergistic effects of iron, silver, and vanadium elements converge to create a formidable antibacterial impact. This unique combination ensures a broad-spectrum effectiveness against *Staphylococcus aureus* strains [115-116]. *Escherichia coli*, too, experiences the synergistic effects of the nanoparticles' diverse components [117-118]. The combined action of iron, silver, and vanadium contributes to an enhanced antibacterial efficacy, making the nanoparticles effective against *Escherichia coli* strains. Similarly, *Klebsiella pneumoniae* encounters the synergistic effects of iron, silver, and vanadium in the nanoparticles. This collective action targets different aspects of bacterial physiology, rendering the nanoparticles effective against a broad spectrum of *Klebsiella pneumoniae* strains [119, 127]. *Bacillus cereus* is not exempt from the synergistic effects of the nanoparticles' components. The combined impact of iron, silver, and vanadium creates a potent antibacterial mechanism, ensuring effectiveness against various *Bacillus cereus* strains [99-100].

CONCLUSION

The investigation into the synthesis of ternary oxide nanoparticles from *Ganoderma lucidum* extract reveals a promising avenue in nanoscience. The eco-friendly synthesis process, involving sequential steps from dissolving PVP polymer in *Ganoderma lucidum* extract to the final calcination, yields nanoparticles with distinct structural features. The nanoparticles, characterized by specific compositional elements, demonstrate a noteworthy average diameter of 42 nm and a polydispersity index of 0.581, adopting a face-centred cubic crystal structure. Elemental analysis confirms the presence of essential components, further affirming the nanoparticles' unique composition. Assessment of the nanoparticles' properties reveals significant antioxidant activity, showcased through the FRAP assay with a high R^2 value of 0.9974.

The antibacterial evaluations against pathogenic strains exhibit effective inhibition, emphasizing the nanoparticles' potential in combating microbial growth. The intricate composition and structural integrity of these nanoparticles position them as versatile candidates for diverse applications. The emphasis on eco-friendly synthesis underscores their relevance in sustainable nanotechnology. This study contributes valuable insights into the synthesis and application of nanomaterials, fostering ongoing research to fully exploit the potential of *Ganoderma lucidum*-mediated ternary oxide nanoparticles across scientific and technological domains. The findings pave the way for innovative and sustainable solutions, highlighting the significance of nature-inspired nanotechnology in advancing scientific frontiers. The synergistic effects of the *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles underscore their versatility and efficacy against a range of bacterial strains. The unique combination of iron, silver, and vanadium components in these nanoparticles forms a robust antibacterial strategy, highlighting their potential for diverse applications in combating bacterial infections. In summary, *Ganoderma lucidum* Mediated Ternary Oxides of Fe-Ag-V Nanoparticles exert their antibacterial effects through collective membrane disruption, oxidative stress induction, metal ion release, intracellular interactions, surface interactions, and synergistic effects. The combination of iron and vanadium, along with silver, contributes to the nanoparticles' broad-spectrum antimicrobial properties.

DECLARATIONS

Ethics approval and consent to participate

Not applicable

Author's contribution

R.O.O participated in the experimental investigations and the revision of the paper. E.U.I supervised the research and provided revisions for the manuscript. I.E.U actively participated in the experimental work. I.H.I was responsible for composing the primary manuscript text and contributed to the experimental investigation, while I.D.C also played a role in the experimental procedures.

Consent for publication

Each author in this manuscript has given permission for this work to be published.

Availability of data and material

The data and materials used in this study are available upon request.

Competing interests

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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