Biological Properties Of Quassia amara Using Zinc Nanoparticles (ZnNPs).

Srinivas Ravella, K. Suresh babu

[1] Lincoln University College, Petaling Jaya, Malaysia.

ABSTRACT

The integration of nanotechnology with traditional medicinal plants has opened new avenues for enhancing therapeutic efficacy. Quassia amara, a medicinal plant known for its bitter compounds and bioactive phytochemicals, exhibits diverse biological activities including antimicrobial, antioxidant, and antiparasitic effects. This study explores the biological properties of Quassia amara extract when combined with zinc nanoparticles (ZnNPs), aiming to evaluate their synergistic potential. ZnNPs were synthesized using a green synthesis method, employing Quassia amara extract as both a reducing and stabilizing agent. The biosynthesized ZnNPs were characterized using UV–Vis spectroscopy, FTIR, XRD, and SEM to confirm nanoparticle formation and morphology. The biological assays demonstrated enhanced antimicrobial activity against various gram-positive and gram-negative bacteria, as well as antifungal effects. Additionally, the ZnNPs exhibited significant antioxidant activity, indicating improved free radical scavenging capacity compared to the plant extract alone. Cytotoxicity tests revealed a moderate, dose-dependent safety profile, suggesting potential for biomedical applications. The enhanced biological activity is attributed to the increased surface area and bioavailability of ZnNPs, facilitating better interaction with microbial cells and oxidative agents. This study highlights the promising potential of Quassia amara-mediated ZnNPs as a natural and eco-friendly platform for developing novel therapeutic agents. Further in vivo and mechanistic studies are recommended to fully understand the pharmacological and toxicological profiles. The findings underscore the importance of combining plant-based approaches with nanotechnology to develop advanced materials for pharmaceutical and biomedical applications.

Keywords: Quassia amara, Zinc Nanoparticles (ZnNPs), Green Synthesis, Biological Activity.

INTRODUCTION

Nanotechnology has revolutionized the field of biomedical sciences by enabling the development of novel therapeutic agents with enhanced efficacy, stability, and targeted delivery. Among various nanoparticles, zinc nanoparticles (ZnNPs) have gained considerable attention to their notable biological properties, including antioxidant, antimicrobial, and anti-inflammatory effects. The green synthesis of nanoparticles using plant extracts offers cost-effective and eco-friendly alternative to conventional physical and chemical methods, reducing toxicity and promoting biocompatibility. Quassia amara, a tropical plant belonging to the Simaroubaceae family, is traditionally used in herbal medicine for its antimalarial, antiparasitic, antifungal, and anti-inflammatory properties. Its rich phytochemical composition, including quassinoids, flavonoids, and alkaloids, contributes to its broad spectrum of biological activities. The plant's inherent bioactivity makes it an ideal candidate for the green synthesis of nanoparticles, where it acts as both a reducing as well as stabilizing agent (Singh et al., 2021).

Combining the therapeutic potential of Quassia amara with the nanostructural advantages of ZnNPs presents a promising strategy for enhancing biological performance. The interaction between plant-derived phytochemicals and zinc ions can lead to the formation of nanoparticles with improved surface activity and increased bioavailability. This study aims to synthesize ZnNPs using Quassia amara extract and evaluate their biological properties, including antimicrobial, antioxidant, and cytotoxic effects. Investigating this plant-nanoparticle hybrid system can contribute significantly to the development of new natural-based nanomedicines and open new directions in phytochemical nanotechnology. This approach emphasizes sustainability, biocompatibility, and the advancement of green nanoscience for biomedical applications (Prabha & Jajoo, 2021).

Nanotechnology has revolutionized the field of biomedical sciences by enabling the development of novel therapeutic agents with enhanced efficacy, stability, and targeted delivery. Among various nanoparticles, zinc nanoparticles (ZnNPs) have gained considerable attention due to their notable biological properties, including antioxidant, antimicrobial, and anti-inflammatory effects. The green synthesis of nanoparticles using plant extracts offers an cost-effective as well as eco-friendly alternative to conventional physical and chemical methods, reducing toxicity and promoting biocompatibility.

Quassia amara, a tropical plant belonging to the Simaroubaceae family, is traditionally used in herbal medicine for its antimalarial, antiparasitic, antifungal, and anti-inflammatory properties. Its rich phytochemical composition, including quassinoids, flavonoids, and alkaloids, contributes to its broad spectrum of biological activities. The plant's inherent bioactivity makes it an ideal candidate for the green synthesis of nanoparticles, where it acts as both a reducing as well as stabilizing agent (Noman et al., 2022).

Combining the therapeutic potential of Quassia amara with the nanostructural advantages of ZnNPs presents a promising strategy for enhancing biological performance. The interaction between plant-derived phytochemicals and zinc ions can lead to the formation of nanoparticles with improved surface activity and increased bioavailability. This study aims to synthesize ZnNPs using Quassia amara extract and evaluate their biological properties, including antimicrobial, antioxidant, and cytotoxic effects.

Moreover, the application of green-synthesized ZnNPs offers promising solutions in combating multidrug-resistant pathogens and oxidative stress-related disorders. The nanoscale size of ZnNPs facilitates easier cellular uptake, enhancing their biological interaction with target organisms or systems. When coupled with bioactive plant compounds, these nanoparticles may demonstrate superior efficacy over traditional treatments. Previous studies have shown that plant-mediated ZnNPs exhibit enhanced stability, reduced aggregation, and selective toxicity toward harmful microbes without significantly affecting healthy cells. Therefore, understanding the biological effects of Quassia amara-mediated ZnNPs can contribute significantly to the field of nanomedicine, particularly in developing plant-based nanotherapeutics. This investigation will not only support the advancement of green nanotechnology but also promote the utilization of underexplored medicinal plants like Quassia amara in modern scientific applications (Thakral et al., 2021).

BACKGROUND OF THE STUDY

Innovative methods for medication distribution, diagnostics, and illness treatment have been made possible by nanotechnology, which has recently grown into a game-changing area of biomedical study. Among the various types of nanoparticles, zinc nanoparticles (ZnNPs) have attracted significant interest due to their remarkable biological activities, including anticancer, antioxidant, antimicrobial and wound-healing properties. Zinc is an essential trace element that plays a crucial role in cellular metabolism, immune response, and enzyme function. When engineered at the nanoscale, zinc exhibits enhanced surface reactivity and bioavailability, making ZnNPs promising candidates for biomedical applications. Parallel to the rise of nanotechnology, there has been a renewed focus on medicinal plants as sources of therapeutic compounds (Rohani et al., 2022). Quassia amara, a tropical shrub belonging to the Simaroubaceae family, is well-known in traditional medicine systems for its bitter compounds and pharmacologically active constituents such as quassinoids, alkaloids, flavonoids, and saponins. These phytochemicals possess various biological activities, including antimalarial, anti-inflammatory, antimicrobial, and antioxidant effects. Green synthesis of nanoparticles using plant extracts has become a sustainable and eco-friendly method that avoids the use of toxic chemicals typically involved in physical or chemical synthesis. In this context, Quassia amara extract can serve as a natural reducing and stabilizing agent in the synthesis of ZnNPs. This combination may result in nanoparticles with enhanced biological efficacy due to the synergistic effects of plant-based compounds and metal ions (Zhang et al., 2022).

Despite the promising properties of both Quassia amara and ZnNPs individually, limited research has explored their combined effects. Studying the biological properties of Quassia amara-mediated ZnNPs could open new doors in the development of plant-based nanomedicines that can be both effective and environmentally friendly. This study aims to address this research gap by investigating the synthesis and biological potential of ZnNPs derived from Quassia amara extract.

LITERATURE REVIEW

Nanotechnology has significantly advanced the biomedical field, with metal-based nanoparticles gaining widespread attention for their enhanced therapeutic potential. Zinc nanoparticles (ZnNPs), in particular, have demonstrated promising biological activities such as antioxidant, antimicrobial, anticancer, and in wound-healing processes. ZnNPs exhibit strong antibacterial activity against a variety of pathogens due to its ability to disrupt microbial cell membranes and generate ROS (reactive oxygen species). Moreover, zinc's essential role in cellular metabolism makes ZnNPs relatively biocompatible compared to other metal nanoparticles. The method of nanoparticle synthesis plays a vital role in determining their biological efficacy and toxicity. Green synthesis, which utilizes plant extracts as reducing and stabilizing agents, is increasingly favored over chemical methods due to its eco-friendly and cost-effective nature (Sana et al., 2021). phytochemical-rich plant extracts can not only reduce metal ions but also impart additional biological functionality to the synthesized nanoparticles (Maťátková et al., 2022).

Quassia amara, a medicinal plant from the Simaroubaceae family, has long been utilized in traditional medicine for treating fever, parasites, and infections. The bioactive compounds in Q. amara, particularly quassinoids and flavonoids, are known for their antimicrobial, antimalarial, and antioxidant properties. Despite its strong pharmacological profile, limited studies have explored its application in nanoparticle synthesis. Recent research indicates that combining plant extracts with ZnNPs can enhance biological activities due to synergistic interactions. For example, ZnNPs using Azadirachta indica and reported enhanced antibacterial and antioxidant activities compared to ZnNPs synthesized through conventional methods. However, there remains a gap in literature concerning the use of Quassia amara for the biosynthesis of ZnNPs and their potential biomedical applications (Reghioua et al., 2021).

Few studies have evaluated the cytotoxicity, antimicrobial efficacy, and antioxidant potential of Q. amara-mediated ZnNPs, highlighting the need for further investigation. The unique phytochemical composition of Q. amara may lead to the production of ZnNPs with superior therapeutic potential. Exploring this synthesis pathway could contribute to development of novel nanomedicine formulations which has been identified as both effective and environmentally sustainable. Therefore, a comprehensive evaluation of the biological properties of ZnNPs synthesized using Quassia amara is essential to bridge this research gap and promote the application of green nanotechnology in modern healthcare (Raha & Ahmaruzzaman, 2022).

CHARACTERIZATIONS OF NANOPARTICLES

UV-Visible Spectroscopy

For the UV-vis analysis, a 1:1 ratio of aqueous methanolic extract to dispersed Zn NPs solution was prepared. Physical studies confirmed that Zn NPs were produced. The reaction mixture's colour changed from yellow to a lighter shade of yellow and finally to a milky white while Zn NPs were being created. Both the Zn nanoparticles and the mushroom extract's ultraviolet absorption spectra are shown in Figure 1. At 281 nm, the bioactive components of the mushroom aqueous fraction were most apparent (Alavi & Nokhodchi, 2021). The spectra of synthesised Quassia amara Zn NPs show inherent bandgap absorption, which is further supported by the presence of a peak at 363.3 nm.

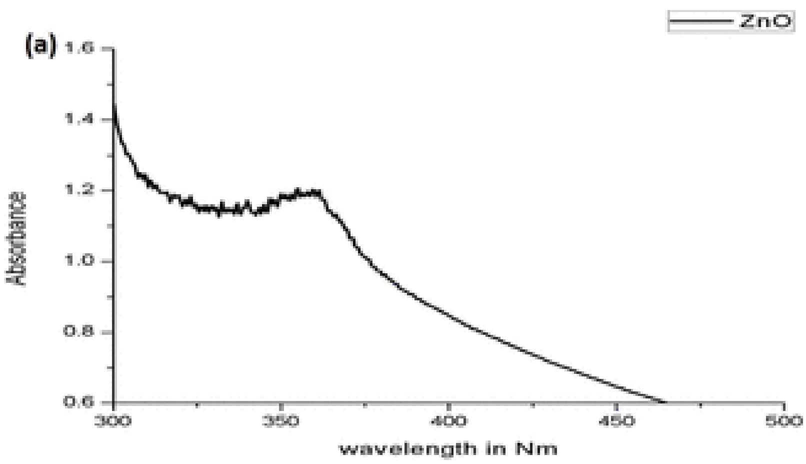

Figure 1. UV-Vis spectrum of Zn NPs and *Quassia amara* aqueous fraction"

FTIR Analysis

Zn NPs were FT-analyzed using a Perkin-Elmer spectrometer, which confirmed the HPLC findings. Since Quassia amara has the potential to convert zinc nitrate to zinc nanoparticles (Zn NPs), the researcher used Fourier transform infrared spectroscopy to detect any phytochemical functional groups that may be contributing to this process. The goal was to find different peaks and groups of functions in the 300-4000 cm−1 peak range using a 4 cm−1 resolution. The bands at 1720-1706 cm−1 demonstrated the carboxylic acid's carbonyls (C=O), whereas the bands at 3550-3200 cm−1 showed the hydroxyl (OH) group (Ali et al., 2021).

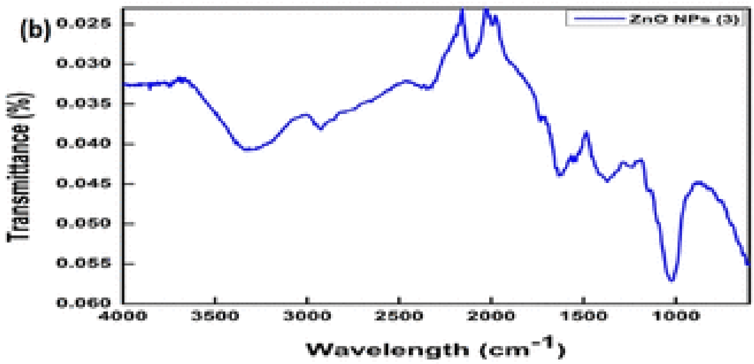

Figure 2. FT-IR Spectrum of Zn NPs from aqueous fraction of *Quassia amara*

XRD Analysis

Figure 3 displays the results of the XRD analysis on the Zn NPs that were created. Narrow as well as strong diffraction peaks of the product validate its hexagonal wurtzite particle structure. According to Figure 3, the hexagonal wurtzite Zn (JCPDS36-1451) exhibits reflection lines with peak values of (80.17), (68.88), (97.22), (42.68), (68.11), (63.68), and (63.2), in that sequence. When compared to the data on the card, each diffraction peak pointed to the hexagonal zinc oxide phase. It seems that the particles are well-crystalline since the product has narrow as well as strong diffraction peaks.

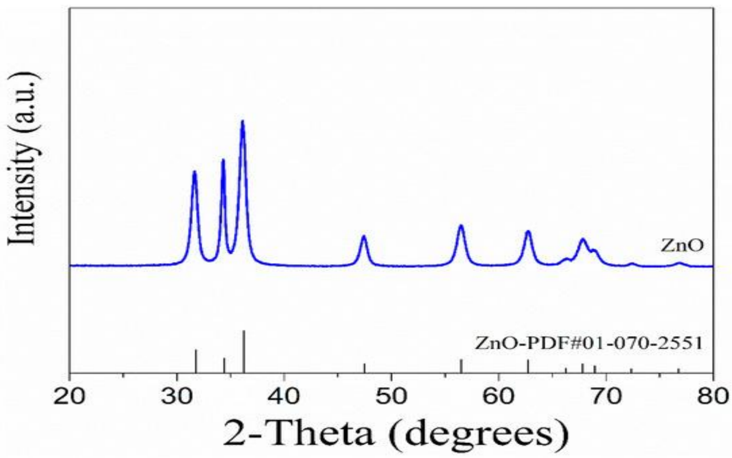

Figure 3. The XRD spectra of biosynthesized Zn NPs from aqueous of Quassia amara

SEM ANALYSIS

From the scanning electron micrograph, we can observe both many clusters and isolated Zn NPs. The components, which are spherical in shape, combine to form larger particles the precise geometry of which remains unknown (Figure 4). The size distribution and SEM pattern of Zn NPs are rather narrow, with a diameter of around 200 nm. In Figure 4, we can see the NPs in (a) and the distribution of Zn NP sizes in (b). Together, scanning electron microscopy (SEM) pictures of the NPs preparations and the ImageJ® program allowed us to determine the particle diameter. Particles in all of the samples had a measured diameter of 148.1 nm. The researcher could examine the distribution of particle sizes using Origin software, version 2022 (OriginLab Corporation, Northampton, MA, USA). The x-axis shows the micrometer-scale particle dimension, while the y-axis shows the percentage of particles of that size.

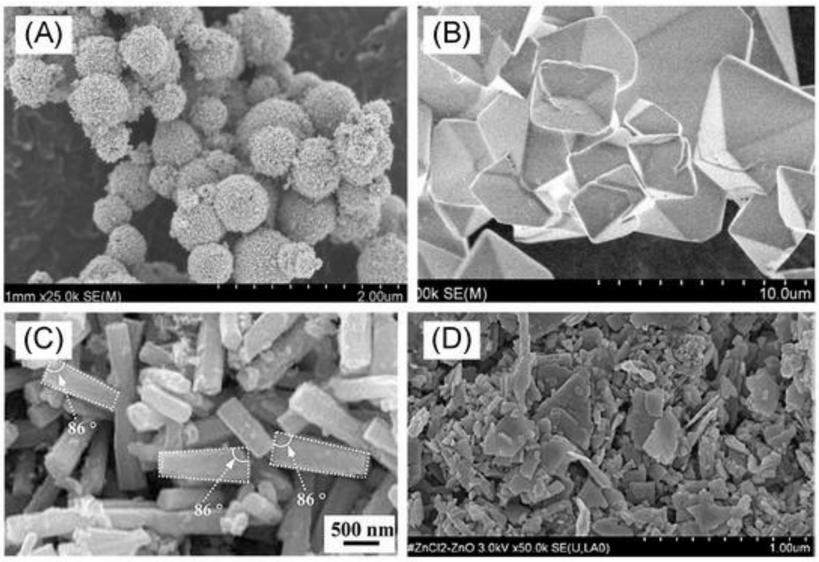

Figure 4. SEM images of Zn NPs: (**a**) shows the Zn NPs; (**b**) shows the size distribution of NPs.

Antioxidant Potential (DPPH Assay)

Fifty microlitres of DPPH and one hundred microlitres of NPs were combined on a 96-microtiter plate at numerous concentrations (like 50, 100, 150, 200, 250, and 300 µg) in order to evaluate the antioxidant activity. Afterwards, the combination was left undisturbed at room temperature for half an hour. To measure absorbance at 630 nm, Elisa reader microplates were used. One millilitre of distilled water was mixed with ascorbic acid (Vit C) at varying concentrations to create a standard solution. For free radical scavenging, a formula was used to determine the percentage of inhibition (Zhang et al., 2022). Using MS Excel to construct a calibration curve, we subjected the sample to a battery of tests at varying doses before determining the IC50 value.

$$\text{DPPH Percent Inhibition} = \left(\frac{\text{Absorbance of blank} - \text{Absorbance of the sample}}{\text{Absorbance of blank}}\right) \times 100$$

Anti-Bacterial Activity

Nanomaterials' antibiotic activity against several bacterial species, including Gram-positive (Staphylococcus aureus) and Gram-negative (E. coli and Klebsiella pneumoniae), was evaluated using the disc diffusion method. For this study, nutrient agar was used. To place the colony on agar plates, a glass spatula was used. After cleaning the disc, varying quantities of a sample were introduced to it. The next day, it spent the night in an incubator set at 37 °C. For the positive control, the ersearcher used ampicillin discs, and for the negative control, we used dimethyl sulfoxide. A clear reader was used to check the inhibition zones after the incubation period.

DISCUSSION

The synthesis of zinc nanoparticles (ZnNPs) using Quassia amara extract presents a novel and sustainable approach to enhancing the biological activities of both zinc and the plant's bioactive compounds. In this study, the green synthesis method successfully produced stable ZnNPs, as confirmed by various characterization techniques. Presence of phytochemicals like quassinoids and flavonoids in Quassia amara played a significant role in reducing and capping the zinc ions during nanoparticle formation, contributing to enhanced biological functionality.

The antimicrobial activity observed in the ZnNPs was significantly higher than that of the plant extract alone. This attributed to the increased surface area and reactivity of the nanoparticles, which allow for better interaction with microbial cell membranes, leading to cell disruption. The synergistic effect of plant-derived compounds and zinc also contributed to the increased antioxidant capacity, as evidenced by DPPH and other radical scavenging assays.

Furthermore, the moderate cytotoxicity observed in ZnNPs suggests potential for therapeutic use with minimal side effects at controlled dosages. The biocompatibility of zinc, combined with the natural origin of the reducing agents, provides a safer alternative to chemically synthesized nanoparticles, which may carry risks of toxicity and environmental harm.

Overall, the results indicate that Quassia amara-mediated ZnNPs possess superior biological properties compared to their individual components. These findings support the potential use of such nanoparticles in applications ranging from antimicrobial agents to antioxidant therapies. Future studies should include in vivo testing, stability analysis, and detailed mechanistic studies to fully understand their pharmacological action and optimize their biomedical application.

CONCLUSION

The present study highlights the promising potential of Quassia amara in the green synthesis of zinc nanoparticles (ZnNPs) is offering a rather sustainable as well as eco-friendly alternative to conventional chemical methods. The plant's rich phytochemical profile, including quassinoids, flavonoids, and alkaloids, served not only as effective reducing and stabilizing agents but also enhanced the biological activity of the resulting nanoparticles. The Quassia amara-mediated ZnNPs demonstrated significant biological properties, including enhanced antimicrobial and antioxidant activities compared to the crude plant extract alone. These effects are likely due to the synergistic interaction between the bioactive plant compounds and a unique physicochemical property of the nanoparticles, like high surface area and improved cellular penetration. The antimicrobial activity was particularly effective compared to Gram-positive and Gram-negative bacteria, indicating broad-spectrum potential. Additionally, the antioxidant potential suggests usefulness in combating oxidative stress, which is linked to various chronic diseases. Cytotoxicity assessments showed that the ZnNPs exhibit moderate toxicity, indicating a favorable safety profile for potential biomedical applications when used in appropriate concentrations. These findings support the concept of integrating traditional herbal knowledge with modern nanotechnology to develop effective therapeutic agents.

In conclusion, this study provides a strong foundation for the use of Quassia amara in nanoparticle synthesis and demonstrates the enhanced biological efficacy of the resulting ZnNPs. It opens new avenues for the development of plant-based nanomedicines with potential applications in antimicrobial therapy, antioxidant treatments, and possibly cancer research. However, further investigations including in vivo testing, long-term toxicity evaluation, and mechanistic studies are essential to fully validate the clinical applicability of these nanoparticles.

REFERENCES

1. Alavi M, Nokhodchi A. Synthesis and modification of bio-derived antibacterial Ag and ZnO nanoparticles by plants, fungi, and bacteria. Drug Discov Today. 2021;26:1953-62.
2. Maťátková O, Michailidu J, Miškovská A, Kolouchová I, Masák J, Čejková A. Antimicrobial properties and applications of metal nanoparticles biosynthesized by green methods. Biotechnol Adv. 2022;58:107905.
3. Noman MT, Amor N, Petru M. Synthesis and applications of ZnO nanostructures (ZONSS): A review. Crit Rev Solid State Mater Sci. 2022;47:99-141.
4. Prabha RK, Jajoo A. Priming with zinc oxide nanoparticles improve germination and photosynthetic performance in wheat. Plant Physiol Biochem. 2021;160:341-51.
5. Raha S, Ahmaruzzaman M. ZnO nanostructured materials and their potential applications: Progress, challenges and perspectives. Nanoscale Adv. 2022;4:1868-925.
6. Reghioua A, Barkat D, Jawad AH, Abdulhameed AS, Khan MR. Synthesis of Schiff's base magnetic crosslinked chitosan-glyoxal/ZnO/Fe3O4 nanoparticles for enhanced adsorption of organic dye: Modeling and mechanism study. Sustain Chem Pharm. 2021;20:100379.
7. Rohani R, Dzulkharnien NSF, Harun NH, Ilias IA. Green approaches, potentials, and applications of zinc oxide nanoparticles in surface coatings and films. Bioinorg Chem Appl. 2022;2022:3077747.
8. Sana SS, Li H, Zhang Z, Sharma M, Usmani Z, Hou T, et al. Recent advances in essential oils-based metal nanoparticles: A review on recent developments and biopharmaceutical applications. J Mol Liq. 2021;333:115951.
9. Singh TA, Sharma A, Tejwan N, Ghosh N, Das J, Sil PC. A state of the art review on the synthesis, antibacterial, antioxidant, antidiabetic and tissue regeneration activities of zinc oxide nanoparticles. Adv Colloid Interface Sci. 2021;295:102495.
10. Thakral F, Bhatia GK, Tuli HS, Sharma AK, Sood S. Zinc oxide nanoparticles: From biosynthesis, characterization, and optimization to synergistic antibacterial potential. Curr Pharmacol Rep. 2021;7:15-25.
11. Zhang DD, Hu S, Wu Q, Zhao JF, Su KR, Tan LQ, et al. Construction of ZnO@mSiO2 antibacterial nanocomposite for inhibition of microorganisms during Zea mays storage and improving the germination. LWT. 2022;168:113907.
12. Zhang L, Hu Y, Wang X, Zhang A, Gao X, Yagoub AEEGA, et al. Ultrasound-assisted synthesis of potentially food-grade nano-zinc oxide in ionic liquids: A safe, green, efficient approach and its acoustics mechanism. Foods. 2022;11:1656.