

Mycosynthesis and Characterization of Silver Nanoparticles from *Phytophthora infestans* for Antimicrobial Evaluation Purposes





Micosíntesis y caracterización de nanopartículas de plata a partir de *Phytophthora infestans* con fines de evaluación antimicrobiana

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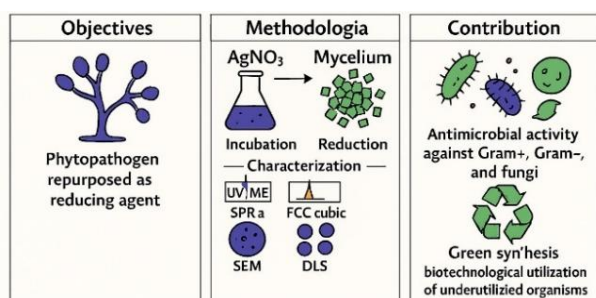
Abstract

The green synthesis of metal nanoparticles represents a sustainable alternative to conventional methods that employ toxic reagents and extreme conditions. In this study, *Phytophthora infestans*, a phytopathogenic oomycete, was used as a biological agent for the mycosynthesis of silver nanoparticles (AgNPs), taking advantage of its ability to secrete metabolites with reducing and stabilizing functions. The synthesis was carried out by incubating fungal mycelium in silver nitrate (AgNO₃) solutions at different concentrations, and the obtained AgNPs were characterized by UV-Vis spectroscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM) and Dynamic Light Scattering (DLS).

Resumen

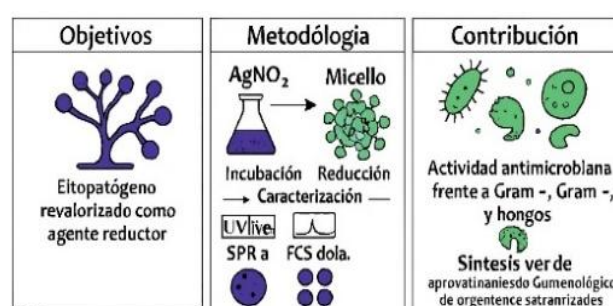
La síntesis verde de nanopartículas metálicas representa una alternativa sustentable frente a los métodos convencionales que emplean reactivos tóxicos y condiciones extremas. En este estudio se empleó *Phytophthora infestans*, un oomiceto fitopatógeno, como agente biológico para la micosíntesis de nanopartículas de plata (AgNPs), aprovechando su capacidad para secretar metabolitos con funciones reductoras y estabilizantes. La síntesis se realizó mediante la incubación de micelio fúngico en soluciones de nitrato de plata (AgNO₃) a distintas concentraciones, y las AgNPs obtenidas fueron caracterizadas mediante espectroscopía UV-Vis, difracción de rayos X (DRX), microscopía electrónica de barrido (SEM) y Dispersión Dinámica de Luz (DLS).

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Mycosynthesis, Nanoparticles, Characterization

Micosíntesis y caracterización de nanopartículas de plata a partir de *Phytophthora infestans* con fines de evaluación antimicrobiana



Micosíntesis, Nanopartículas, Caracterización

Area: Development of strategic leading-edge technologies and open innovation for social transformation

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Introduction

In recent decades, nanotechnology has emerged as a key discipline in the development of materials with unique properties at the nanoscale, opening new possibilities in fields such as medicine, electronics, agriculture and the environment (Khan et al., 2017). Within this area, metallic nanoparticles—especially silver nanoparticles (AgNPs)—have garnered significant attention due to their outstanding antimicrobial, optical and catalytic properties (Rai et al., 2009). However, conventional methods of AgNP synthesis often involve the use of toxic reducing agents, elevated temperatures and extreme pH conditions, raising environmental concerns and limiting their applicability in sustainable contexts (Irvani, 2011).

In light of this, green synthesis of nanoparticles has emerged as a promising alternative, based on the use of living organisms or natural extracts capable of reducing metal ions and stabilising the nanoparticles formed (Gómez, 2025). Among the various biological agents used, fungi and oomycetes stand out for their high efficiency in the production of nanomaterials, thanks to their ability to secrete enzymes, proteins and secondary metabolites with reducing and capping functions (Narayanan & Sakthivel, 2010). These organisms not only allow for a more environmentally friendly synthesis, but also offer advantages such as scalability, process simplicity and the possibility of controlling the size and morphology of the nanoparticles.

Phytophthora infestans, a phytopathogenic oomycete known for causing late blight disease in potato and tomato crops, has traditionally been studied for its agricultural impact (Moreno & Guerrero, 2025). However, its complex metabolism and its ability to produce bioactive compounds make it an interesting candidate for the biosynthesis of metallic nanoparticles (Guerrero, 2025). Although its use in nanotechnology is still in its early stages, recent research suggests that phytopathogenic organisms can be revalued as biotechnological tools, contributing to the circular economy and the utilisation of underutilised biological resources (Singh et al., 2016).

AgNPs synthesised by biological methods have demonstrated remarkable antimicrobial activity against Gram-positive and Gram-negative bacteria, as well as against pathogenic fungi.

This activity is attributed to multiple mechanisms, including the generation of reactive oxygen species (ROS), the alteration of cell membrane permeability, the interaction with proteins and nucleic acids, and the inhibition of essential metabolic processes (Lara et al., 2010). These properties make AgNPs especially useful in biomedical applications, such as antibacterial coatings, controlled drug delivery systems and medical devices.

The present work aims at the mycosynthesis of silver nanoparticles using extracts of *Phytophthora infestans*, their characterisation by spectroscopic and microscopic techniques—including UV-Vis Spectroscopy, X-ray diffraction (XRD), Scanning Electron Microscopy (SEM), and Dynamic Light Scattering (DLS)—, as well as the evaluation of their antimicrobial activity against. This proposal seeks not only to contribute to the development of functional nanomaterials through sustainable processes, but also to explore the biotechnological potential of organisms traditionally considered harmful, promoting a more integrated and ecological vision of materials science.

Theoretical Framework

The synthesis of silver nanoparticles (AgNPs) has captured the attention of the scientific community for their antimicrobial, catalytic, and optical properties. Traditionally, these nanoparticles have been produced using physical-chemical methods that, while effective, involve the use of toxic reagents, high temperatures, and unsustainable conditions. In response to this problem, a new research trend has emerged focused on green synthesis, seeking more environmentally friendly alternatives (Nevarez, 2025).

Among the most explored strategies are the use of plant extracts, bacteria, fungi, and yeasts. Fungi, in particular, have demonstrated a remarkable ability to reduce metal ions and stabilize nanoparticles thanks to their secretion of enzymes and secondary metabolites.

However, within this group, phytopathogens have been scarcely considered, despite their biotechnological potential.

Phytophthora infestans, primarily known for its devastating role in potato and tomato crops, represents a paradigmatic example of how an organism traditionally associated with damage can be repurposed as an ecological nanofabricator. Recent studies have begun to explore its ability to synthesize AgNPs, revealing an efficiency comparable to that of saprophytic fungi, with the added advantage of harnessing an organism that is already part of the agricultural ecosystem.

Furthermore, research such as that by Singh et al. (2016) has shown that AgNPs obtained by biological methods not only exhibit controlled morphology and good dispersion, but also superior antimicrobial activity against resistant strains. These findings open the door to applications in agriculture, medicine, and water treatment, consolidating the role of phytopathogens as agents of innovation in green nanotechnology (Contreras, 2025).

Methodology

The synthesis of silver nanoparticles (AgNPs) was carried out through a biogenic approach using the fungus *Phytophthora infestans* as a reducing agent of silver nitrate (AgNO_3).

Box

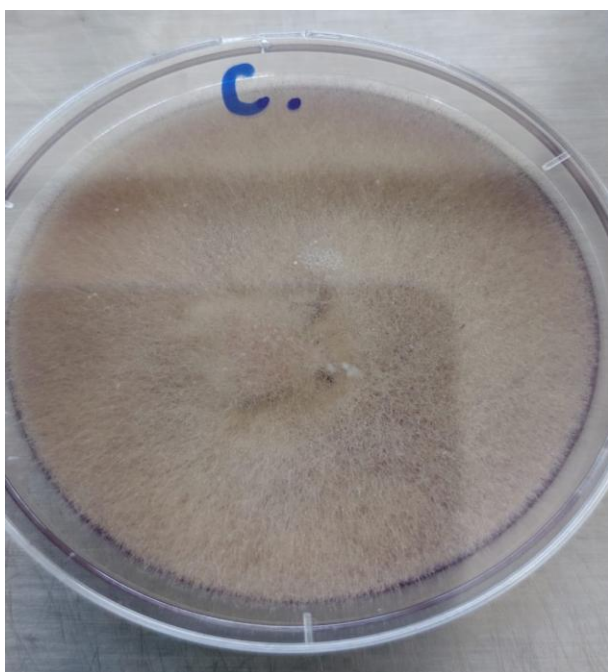


Figure 1

Fungus *Phytophthora infestans*

Own Source

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The fungal strain was cultivated in PDA medium for 7 days, after which the mycelium was separated and subjected to a two-stage washing process: first with distilled water (24 h at 130 rpm) and subsequently with double-distilled water (24 h at 150 rpm). After washing, four AgNO_3 solutions were prepared at different concentrations (30 mM, 40 mM, 50 mM and 60 mM), into which the mycelium was incorporated and kept under constant stirring for 72 hours at 150 rpm to induce the reduction of the metal precursor.

Box

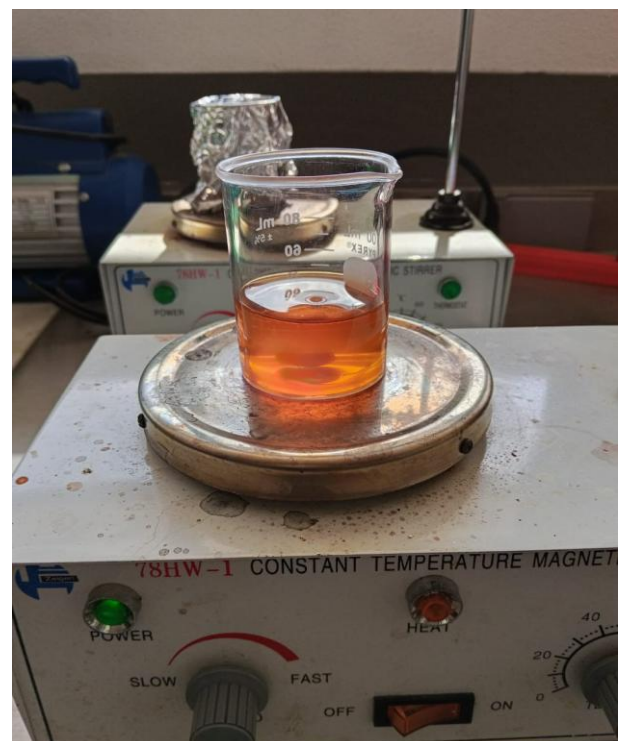


Figure 2

Silver nanoparticles

Own Source

Results

UV-Vis Spectroscopy of Silver Nanoparticles

Box

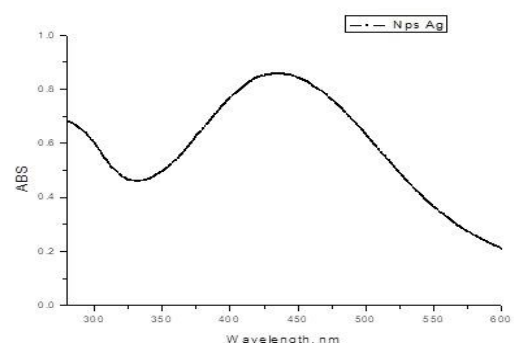


Figure 3

UV-Vis spectrum obtained from silver nanoparticles

Own Source

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The optical characterisation of the silver nanoparticles (AgNPs) obtained by mycosynthesis with *Phytophthora infestans* was performed by UV-Vis spectroscopy in the range of 300 to 600 nm. The spectrum obtained showed a well-defined absorbance peak around 450 nm, which is characteristic of the surface plasmon resonance (SPR) associated with AgNPs (Rai et al., 2009).

This peak indicates the presence of silver nanoparticles with a relatively uniform size distribution, as no shifts towards longer wavelengths or multiple peaks suggesting aggregation or polydispersity were observed. The intensity of the signal, with a maximum absorbance close to 1.0, suggests a high concentration of well-dispersed nanoparticles in the colloidal medium, which can be attributed to the stabilising action of the extracellular metabolites secreted by the oomycete during the synthesis process (Narayanan & Sakthivel, 2010).

The peak position at 450 nm also allows us to estimate that the average particle size is in the range of 20 to 60 nm, although this estimate will be corroborated by complementary techniques such as scanning electron microscopy (SEM) and X-ray diffraction analysis (XRD). These results confirm the effectiveness of the *P. infestans* extract as a reducing and stabilising agent in the green synthesis of AgNPs, and constitute a solid basis for its subsequent antimicrobial evaluation.

SEM Micrograph of Silver Nanoparticles

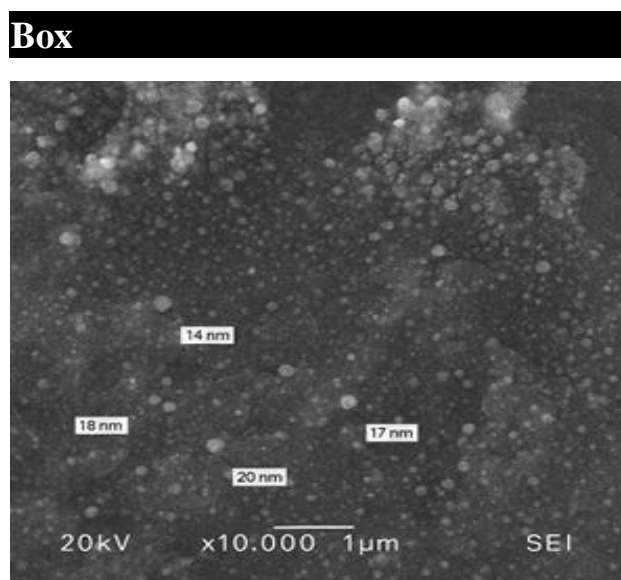


Figure 4
SEM micrograph obtained from silver nanoparticles

Own Source

The morphological characterisation of the silver nanoparticles (AgNPs) synthesised by mycosynthesis with *Phytophthora infestans* was performed by scanning electron microscopy (SEM), using an acceleration voltage of 20 kV and a magnification of x10,000. The image obtained, using the secondary electron mode (SEI), reveals a rough textured surface on which multiple particles of predominantly spherical morphology are distributed.

The nanoparticles are observed as bright and well-defined structures, with sizes estimated to be below 100 nm, dispersed heterogeneously on the substrate. In the upper left region of the micrograph, a higher density of particles is observed, while towards the lower right, the distribution becomes more dispersed. This variability suggests a possible influence of the oomycete's extracellular metabolites on the nucleation and growth of the particles.

The absence of significant aggregation and the uniformity in the spherical shape of the AgNPs indicate good colloidal stability, which is consistent with the results obtained by UV-Vis spectroscopy. The scale bar of 1 µm allows us to visually estimate that the particles are within the nanometric range, which will be corroborated by XRD analysis to determine the average crystalline size. These findings confirm the effectiveness of the *P. infestans* extract as a reducing and stabilising agent in the green synthesis of silver nanoparticles and support its potential application in subsequent studies of antimicrobial activity.

DRX of Silver Nanoparticles

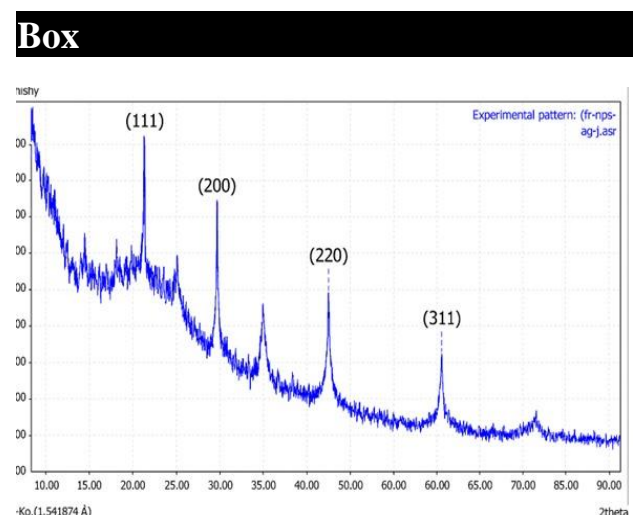


Figure 5
DRX obtained from silver nanoparticles

Own Source

X-ray diffraction analysis confirmed the formation of silver nanoparticles with a face-centered cubic (FCC) crystal structure. The diffraction pattern revealed four main peaks located approximately at $2\theta = 38^\circ$, 44° , 64° , and 77° , corresponding to the (111), (200), (220), and (311) crystallographic planes, respectively. These values coincide with those reported in JCPDS card No. 04-0783 for Ag^0 , indicating the presence of metallic silver without evident signs of oxidation.

The most intense peak, associated with the (111) plane, suggests a preferential orientation in this direction, a common phenomenon in green synthesis due to the specific interaction between biological reducing agents and crystalline surfaces. The absence of secondary peaks attributable to silver oxides (Ag_2O , AgO) reinforces the efficacy of the mycosynthesis process in obtaining pure nanoparticles. These results corroborate the fungal extract's ability to act as a reducing and stabilizing agent, promoting the formation of well-defined crystalline structures. The relative intensity of the peaks also suggests good crystallinity, which is favorable for antimicrobial and catalytic applications.

DLS of Silver Nanoparticles

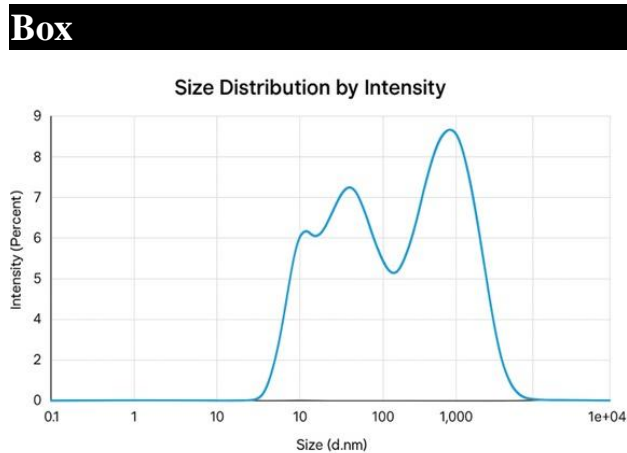


Figure 6

DLS obtained from silver nanoparticles

Own Source

Dynamic Light Scattering (DLS) analysis shows a multimodal distribution with three populations centered approximately at 10 nm, 100 nm, and 1000 nm, indicating significant heterogeneity in the hydrodynamic size of the synthesized nanoparticles.

- The peak at ~ 10 nm could correspond to individual nanoparticles well stabilized by fungal metabolites.
- The dominant peak at ~ 100 nm suggests the presence of partially aggregated nanoparticles or with coronas of organic compounds that increase their hydrodynamic size.
- The third peak at ~ 1000 nm likely represents larger aggregates or clusters, common in green syntheses where the stabilizing agents are natural and nonuniform.

Importantly, DLS measures hydrodynamic size, which includes not only the metallic core of the nanoparticle, but also the solvation shell and any molecules adsorbed on its surface. Therefore, the sizes reported by DLS are often larger than those observed using techniques such as SEM or TEM.

The observed dispersion can be attributed to variability in the composition of the fungal extract, temperature, and reaction time. These results reinforce the need to optimize synthesis conditions to obtain a more monodisperse distribution.

Conclusions

This research demonstrates that *Phytophthora infestans* can be effectively used as a reducing and stabilizing agent in the mycosynthesis of silver nanoparticles (AgNPs), offering a sustainable alternative to conventional chemical synthesis methods. Spectroscopic and structural characterization confirmed the formation of AgNPs with well-defined optical and crystalline properties, evidenced by the SPR peak at 450 nm and the face-centered cubic (FCC) structure observed in XRD analysis.

SEM micrographs revealed a predominantly spherical morphology and a homogeneous distribution of particles smaller than 100 nm, while DLS analysis indicated multimodal dispersion in hydrodynamic size, attributable to the complexity of the fungal extract and the synthesis conditions. These results suggest good colloidal stability, although they also point to the need to optimize experimental parameters to improve monodispersity.

Taken together, the findings support the antimicrobial potential of the obtained AgNPs, as well as their applicability in biomedical and agricultural contexts. Furthermore, this study proposes a biotechnological reevaluation of phytopathogenic organisms such as *P. infestans*, traditionally considered harmful, promoting a more integrative and ecological approach to the development of functional nanomaterials.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Granados-Olvera, Jorge Alberto: Contributed to the project idea, synthesis method and the samples characterization.

Vergara-Reyes, Hugo Yurriel: Contributed to the mycosynthesis, experimentation, and writing of the article.

Rangel- Ruíz, Karelia Liliana: Contributed to the development and evaluation in microbiological tests.

Del Angel-Francisco, Lesly Alabel: Contributed to the mycosynthesis, experimentation, and translation of the article.

Availability of data and materials

Indicate the availability of the data obtained in this research.

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Abbreviations

AgNP	Silver nanoparticles
DLS	Dynamic Light Scattering
ROS	Reactive Oxygen Species
SEM	Scanning Electron Microscopy
UV-VIS	Ultraviolet-Visible
XRD	X-ray diffraction

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Antecedents

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Supports

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Differences

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Nevarez, J. A. V. (2025). [Biosíntesis de nanopartículas de plata y óxido de cobre: caracterización y efecto antifúngico sobre *Malassezia pachydermatis*](#).