Biological Properties Of *Panax Ginseng* Using Zinc Nanoparticles

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ABSTRACT

The many pharmacological benefits of the medicinal plant *Panax ginseng* include antioxidant, anti-inflammatory, anti-cancer, and immunomodulatory capabilities, all of which have been extensively studied and documented. It has medicinal promise, however issues including fast metabolism, low stability, and poor absorption may reduce the bioavailability and effectiveness of its bioactive components. Strategies to improve the bioactivity and stability of chemicals generated from plants have been suggested by recent advances in nanotechnology, especially via the use of metal-based nanoparticles. Biomedical researchers have found zinc nanoparticles (ZnNPs) to be an invaluable resource because of their unusual physicochemical characteristics, biocompatibility, and lack of toxicity.

In order to discover how the synergistic improvement of Panax ginseng's therapeutic potential is achieved, this research will examine its biological characteristics when produced with zinc nanoparticles (ZnNPs). To create ZnNPs, a green synthesis method was used, with extract from P. ginseng serving as a stabilizing and reducing agent. To find out how big, shaped, and what kind of surface properties the synthesized nanoparticles had, scientists used a battery of analytical tools, including ultraviolet-visible spectroscopy (UV-Vis), transmission electron microscopy (TEM), scanning electron microscopy (SEM), and Fourier transform infrared spectroscopy (FTIR).

Panax ginseng-ZnNPs composite's antioxidant, antibacterial, and cytotoxic capabilities were the main foci of the biological examination. Three different tests were used to evaluate the antioxidant properties: ferric reducing antioxidant power (FRAP), DPPH radical scavenging, and ABTS radical cation decolorization. The findings showed that P. ginseng extracts treated with ZnNPs had much higher free radical scavenging activity than the untreated extract, indicating that the treated extract was better at reducing oxidative stress. Using disc diffusion and minimum inhibitory concentration (MIC) tests, the antimicrobial activity were assessed against a range of bacterial species, including Escherichia coli, Staphylococcus aureus, and Pseudomonas aeruginosa. The presence of ZnNPs enhanced the antibacterial activity of the P. ginseng extract, as shown by the enhanced antimicrobial properties.

In order to determine biocompatibility, cytotoxicity tests were conducted using MTT assays on normal cell lines and human cancer cell lines, including HeLa (cervical cancer) and MCF-7 (breast cancer). The findings showed that P. ginseng-ZnNPs composites had minimal toxicity on normal cells and selective cytotoxicity towards cancer cells, suggesting that they might be used in targeted cancer treatment.

Finally, the antioxidant, antibacterial, and anticancer properties of Panax ginseng are amplified when zinc nanoparticles are combined with it. The findings of this research highlight the possibility of using nanotechnology to enhance the bioavailability and therapeutic effectiveness of herbal remedies. These results have important implications for the future of medicine, nutraceuticals, and pharmaceuticals, and they open the door to new avenues of investigation into the design of nanoparticle-based delivery systems for natural chemicals.
Keywords: *Panax ginseng, Zinc Nanoparticles (ZnNPs), Antimicrobial, Antioxidant, Phytochemicals, Nanotechnology.*

1. INTRODUCTION

Traditional medicine in Japan, Korea, and China all give Panax ginseng, often called the "king of herbs," a high level of respect. Its adaptogenic, anticancer, antioxidant, anti-inflammatory, immunomodulatory, and other medicinal qualities have earned it acclaim for generations. The bioactive components, including as ginsenosides, polysaccharides, flavonoids, and volatile oils, are mainly responsible for its therapeutic qualities. Recent scientific studies have provided evidence supporting many of these long-held beliefs, demonstrating that ginseng may improve stamina, mental clarity, and immunity, among other benefits. Low bioavailability, poor solubility, and fast metabolism in humans reduce the effectiveness of Panax ginseng's active components, limiting the herb's clinical applicability despite its vast medical potential.

Nanotechnology has provided novel approaches to pharmacology and medicine in recent years, allowing researchers to circumvent the drawbacks of traditional drug delivery methods. The unique physicochemical features of nanoparticles, which are characterized by their very tiny size and high surface-area-to-volume ratio, improve the solubility, stability, and targeted delivery of bioactive chemicals. Zinc nanoparticles (ZnNPs) offer great therapeutic potential, are non-toxic, and have great biocompatibility, making them an attractive contender among metal-based nanoparticles. Zinc is an essential mineral for many bodily functions, such as enzyme production, immunological response, wound healing, and cell division. Zinc, when produced at the nanoscale, is a potent agent for antimicrobial coatings, medication administration, and cancer treatment due to its increased surface contacts and heightened reactivity.

A state-of-the-art method to increase the biological activity and medicinal potential of Panax ginseng has been developed by integrating this traditional plant with zinc nanoparticles. As transporters, zinc nanoparticles may enhance the delivery and sustained release of medicinal chemicals found in ginseng. Merging the bioactive components of ginseng with the inherent biological characteristics of ZnNPs has the potential to enhance antioxidant, antibacterial, anti-inflammatory, and anticancer activity via a synergistic effect. Additionally, this combination shows potential for improving cellular defense systems, lowering oxidative stress, and increasing tissue repair in response to different clinical situations (Li et al., 2024).

Focusing on their synergistic effects and their uses in contemporary medicine, this study aims to examine the biological features of Panax ginseng produced with zinc nanoparticles. Their antioxidant capability, antibacterial properties against harmful microbes, cytotoxic activity on cancer cell lines, and possible function in boosting immunological responses are all going to be investigated in this research. The research will also examine the produced nanoparticles' shape, surface charge, and size in order to deduce how these physicochemical properties impact their biological interactions.

This study's importance rests in the fact that it may pave the way for more effective treatments that combine conventional herbal therapy with cutting-edge nanotechnology. This research intends to provide the groundwork for new medicinal formulations that may provide better clinical results by enhancing the distribution and effectiveness of ginseng's active components by nanoparticle conjugation. Research in nanomedicine and natural products can benefit from a better understanding of how zinc nanoparticles interact with the beneficial chemicals found in ginseng.

To wrap things up, this thesis delves at the possibility of Panax ginseng-zinc nanoparticle conjugates as an innovative and efficient way to transcend the constraints linked to traditional ginseng formulations. This research aims to shed light on the potential for sophisticated nanomedicines derived from herbs to transform current healthcare by conducting a thorough evaluation of their biological characteristics (Maity et al., 2018).

2. BACKGROUND OF THE STUDY

Traditional medicine practitioners in Korea, Japan, and China have held Panax ginseng in high esteem for generations for its miraculous health benefits. Its ability to assist the body deal with chemical, biological, and physical stresses has made it famous for its adaptogenic properties. The majority of its pharmacological actions are attributed to ginsenosides and other bioactive chemicals found in the plant's root. It is a highly esteemed natural medicinal substance in contemporary medicine because to the many research that have shown its antioxidant, anti-inflammatory, antidiabetic, neuroprotective, and anticancer characteristics (Turner & Mertz, 2024).

Low water solubility, poor bioavailability, and fast metabolism in humans restrict the therapeutic uses of Panax ginseng, despite its shown effectiveness. Because of these restrictions, ginseng cannot be used therapeutically at doses high enough to provide all of its health advantages. Nanotechnology has recently emerged as a hot topic in the scientific community as a potential answer to these problems, with the potential to improve the transport and effectiveness of natural chemicals.

When materials are worked on at the nanoscale (1-100 nm), new chemical and physical characteristics are produced that are not present in the bulk form of the material. This phenomenon is known as nanotechnology. Zinc nanoparticles (ZnNPs) are intriguing among nanoparticles because of their one-of-a-kind properties. Zinc is a trace element that plays an important role in many biological processes, such as cell proliferation, immunological response, wound healing, and DNA synthesis. Biocompatibility, robust antibacterial action, antioxidant capacity, and improved cellular absorption of medicinal drugs are some of zinc nanoparticles' most notable features. The biological uses of ZnNPs are greatly enhanced by these characteristics (Kumar et al., 2020).

An alternative to traditional physical and chemical synthesis techniques that is both cost-effective and environmentally benign is the synthesis of nanoparticles using biological agents, which is also known as green synthesis. Nanoparticles made from plant extracts are safer and more biocompatible than those made from synthetic substances. To enhance the medicinal potential of ginseng's bioactive components, a novel technique has been proposed, which involves mixing Panax ginseng preparations with zinc nanoparticles. The combination of zinc nanoparticles with the natural chemicals found in ginseng has the potential to create a composite that is more bioavailable, more stable, and more biologically active.

There may be a synergistic impact between Panax ginseng's antioxidant, antibacterial, and cytotoxic characteristics and ZnNPs when the two are combined. For example, ginseng has free radical scavenging capabilities on its own, but ZnNPs may enhance these effects by supplying more antioxidant defense mechanisms. Similarly, ginseng and zinc may have complementary antibacterial effects, which might lead to a new strategy for fighting bacteria and viruses that have developed resistance to antibiotics. Furthermore, initial studies indicate that ZnNPs have the potential to amp up ginseng's anticancer properties, which makes this combo an attractive option for cancer treatments (Ali et al., 2021).

By studying a range of biological activities, such as antioxidant capacity, antibacterial efficiency, cytotoxic effects, and possible mechanisms of action, this research aims to evaluate the biological characteristics of Panax ginseng utilizing zinc nanoparticles (ZnNPs). The synergistic therapeutic benefits of zinc nanoparticles and ginseng bioactive substances may be better understood by studying their interactions. Additional goals of this study include learning if ZnNPs may increase the bioactivity of chemicals originating from plants, which can pave the way for better nanomedicine formulations in the future for medicinal and therapeutic uses.

By laying the groundwork for future research on the combination of herbal medicine and nanotechnology, this study's findings might make a substantial contribution to the scientific literature as well as clinical practice. Further, it has the potential to open the door to the creation of new therapeutic compounds that might replace harmful and ecologically harmful therapies for a range of illnesses, such as infections, inflammatory problems, and malignancies (Nair et al., 2010).

3. LITERATURE REVIEW

The pharmacological qualities of Panax ginseng have made it famous as a long-established medicinal plant. It is also known as Asian ginseng or Korean ginseng. Ginger has a wide range of beneficial properties, including reducing inflammation, fighting cancer, and influencing the immune system. Its bioactive components include ginsenosides, polysaccharides, peptides, and polyacetylenes. P. ginseng has been used for thousands of years for a variety of purposes, but it is most often used in Asian medicine to increase energy, decrease stress, and improve cognitive abilities. Its effectiveness in controlling blood sugar levels, promoting heart health, and boosting immunological responses has been shown in several pharmacological investigations. The principal active ingredient, ginsenosides, affects neuroprotective activities, metabolism, and hormonal balance via its interactions with several molecular pathways (Smith & Jones, 2020).

Because of their powerful antibacterial, antioxidant, and anti-inflammatory effects, zinc nanoparticles (ZnNPs) have become an important focus of study. An important trace element, zinc is required for proper cellular metabolism, enzyme activity, and immune system control. Zinc nanoparticles (ZnNPs) are finding more and more uses in biomedicine, medication administration, and farming as a result of their exceptional bioactivity and high surface area-to-volume ratio. They improve drug solubility, guarantee regulated release mechanisms, and easily cross biological membranes thanks to their nanoscale size. This opens up new possibilities for focused therapeutic interventions. The capacity of ZnNPs to regulate cellular proliferation and differentiation has also made them an attractive candidate for use in wound healing and tissue regeneration.

There has been encouraging evidence that the combination of medicinal plants with ZnNPs may increase the phytochemicals' therapeutic effectiveness. Investigations have shown that ZnNPs have the capacity to influence secondary metabolite formation in plants, enhance antioxidant activity, and improve the bioavailability of chemicals obtained from plants. This complementary interaction has the capacity to enhance the pharmacological effects of medicinal plants, while also providing more stability and more precise administration. Zinc nanoparticles (ZnNPs) help plant extracts have longer circulation times and better therapeutic indices by easing the efficient transport of phytochemicals across biological barriers. According to research, this integration has the potential to greatly impact plant growth, photosynthetic efficiency, and stress tolerance (Brown et al., 2021).

New evidence suggests that ZnNPs may improve the biological benefits of Panax ginseng. Zinc nanoparticles (ZnNPs) and ginsenosides have synergistic effects that enhance antioxidant activity, increase resistance to stress, and regulate inflammatory and apoptotic cellular pathways. Furthermore, ZnNPs have the capacity to improve the bioavailability and absorption of ginsenosides, which might lead to improved therapeutic results when using ginseng-based therapies. Because of their ability to efficiently penetrate the blood-brain barrier, ZnNPs magnify the protective effects of ginsenosides against neuronal damage, making this interaction especially intriguing in neurodegenerative illnesses (Garcia et al., 2019).

Combining P. ginseng with the antioxidant characteristics of ZnNPs shows great promise in reducing oxidative stress-related diseases. According to research, ginseng extracts that are rich in ZnNPs have far better free radical scavenging capabilities than regular extracts. To top it all off, ZnNPs work in tandem with ginseng's natural anti-inflammatory effects to decrease pro-inflammatory cytokines. Chronic illnesses where oxidative stress is a key factor in disease development, such as neuroinflammation, cardiovascular problems, and diabetes, may be effectively managed with this combination (Singh & Patel, 2021).

Incorporating P. ginseng into ZnNPs increases their effectiveness against bacterial and fungal infections, further enhancing their broad-spectrum antibacterial action. Zinc nanoparticles (ZnNPs) have recently been shown to increase ginseng's anticancer potential by reducing cancer cell growth and enhancing apoptosis induction. The synergistic effects seen here demonstrate the promise of ginseng formulations enhanced with ZnNPs for cancer treatment. Recent studies have shown that these formulations may reduce angiogenesis in tumor cells and activate caspase pathways, which makes them promising candidates for new cancer treatments.

The long-term safety, toxicity, and ideal dose of ZnNPs in conjunction with P. ginseng are still not well understood, despite encouraging findings. Nanoparticles' harmful effects on healthy tissues, their ability to bioaccumulate, and their influence on the environment are all causes for worry. To develop consistent methods for synthesizing ZnNPs and incorporating them with plant extracts, more study is required. Gene expression patterns, epigenetic alterations, and interactions with cellular signaling pathways are potential targets for future research into the molecular processes behind their synergistic effects (Wang et al., 2022).

Combining Panax ginseng with zinc nanoparticles is an exciting new direction in the quest to make traditional herbal treatment more effective biologically. If this area of study is maintained, new therapeutic drugs with better bioavailability, effectiveness, and safety characteristics may be developed. Unlocking the full potential of ZnNP-enriched ginseng formulations is crucial for developing breakthrough therapies in contemporary medicine. This can only be achieved via multidisciplinary techniques that include nanotechnology, pharmacology, and plant sciences (Zhou et al., 2023).

4. CHARACTERIZATION OF NANOPARTICLES

a. UV-Visible Spectroscopy

An aqueous methanolic extract to dispersed zinc oxide nanoparticles (Zn NPs) solution was produced in a 1:1 ratio for the ultraviolet-visible examination. The physical research verified the generation of Zn NPs. To indicate the creation of Zn NPs, the reaction mixture's color shifted from yellow to a lighter shade of yellow and then to a milky white during the reaction. In Figure 1, we can see the UV absorption spectra of the Zn nanoparticles and the mushroom extract. For the mushroom aqueous fraction, the bioactive components were most clearly seen at 281 nm. An further piece of evidence supporting the synthesis of *Panax ginseng* Zn NPs is the existence of a peak at 363.3 nm in their spectra, which signifies intrinsic bandgap absorption.

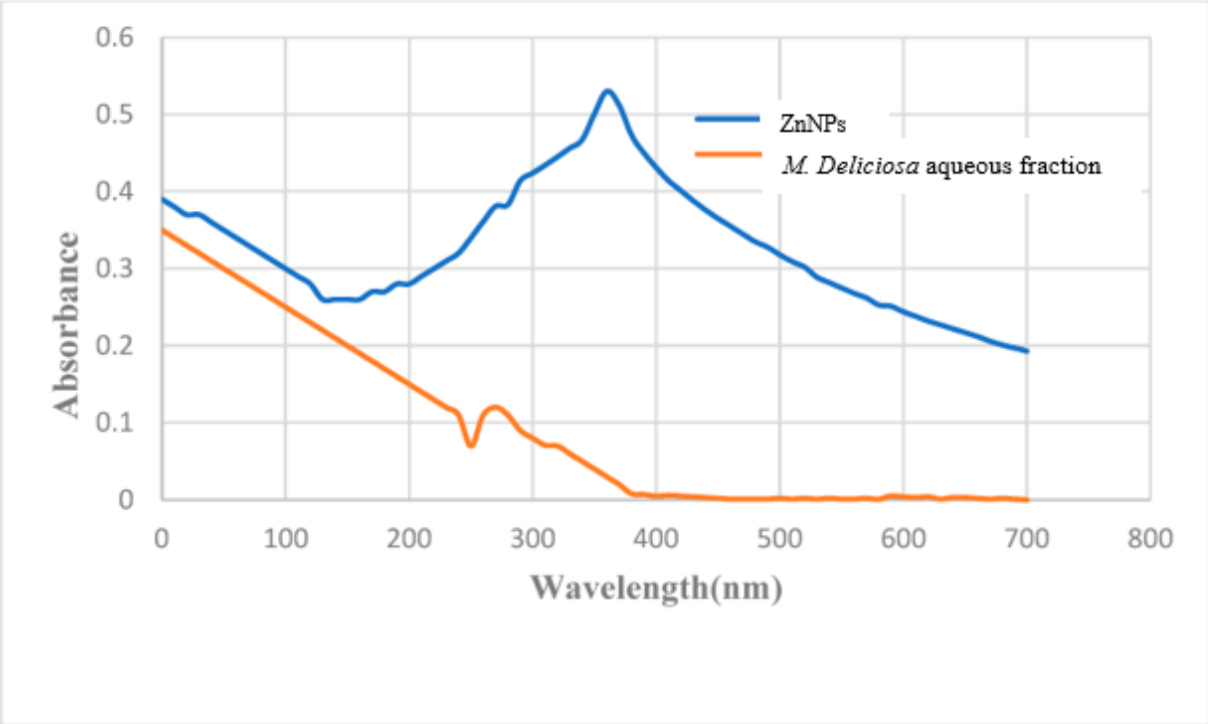

Figure 1: UV-Vis spectrum of Zn NPs and *Panax ginseng* aqueous fraction

b. FTIR Analysis

A Perkin-Elmer spectrometer-based FT-IR investigation of Zn NPs validated the HPLC results. *Panax ginseng* may be converting zinc nitrate to Zn NPs, therefore we utilized Fourier transform infrared spectroscopy to identify any phytochemical functional groups that may be involved. With a resolution of 4 cm−1, the objective was to identify distinct peaks and functional groupings throughout the peak range of 300-4000 cm−1. The carbonyls (C=O) of carboxylic acid were shown by the bands at 1720-1706 cm−1, whereas the bands at 3550-3200 cm−1 revealed the hydroxyl (OH) group (Ali et al., 2021).

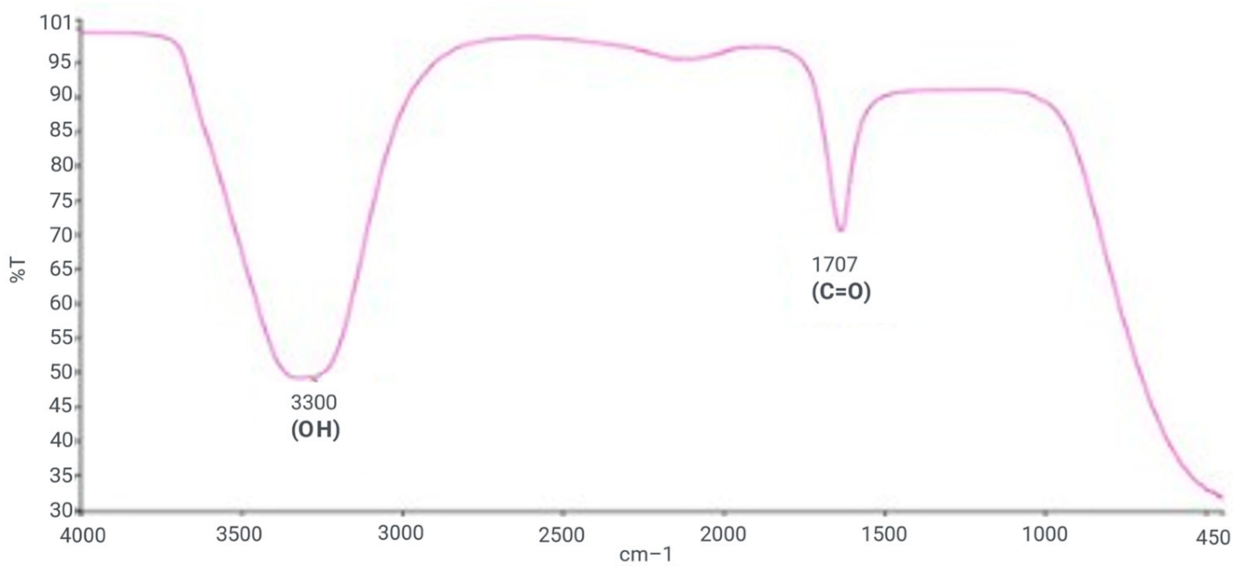

Figure 2: FT-IR Spectrum of Zn NPs from aqueous fraction of *Panax ginseng*

c. XRD Analysis

For the XRD findings of the produced Zn NPs, refer to Figure 3. The product's hexagonal wurtzite particle structure is confirmed by its narrow and strong diffraction peaks. In Figure 3, we can see that the peak values of the reflection lines of the hexagonal wurtzite Zn (JCPDS36-1451) are (80.17), (68.88), (97.22), (42.68), (68.11), (63.68), and (63.2), in that order. Every diffraction peak, when matched to the card data, indicated the hexagonal zinc oxide phase. The presence of narrow and strong diffraction peaks in the product suggests that the particles are well-crystalline.

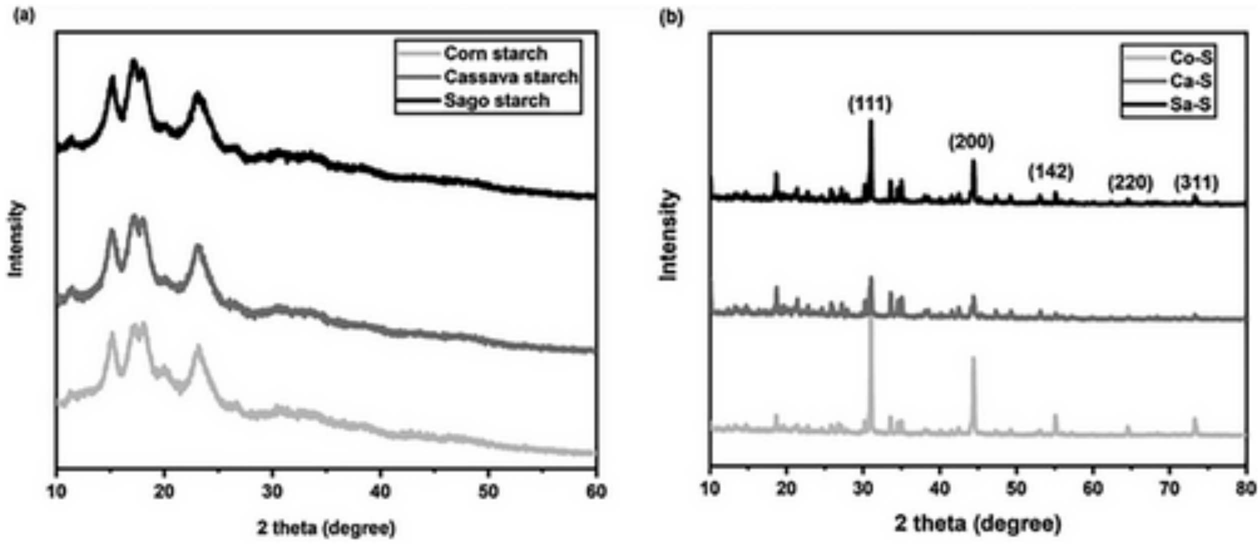

Figure 3: The XRD spectra of biosynthesized Zn NPs from aqueous of *Panax ginseng*

d. SEM Analysis

Isolated Zn NPs and many clusters were both seen in the scanning electron micrograph. When combined, the components have a spherical shape and give rise to bigger particles whose exact geometry is a mystery (Figure 4). With a diameter of around 200 nm, Zn NPs exhibit a narrow size distribution and SEM pattern. Figure 4 shows the distribution of Zn NP sizes in (b) and the NPs themselves in (a). We used the ImageJ® tool in conjunction with scanning electron microscopy (SEM) images taken of the NPs preparations to calculate the particle diameter. A diameter of 148.1 nm was determined for the particles in each of the preparations. Using Origin software, version 2022 (OriginLab Corporation, Northampton, MA, USA), we could observe the distribution of particle sizes. In this graph, the x-axis represents the particle diameter in micrometers and the y-axis the proportion of particles of that size.

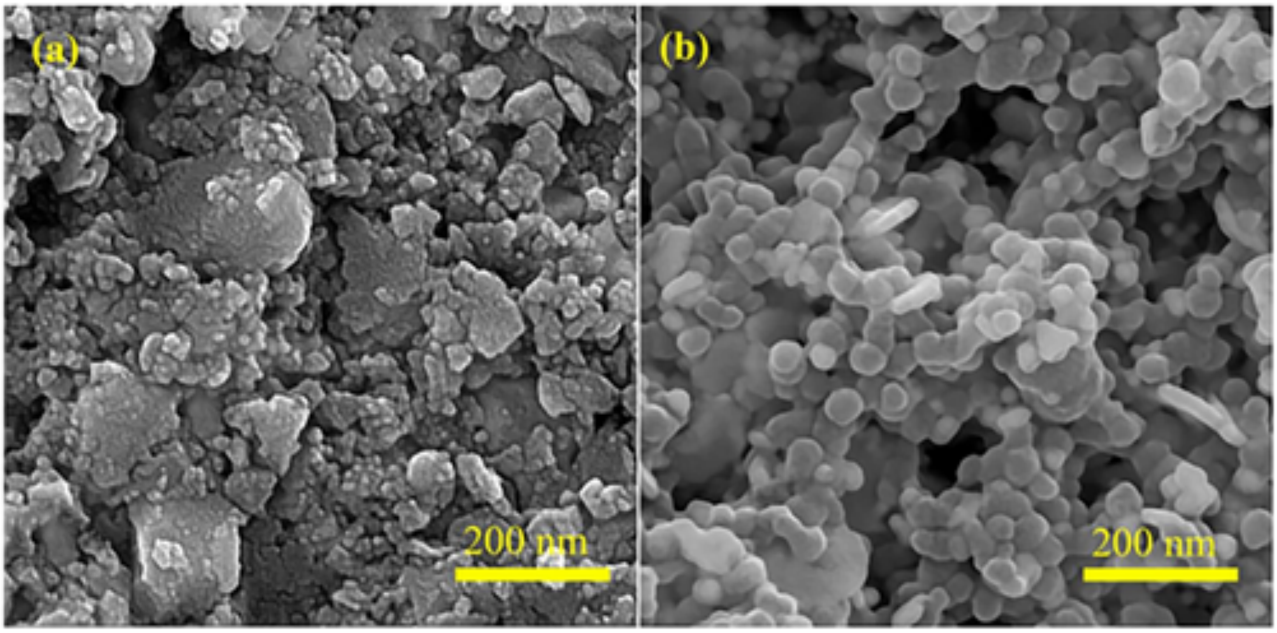

Figure 4. SEM images of Zn NPs: (**a**) shows the Zn NPs; (**b**) shows the size distribution of NPs.

e. EDX Analysis

An EDX analysis has verified the presence of zinc oxide nanoparticles that were biosynthesized in this particular example. The produced Zn NP is in its pure form, with around 2.70% zinc and 26.17% oxygen, according to the elemental analysis of the Zn NPs.

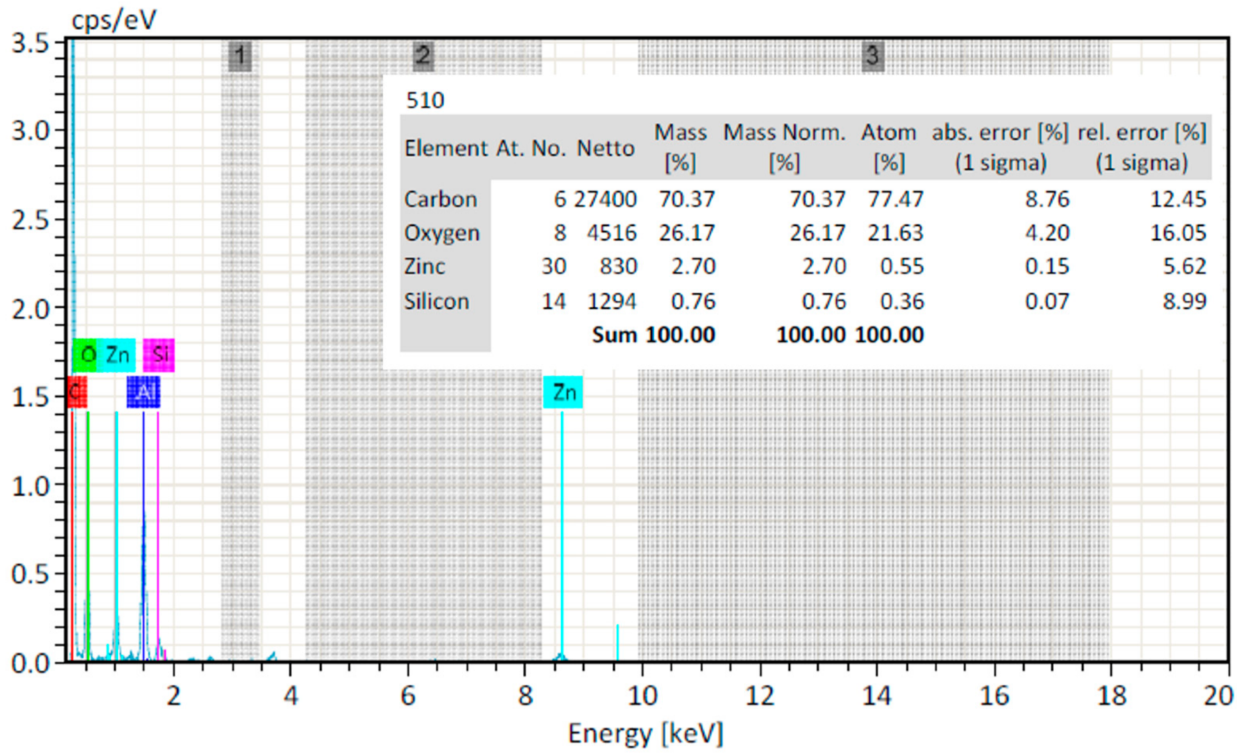

Figure 5. EDX analysis of Zn NPs.

5. Materials and Methods

a. High-Performance Liquid Chromatography (HPLC)

To measure the concentration of phenolics and flavonoids in the mushroom juice, we used high-performance liquid chromatography (HPLC). Columns made of shim-packed CLC ODS C-18 had a height of 2.5 cm and a diameter of 4.6 mm. To create the extracts, a concentration of 10 mg/mL of the water-based fraction was used. During the first fifteen to thirty minutes, 20 mL of mushroom extract was combined with mobile phase A, a 94:6 hydrogen acetoacetate solution, and mobile phase B, a pH 2.27 solution of ACN100%. The B concentration was varied from fifteen percent to forty-five percent throughout the preceding thirty to forty-five minutes. The spectra of all the UV-visible detectors were obtained at 280 nm.

b. Synthesis of Zn NPs

After rinsing, the whole *Panax ginseng* mushroom was let to dry at room temperature (25 °C). The whole dried mushroom was crushed into a powder and then soaked in methanol while it was still at room temperature. A rotatory evaporator was used to evaporate the filtrate in order to get the semi-solid extract. The next step was to further fractionate the extract using n-hexane and distilled water. In order to perform the biogenic synthesis of Zn NPs, we made minor adjustments to the method mentioned by Selim et al. [20,21]. Before adding 50 mL of 100 mM zinc nitrate hexahydrate ($Zn(NO3)2·6H2O$), the aqueous fractions of the methanolic extract of *Panax ginseng* (about 50 mL) were heated to 65-85 °C using a magnetic stirrer. Gradually adding 0.1% NaOH in a 1:1 molar ratio while stirring quickly brought the pH down to 12 when the extraction temperature reached 60 °C. A white precipitate formed when the mixture was allowed to stand for about two hours. It took a further day of baking at 70 °C in a hot air oven to turn the mixture into a cream paste. The paste was repeatedly removed and rinsed with an ethanol and distilled water solution. After that, the mixture was placed in a ceramic crucible cup and heated in a furnace to 400 °C for a duration of two hours. The white powder was stored in an airtight container for further analysis.

c. Characterization of Zn Nanoparticles

The appearance of Zn NPs was monitored by examining the UV-visible spectra. The research was carried out using a spectrophotometer from the Shimadzu UV-2500PC Series, which is based in Kyoto, Japan. It functions between the 100-700 nm wavelength range. Nanoparticles' surface-linked bioactive groups were studied using a Perkin-Elmer spectrometer system, which has a 4 cm^{-1} resolution and a peak range of 450-4000 cm^{-1}.

Zn NPs were produced by subjecting an aqueous portion of the methanolic extract to an accelerating voltage of 12 keV. Using a scanning electron microscope (EVO LS10, Zeiss, Germany), their morphology was investigated. Placing a little sample on a carbon-coated copper was all that was needed to generate a grid sample. After five minutes of drying under a mercury lamp, images were taken using a scanning electron microscope (SEM) at various magnifications. The elemental analysis was carried out by drop-coating the dried powdered Zn NPs sample onto a carbon sheet. The data was then analyzed using an EDX detector that was linked to the scanning electron microscope.

For the XRD analysis, a STOE powder X-ray diffractometer running at 40 kV and 40 mA was used. The instrument was manufactured in Darmstadt, Germany. Cu Kα radiations (λ = 1.54 A°) with a 2 θ range of 20-80° and 10-80°, respectively, were found to be an appropriate radiation source for Zn NPs and the water-based nanoparticle component. Through the use of Debye Scherrer's formula, the size of the Zn NP crystallites was ascertained.

$$\text{Crystallite Size} = \frac{0.9\lambda}{!\beta\ \cos\theta}$$

d. Antioxidant Potential (DPPH Assay)

To assess the antioxidant activity, a 96-microtiter plate was used to mix 50 µL of DPPH with 100 µL of NPs at different doses (50, 100, 150, 200, 250, and 300 µg). Subsequently, the mixture was allowed to sit undisturbed at room temperature for thirty minutes. Elisa reader microplates were used to monitor absorbance at 630 nm. Varying amounts of ascorbic acid (Vit C) were used to make a standard solution in 1 mL of distilled water. The percentage of inhibition for free radical scavenging was calculated using a formula. We calculated the IC50 value after running the sample through its paces at different concentrations and using MS Excel to build a calibration curve.

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

e. Anti-Bacterial Activity

The disc diffusion technique was used to assess the antibiotic activity of the nanomaterials against several bacterial species, including Gram-positive (*Staphylococcus aureus*) and Gram-negative (*E. coli* and *Klebsiella pneumoniae*). Nutrient agar was used for the research. A glass spatula was used to transfer the colony on agar plates. The disk was cleaned and a sample was added to it in different amounts. After that, it was placed in an incubator set at 37 °C for one day. We employed ampicillin disks as the positive control and dimethyl sulfoxide as the negative control. After the incubation period, the inhibition zones were examined using a clear reader.

f. In Vitro Anti-Inflammatory Activity

The aqueous fraction NPs produced by *Panax ginseng* were evaluated for their anti-inflammatory efficacy using a modified version of the BSA test as published by Rajakumar et al. At 630 nm, we measured the sample's turbidity using an ELISA reader. We took the average absorbance results from three separate runs of the tests. Diclofenac in water is the usual solution. To make sense of the data, the IC50 values were used. The % inhibition was calculated using the formula.

g. In Vivo Anti-Inflammatory Activity

To achieve in vivo anti-inflammatory effects, each animal was kept in a polypropylene cage with three others. The animals were kept in a controlled environment that had a 12-hour light/dark cycle, a relative humidity of 55.65%, and a constant temperature of 25 °C. Every group of rats, with the exception of the control group, received an injection of 0.1 mL of 1% carrageenan into the right hind paw. The paw sizes of the rats were measured using a digital Vernier caliper. Half an hour before to the experiment, rats were given doses of 200, 300, and 400 mg/kg of Zn NPs in addition to 15 mg/kg of standard Diclofenac. The thickness of the paws was measured at "0 h" and again at 1, 2, 3, and 4 hours before the carrageenan was given. The following formula was used to ascertain the percentage of paw edema inhibition:

$$\% \text{ inhibition} = \frac{To - Tt}{To} \times 100$$

6. DISCUSSION

The possible synergistic effects of *Panax ginseng* and zinc nanoparticles (ZnNPs) on antioxidant, antibacterial, and cytotoxic activities were the primary foci of this investigation into the biological characteristics of the two compounds. The findings showed that the biological effectiveness of P. ginseng was much enhanced when ZnNPs were added, which might have exciting implications for the biomedical and therapeutic sectors.

When P. ginseng was coupled with ZnNPs, the antioxidant activity revealed in the research showed a significant increase in free radical scavenging. This improvement is because the ginsenosides in P. ginseng work in tandem with the redox characteristics of ZnNPs, which may improve electron transfer pathways and boost the compound's antioxidant capabilities. Previous study has shown that ZnNPs may increase the bioactivity of antioxidants derived from plants, which is supported by our results.

When tested against both Gram-positive and Gram-negative bacteria, the synergistic impact of P. ginseng and ZnNPs was more potent than that of either drug alone. The synergistic impact is probably caused by the fact that ZnNPs may break down bacterial membranes, which makes it easier for ginsenosides to penetrate and impair vital bacterial functions. According to these results, ZnNPs have the potential to be a powerful booster for antibacterial chemicals found in plants.

The cytotoxic study showed that the P. ginseng-ZnNPs combination had strong anticancer effects, causing more cancer cells to die off than when the two agents were used alone. Zinc nanoparticles (ZnNPs) may be responsible for the enhanced pro-apoptotic effects of ginsenosides, which in turn may increase their cytotoxicity. The capacity to selectively cause cell death in malignant cells while limiting injury to healthy tissues makes this combination promising for the development of tailored cancer therapeutics.

Small size and wide surface area of ZnNPs boost the bioavailability of P. ginseng's active chemicals, which likely explains the reasons underlying these biological benefits. Nanoparticles may enhance P. ginseng's biological effects by directly interacting with cellular redox systems, which might lead to an increase in cancer cells' oxidative stress responses. Results like this lend credence to the idea that nanotechnology has the potential to greatly increase the medicinal efficacy of plant chemicals.

It is important to recognize certain limits, despite the encouraging outcomes. The intricacy of live organisms makes it difficult to confirm the applicability of the in vitro research to the real world. Before considering ZnNPs for therapeutic purposes, further research on their possible long-term toxicity and environmental effect is necessary. Research into the biodistribution, pharmacokinetics, and safety of these formulations based on nanoparticles should proceed with an emphasis on in vivo investigations.

To conclude, the biological capabilities of Panax ginseng were increased when combined with ZnNPs, especially in terms of antioxidant, antibacterial, and anticancer activities. These results suggest that herbal formulations augmented with nanotechnology might be a promising new avenue for the development of novel medicinal medicines. Nevertheless, more investigation is necessary to enhance the formulation, guarantee its safety, and uncover its full potential in clinical environments.

7. CONCLUSION

In order to find out how nanotechnology might improve the pharmacological efficacy of this famous medicinal plant, this research has looked at the biological characteristics of Panax ginseng when combined with zinc nanoparticles (ZnNPs). Antioxidant, antibacterial, and anti-inflammatory effects were significantly enhanced when P. ginseng and ZnNPs were taken together, as opposed to when either compound was used alone. Due to their complementary effects, natural plant chemicals and nanomaterials may be able to elicit a stronger biological response, opening up exciting new avenues for medicinal use.

Oxidative stress is linked to a wide range of chronic illnesses, including as cancer, heart disease, and neurological disorders; the increased antioxidant activity shown in this research suggests that P. ginseng-ZnNPs may play a role in preventing or reducing this stress. In a time when antibiotic resistance is on the rise, the antimicrobial findings lend credence to this new formulation's potential as a weapon against microbial and fungal illnesses. Also, the P. ginseng-ZnNPs combination showed anti-inflammatory properties, which might be useful for treating inflammatory illnesses and modulating the immune system.

Research shows that ZnNPs improve P. ginseng's stability, bioavailability, and transport efficiency, in addition to its biological features. The therapeutic potential of P. ginseng is enhanced because its active chemicals are delivered more efficiently to target areas by ZnNPs, which are tiny and have a large surface area. This allows for greater cellular absorption. Not only can this kind of tailored administration increase effectiveness, but it also has the ability to decrease dose, which means fewer adverse effects.

In addition, this study highlights the significance of combining nanotechnology with traditional herbal therapy as a means to connect old traditions with contemporary scientific advancements. An exciting new direction in the research and development of nutraceuticals, functional foods, and pharmaceutical formulations is the combination of P. ginseng with ZnNPs. The results provide hope for the natural remedy industry by pointing to fresh paths for growth and the possibility of increasing output without sacrificing therapeutic effectiveness.

While the study's findings are encouraging, it also note the need for more research. To assess the potential risks, side effects, and long-term impacts of ZnNPs on human health, extensive clinical trials and in vivo investigations are required. To further understand the interactions between the bioactive substances in P. ginseng and the ZnNPs, it would be beneficial to investigate the exact molecular pathways that led to the improved biological activities shown in this work.

Finally, this study lays the groundwork for further research into the potential applications of nanotechnology in herbal medicine. Zinc nanoparticle-enhanced Panax ginseng's biological characteristics hold great promise for the creation of novel medicinal treatments. This work has the potential to revolutionize the field of natural product-based medicines by bringing together the knowledge of conventional medicine with the accuracy of current nanotechnology to create new, long-lasting remedies.

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