

Synthesis, characterization, and antimicrobial evaluation of zinc oxide nanoparticles obtained using Aloe vera extract

Síntesis, caracterización y evaluación antimicrobiana de nanopartículas de óxido de zinc obtenidas con extracto de Aloe vera

Granados-Olvera, Jorge Alberto ^a, Hernández-Martínez, Meredith Jaqueline ^b, Calvillo-Beltrán, Sofia Valentina ^c and Rangel-Ruíz, Karelía Liliana ^d

^a Universidad Politécnica de Cuautitlán Izcalli, Universidad Tecnológica Fidel Velázquez • S-5756-2018 • 0000-0003-0546-5328 • 946998

^b Universidad Politécnica de Cuautitlán Izcalli • NYS-9550-2025 • 0009-0008-6320-3725 • 2156846

^c Universidad Politécnica de Cuautitlán Izcalli • KYU-8461-2024 • 0009-0003-8078-7172 • 2052292

^d Universidad Politécnica de Cuautitlán Izcalli • GLQ-8704-2022 • 0000-0003-1805-0447 • 225798

Classification:

Area: Biology, Chemistry and Life Sciences

Field: Life sciences

Discipline: Biotechnology

Subdiscipline: Other

<https://doi.org/10.35429/JEA.2025.12.33.5.1.7>

History of the article:

Received: October 28, 2025

Accepted: December 30, 2025

* [\[jorgealberto.go@upci.edu.mx\]](mailto:jorgealberto.go@upci.edu.mx)

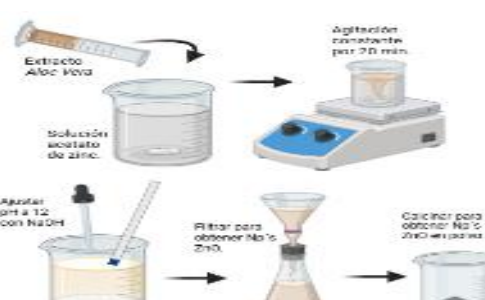
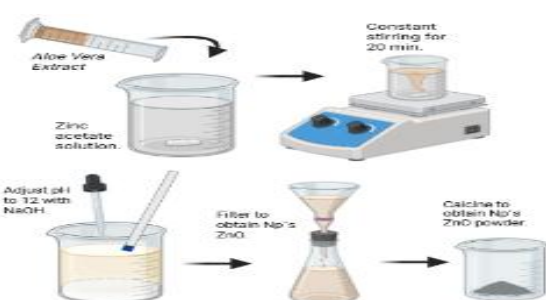


Abstract

The green synthesis of zinc oxide nanoparticles [ZnO-NPs] using *Aloe vera* extract represents a sustainable alternative to traditional methods that employ toxic reagents and energy-demanding conditions. In this study, aqueous extracts of the plant were prepared to be used as reducing and stabilizing agents in the formation of ZnO-NPs, which were later characterized by SEM-EDS, XRD and UV-Vis spectroscopy. The results confirmed the obtaining of nanocrystals with a hexagonal structure, average size of 27.75 nm and the presence of plant metabolites associated with their surface, which contributed to their stability. Likewise, microbiological tests revealed a marked inhibitory effect against *Escherichia coli*, *Salmonella typhi* and *Shigella flexneri*, evidencing that at concentrations above 50 mg the bacteria did not show growth. These findings demonstrate the potential of ZnO-NPs synthesized with *Aloe vera* as antimicrobial agents and promote their application in biomedical, agricultural and environmental settings.

Resumen

La síntesis verde de nanopartículas de óxido de zinc [ZnO-NPs] mediante extracto de *Aloe vera* representa una alternativa sostenible frente a los métodos tradicionales que emplean reactivos tóxicos y condiciones energéticamente demandantes. En este estudio se prepararon extractos acuosos de la planta para utilizarlos como agentes reductores y estabilizantes en la formación de ZnO-NPs, las cuales fueron posteriormente caracterizadas por SEM-EDS, XRD y espectroscopia UV-Vis. Los resultados confirmaron la obtención de nanocristales con estructura hexagonal, tamaño promedio de 27.75 nm y presencia de metabolitos vegetales asociados a su superficie, lo que contribuyó a su estabilidad. Asimismo, las pruebas microbiológicas revelaron un marcado efecto inhibitorio frente a *Escherichia coli*, *Salmonella typhi* y *Shigella flexneri*, evidenciando que a concentraciones superiores a 50 mg las bacterias no presentaron crecimiento. Estos hallazgos demuestran el potencial de las ZnO-NPs sintetizadas con *Aloe vera* como agentes antimicrobianos y promueven su aplicación en ámbitos biomédicos, agrícolas y ambientales.



Synthesis, Characterization, Zinc Nanoparticles

Síntesis, Caracterización, Nanopartículas de Zinc

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

Citation: Granados-Olvera, Jorge Alberto, Hernández-Martínez, Meredith Jaqueline, Calvillo-Beltrán, Sofia Valentina and Rangel-Ruíz, Karelía Liliana. [2025]. Synthesis, characterization, and antimicrobial evaluation of zinc oxide nanoparticles obtained using Aloe vera extract. *Journal of Engineering Applications*. 12[33]1-7: e51233107.



ISSN: 2410-3454/ © 2009 The Author[s]. Published by ECORFAN-Mexico, S.C. for its Holding Bolivia on behalf of Journal of Engineering Applications. This is an open access article under the CC BY-NC-ND license [<http://creativecommons.org/licenses/by-nc-nd/4.0/>]

Peer review under the responsibility of the Scientific Committee MARVID® - in the contribution to the scientific, technological and innovation Peer Review Process through the training of Human Resources for continuity in the Critical Analysis of International Research.



Introduction

Nanotechnology has revolutionized multiple scientific fields by enabling the design of materials with unique properties at the nanometric scale [Rivera Mendoza, 2025]. Among these materials, zinc oxide nanoparticles [ZnO-NPs] have garnered special attention due to their antimicrobial, photocatalytic, optical, and electronic properties [Raghupathi et al., 2011]. Traditionally, the synthesis of ZnO-NPs has been carried out using physical and chemical methods that, although effective, often involve the use of toxic reagents, high temperatures, and unsustainable laboratory conditions [Sirelkhatim et al., 2015].

In response to these challenges, green synthesis has emerged as an ecological alternative that employs natural extracts as reducing and stabilizing agents. This approach not only reduces environmental impact but can also confer additional bioactive [Aranda, 2025] properties to the nanoparticles. Aloe vera extract, rich in phenolic compounds, flavonoids, and enzymes, has proven to be an excellent candidate for the green synthesis of ZnO-NPs [Muruchi Arispe et al., 2025], facilitating the formation of nanometric structures without the need for synthetic additives [Perez Adassus et al., 2020].

Various studies have explored the use of plant extracts such as *Ruta chalepensis* [Mendoza Pérez, 2023], *Camellia sinensis* [Alarcón Hernández, 2022], and *Aloe barbadensis* [Galindo, 2023], demonstrating that the nature of the extract directly influences the morphology, size, and biological activity of the nanoparticles obtained. In particular, ZnO-NPs synthesized with Aloe vera extract have shown significant antimicrobial activity against pathogenic bacteria such as *Escherichia coli* and *Staphylococcus aureus*, attributed to the generation of reactive oxygen species [ROS] and the release of Zn²⁺ ions [Sirelkhatim et al., 2015].

Furthermore, the characterization of these nanoparticles using techniques such as X-ray diffraction [XRD], UV-Vis spectroscopy, and electron microscopy [SEM] has confirmed their zincite-type crystalline structure, sizes between 10 and 50 nm, and the presence of functional groups derived from the plant extract that contribute to their stability [Perez Adassus et al., 2020; Mendoza Pérez, 2023].

In this context, the present work focuses on the synthesis, characterization, and antimicrobial evaluation of ZnO-NPs [Chávez et al., 2025] obtained using Aloe vera extract, with the aim of contributing to the development of functional and sustainable materials for biotechnological and environmental applications [Ramírez et al., 2025].

Methodology

Synthesis

The process began by cutting Aloe vera leaves into very small fragments, which were mixed with 80 mL of distilled water and heated to a controlled temperature between 60 and 70 °C, with the aim of promoting the release of bioactive compounds into the aqueous medium.

Box 1

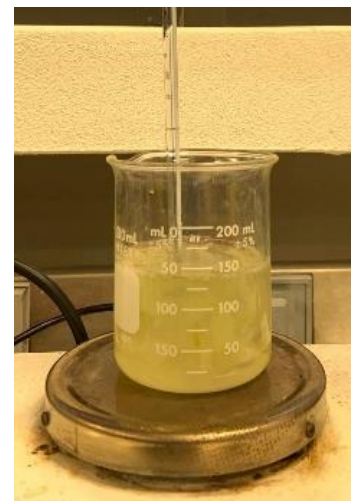
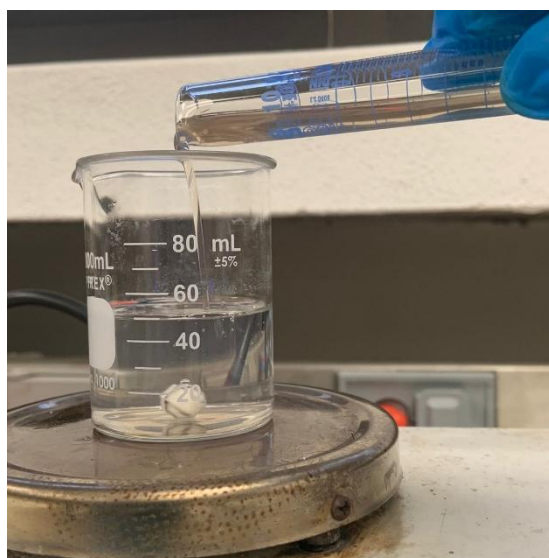


Figure 1
Aloe Vera Extract

Own Source

This mixture was then filtered and stored at 20 °C for later use. In parallel, a solution of 0.1 M zinc acetate [Zn [CH₃COO] ₂] was prepared in 50 mL of distilled water under constant agitation, ensuring its complete homogenization.

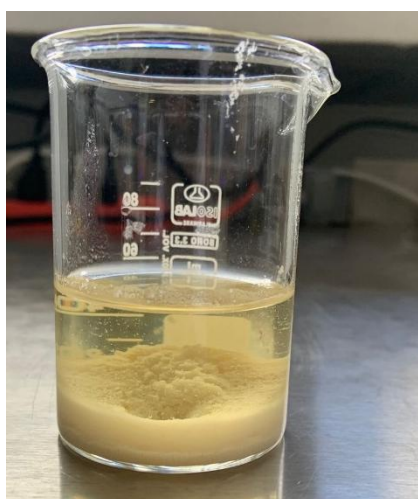
To carry out the synthesis of zinc oxide [ZnO] nanoparticles, 4 mL to 7 mL of the previously cooled Aloe vera extract was added to the zinc acetate solution, maintaining a constant stirring for 20 minutes to promote the interaction between the organic compounds and the metal ions.

Box 2**Figure 2**

Aloe Vera Extract and Zinc Mixture

Own Source

Subsequently, the pH was adjusted by adding a solution of sodium hydroxide [NaOH] to 2 M drop by drop, until a pH value of 12 was reached, a condition that favored the formation of the ZnO precipitate.

Box 3**Figure 3**

Precipitate Obtained

Own Source

The solution obtained was left to rest to allow the sedimentation of the solid, which was recovered by filtration, drying and subjected to a calcination process at 600 °C, thus obtaining the nanoparticles in powder form.

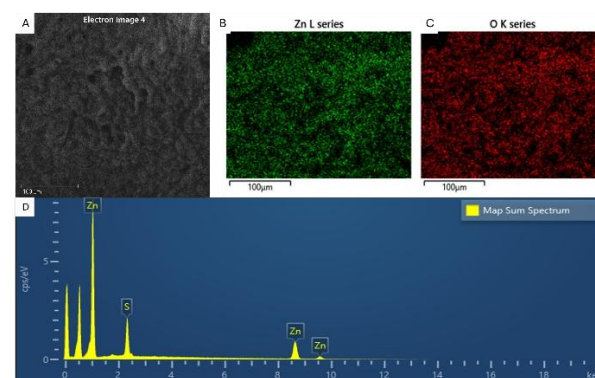
Box 4**Figure 4**

Calcination of the Precipitate and Obtaining the Nanoparticle Powder

*Own Source***Microbiologic analysis**

An analysis of the antimicrobial effect was carried out using the Kirby Bauer method, the sensidiscs were impregnated with 1, 2 and 3 drops of the nanoparticles obtained respectively. Müller Hinton agar was used and tested in triplicate with *E. coli* cultures, which were incubated for 24 and 96 hours at 37°C, in addition a control box was cultured to verify the correct growth of the bacteria.

Once the time had elapsed, the growth of the microorganisms was verified in the case of the control, while for the antimicrobial tests the diameter of the inhibition halos was measured with a vernier's help.

Results**Box 5****Figure 5**

SEM-EDS Characterization

Own Source

Morphological and elemental characterization by SEM-EDS

Micrographs obtained by scanning electron microscopy [SEM] reveal a predominantly irregular morphology, with the formation of nanometer-sized surface aggregates scattered over a heterogeneous matrix [Panel A]. This distribution indicates an anisotropic growth typical of plant extract-assisted synthesis, in which bioactive metabolites – such as saponins, flavonoids or tannins present in Aloe vera – act as reducing and stabilizing agents during ZnO nucleation.

Elemental mapping analysis by energy dispersive spectroscopy [EDS] on Panels B and C confirms a uniform signal of zinc [Zn] and oxygen [O], demonstrating good compositional dispersion of zinc oxide over the entire surface. In particular, the intensity of the Zn [~ 1 keV and ~ 8.6 keV] and O [~ 0.5 keV] peaks in the EDS spectrum [Panel D] coincides with the expected presence of ZnO, while the appearance of a secondary sulfur signal [~ 2.3 keV] suggests the inclusion of traces of residual organosulfur compounds from the plant extract, without affecting the elemental purity of the material.

This comprehensive characterization corroborates the successful formation of ZnO-NPs by green synthesis, highlighting the chemical interaction between the biocomponents of Aloe vera and the surface of the particles. In addition, the morphology and composition observed reinforce the potential of these nanoparticles for antimicrobial applications.

Box 6

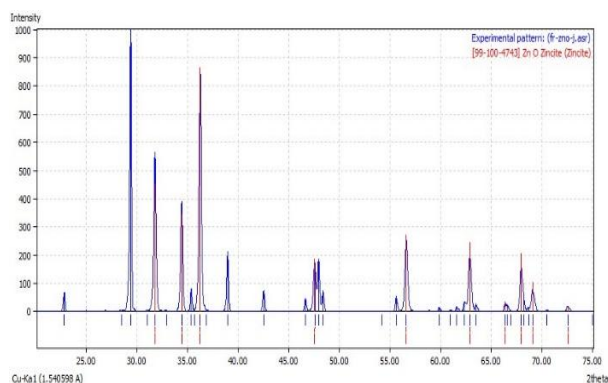


Figure 6

X-ray Diffraction Characterization

Own Source

X-ray Diffraction [XRD]

The sample was characterized by powder X-ray diffraction using a diffractometer operating in coupled mode [$\theta-2\theta$], employing $\text{CuK}\alpha_1$ radiation [$\lambda = 1.5406 \text{ \AA}$]. The diffraction pattern was recorded in the range of 20° to 75° 2θ , allowing the identification of the crystalline phases present.

The observed peaks correlate with PDF file 99-100-4743 from the ICDD, corresponding to the zincite phase of zinc oxide [ZnO], with a hexagonal compact structure [space group $P6_3mc$]. The coincidence in diffraction angles with crystallographic planes such as [100], [002], [101], and [110] confirms the formation of pure ZnO. The absence of peaks attributable to impurities suggests a high structural purity of the synthesized material.

Crystallite Size Estimation: Scherrer equation

The average size of the crystalline domains was estimated using the Scherrer equation:

$$D = \frac{K\lambda}{\beta \cos \theta}$$

Where :

D = is the crystal size

K = is the form factor [0.9]

λ = the radiation wavelength is 1.5406 \AA

β = FWHM is approximately 0.0052 rad

θ = diffraction angle is around 18.125°

Applying experimental values, an average crystal size of 27.75 nm was determined, corresponding to the [101] plane located at $2\theta \approx 36.25^\circ$. Where: D is the crystal size; K is the shape factor [0.9]; λ is the wavelength of radiation [1.5406 \AA]; β is the FWHM in radians [$\approx 0.0052 \text{ rad}$]; and θ is the diffraction angle [$\approx 18.125^\circ$].

This value confirms the formation of nanocrystals, consistent with eco-friendly synthesis processes. The low dispersion of the peaks indicates high crystallinity and structural uniformity.

The formation of ZnO nanometric suggests potential in photocatalytic and antimicrobial applications, particularly in aqueous media.

UV-VIS Characterization

Box 7

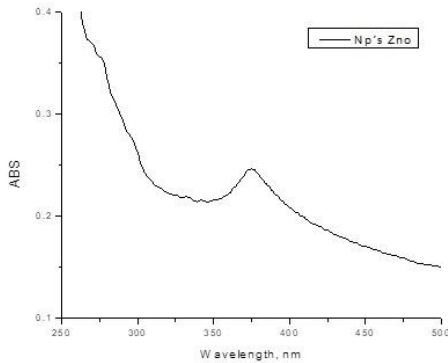


Figure 7

UV-Vis Characterization

Own Source

The UV-Vis spectrum obtained shows an intense absorption band at 255 nm, possibly attributed to residual organic compounds of the plant extract, followed by a second band centered at 355 nm, corresponding to the excitonic border of ZnO. From the latter, a bandgap energy of 3.49 eV was estimated, higher than the typical value reported for commercial ZnO [~ 3.37 eV], which suggests a quantum confinement effect and a possible surface interaction with bioactive metabolites present in the Aloe vera extract.

These results are consistent with previous studies that report optical modifications in ZnO-NPs functionalized with plant extracts, highlighting their potential in photocatalytic and antimicrobial applications.

Sensitivity Testing

As can be seen in the figure 8, for *E. coli*, *S. typhi* and *S. flexneri*, a slight growth can be observed in the box with a concentration of 20mg of ZnONp's, however, for the concentrations of 50 and 100mg no bacterial growth is observed in any of the cases, which indicates that these bacteria have a high sensitivity to ZnONp's.

This effect has already been previously reported in the literature [Gupta et al., 2018; Muthuvel et al., 2020; Sarillana et al., 2021], where it has been reported that ZnONp's synthesized from plants have antibacterial activity.

Box 8

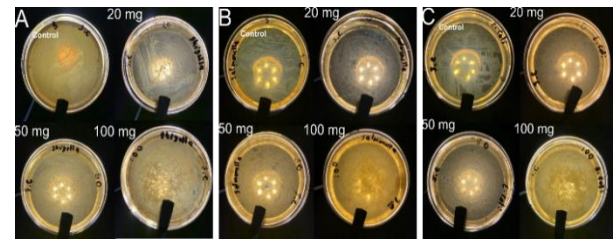


Figure 8

Sensitivity Test

Own Source

Conclusions

The present research confirms that the green synthesis of zinc oxide nanoparticles [ZnO-NPs] using *Aloe vera* extract is an efficient, reproducible and environmentally friendly strategy for obtaining nanomaterials with outstanding antimicrobial properties. The use of plant extracts as reducing and stabilizing agents eliminates the need to employ toxic compounds, high pressures or extreme temperatures, thus reducing the environmental impact and costs associated with the process.

The characterization techniques used, such as SEM-EDS, XRD and UV-Vis, allowed confirming the formation of nanoparticles with a hexagonal zincite-type crystal structure, an average size close to 27.75 nm and a surface functionalized by bioactive metabolites of the plant, which contributed to their stability and potential biological interaction. Such structural and optical properties, together with the observed quantum confinement effect, position these nanoparticles as functional materials with multifaceted applications.

In the microbiological field, the tests demonstrated significant inhibition of the growth of pathogenic bacteria of clinical and food importance such as *Escherichia coli*, *Salmonella typhi* and *Shigella flexneri*. At concentrations of 50 and 100 mg, bacterial growth was completely inhibited, which confirms the sensitivity of these microorganisms to the ZnO-NPs obtained and opens the possibility of using them as alternative agents against the growing antimicrobial resistance.

Overall, the results obtained not only validate the feasibility of using *Aloe vera* in the green synthesis of metal nanoparticles, but also provide solid evidence on its potential in biomedical, agricultural and environmental applications.

Future research could focus on the control of morphology and size distribution, evaluation against a broader spectrum of microorganisms, as well as toxicity and biocompatibility studies in in vitro and in vivo models.

In this way, it will be possible to establish more solid foundations for its incorporation into innovative strategies aimed at health care and environmental sustainability.

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, research method and technique.

Hernández- Martínez, Meredith Jaqueline: Contributed to the synthesis, experimentation, and writing of the article.

Calvillo-Beltrán, Sofía Valentina: Contributed to the experimentation, and translation of the article.

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

Availability of data and materials

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Funding

This research did not receive any funding.

Acknowledgements

This research did not receive funding from any institution, university or company.

Abbreviations

ZnNPs Zinc nanoparticles

SEM Scanning Electron Microscopy
UV-VIS Ultraviolet-Visible
XRD X-ray diffraction

References

Antecedents.

Mendoza Pérez, J. [2023]. *Synthesis and characterization of ZnO nanoparticles using Ruta L. [Rue] extract and their photocatalytic application in the degradation of methylene blue* [Master's thesis, Benemérita Universidad Autónoma de Puebla]. BUAP Repositor

Perez Adassus, M. B., Spetter, C. V., & Lassalle, V. L. [2020]. *Characterization of Zinc oxide nanoparticles synthesized by the green route from Aloe Vera*. University of Buenos Aires.

Raghupathi, K., Koodali, R. T., & Manna, A. C. [2011]. *Size-dependent bacterial growth inhibition and mechanism of antibacterial activity of ZnO nanoparticles*. *Langmuir*, 27[7], 4020–4028.

Sirelkhatim, A., Mahmud, S., Seeni, A., Kaus, N. H. M., Ann, L. C., Bakhori, S. K. M., Hasan, H., & Mohamad, D. [2015]. *Review on Zinc Oxide Nanoparticles: Antibacterial Activity and Toxicity Mechanism*. *Nano-Micro Letters*, 7[3], 219–242.

Basics

Gupta M., Tomar R.S., Kaushik S., Mishra R.K., Sharma D. *Effective Antimicrobial Activity of Green ZnO Nano Particles of Catharanthus Roseus*. *Front. Microbiol.* 2018;9:2030.

Muthuvel A., Jothibas M., Manoharan C. *Effect of Chemically Synthesis Compared to Biosynthesized ZnO-NPs Using Solanum Nigrum Leaf Extract and Their Photocatalytic, Antibacterial and in-Vitro Antioxidant Activity*. *J. Environ. Chem. Eng.* 2020;8:103705.

Supports

Aranda Herrera, B. [2025]. *Desarrollo in vitro de un gel acondicionador a base de AgNPs obtenidas por síntesis verde y su evaluación en los procesos bio-celulares dentales* [Tesis de maestría, UNAM]. Repositorio UNAM

Differences

Alarcón Hernández, C. J. [2022]. *Analysis of the chemical and green synthesis of metal oxide nanoparticles: advantages and disadvantages* [Master's thesis, National Institute of Astrophysics, Optics and Electronics]. INAOE.

Galindo-Guzmán, A. P., Fortis-Hernández, M., De La Rosa-Reta, C. V., Zermeño-González, H., & Galindo-Guzmán, M. [2023]. *Chemical synthesis of zinc oxide nanoparticles and their evaluation in Lactuca sativa seedlings*. Mexican Journal of Agricultural Sciences, 13[spe28].

Discussions.

Chávez, S. A. B., Osornio, X. B., Sánchez, O. A. C., López, C. C., & Parra, G. A. [2025]. *Síntesis y aplicación de nanopartículas de Ag/ZnO para el desarrollo de un limpiador fotocatalítico y antimicrobiano en textiles*. *Revista Aristas*, 12[20], 14–19.

Muruchi Arispe, E. E., Vasquez, B., López, G. P., & Bellotti, N. [2025]. *Síntesis verde de nanopartículas de ZnO asociadas a una sílice natural y sus potencialidades antimicrobianas*. *VIII Jornadas de Investigación, Transferencia, Extensión y Enseñanza*.

Ramírez, J. I. D. L. [2025]. *Soporte de especies de zinc en zeolita A con ayuda de ultrasonido para estimar sus propiedades bactericidas y fotocatalíticas* [Tesis de doctorado, CICESE].

Rivera Mendoza, D. [2025]. *Evaluación del efecto inhibitorio de nanopartículas metálicas, sintetizadas por una vía verde utilizando a Ganoderma sessile, sobre Campylobacter jejuni* [Tesis de maestría, CICESE].

Sarillana Z.C., Fundador E.O., Fundador N.G. *Synthesis of ZnO Nanoparticles Using Theobroma Cacao L. Pod Husks, and Their Antibacterial Activities against Foodborne Pathogens*. *Int. Food Res. J.* 2021;28:102–109.