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Review

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# Edible Mushroom assisted synthesis and applications of metal nanoparticles: A comprehensive review

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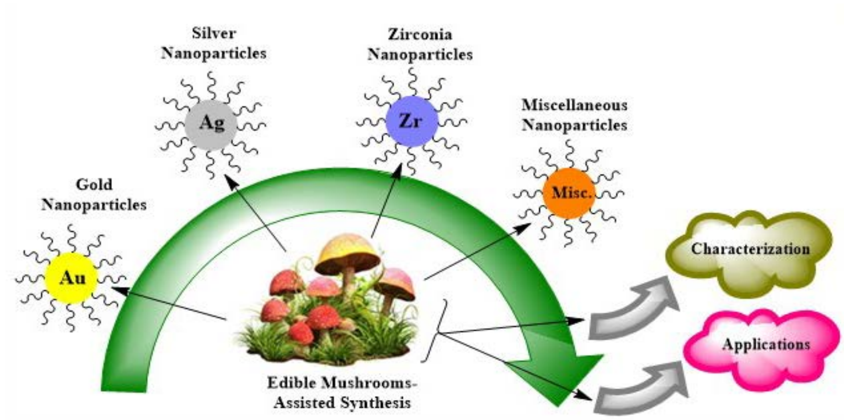
## ABSTRACT




Edible mushrooms have been used as either reducing or stabilizing agents in the biological process of synthesis of nanoparticles. The mushroom-assisted synthesis has been reported to produce large quantities of proteins and has the characteristic large yield and low toxicity issues. The nanoparticles derived from them are coated with special coatings that protect them from external environment, thus improving their life span and stability. This review describes the various mushrooms that assisted in the synthesis of nanoparticles such as silver, gold, zirconia and their tentative use in various biological aspects have been discussed. Moreover, the characterization of various nanoparticles using analytical techniques has also been highlighted.

*Keywords: Edible mushrooms, nanoparticles, gold nanoparticles, silver nanoparticles, zirconia nanoparticles, biosynthesis.*

## INTRODUCTION

Natural products are the hub for various bioactives that possess various medicinal properties.[1–5] Natural products are shown to possess anticancer, antimalarial, antimicrobial, analgesic, anti-Alzheimer, anti-Parkinson, and wound healing effect.[6–12] Out of them, mushrooms are one of the rich sources of bioactives. Mushrooms have been used for therapeutic interventions as well as asource of food. They have been reported in earlier texts such as *Materia Medica* for their use in diseases and ailments. They are rich in polysaccharides and have active moieties needed for immune response. They contain high nutritional value-based ingredients such as vitamins, protein, etc. but it lacks cholesterol.[13] Mushrooms as such do not belong to any taxonomic category. But researchers had tried to name it as the macro fungus that has a budding fruitful body that can be seen through the naked eye and can be sensed through organoleptic evaluation. There are over 20,000 varieties of mushrooms but only 10% of them have been explored. The edible class of mushrooms that have shown therapeutic potential included the *Lentinus, Auricularia, Hericium, Grifola, Flammulina, Pleurotus, Ganoderma,Trametesand Tremella*. The mushroom known as *Pleurotus* has been reported to possess medicinal properties such as anticancer, antioxidant, and antitumor properties.

Owing to the diverse range of active substances that can be derived from mushrooms, they have been browbeaten by investigators for the amalgamation of nanoparticles from them. The proteins of mushrooms had been utilized in the synthesis of metallic nanoparticles such as Ag, Au, etc. Many researchers have developed nanoparticles using mushrooms for therapeutic applications as shown in Table 1. The main benefit of using mushrooms as factories of Nanoparticle synthesis is due to the presence and release of a higher number of extracellular enzymes that further act as a stabilizing agent for synthesis.[14–19] The chemicals secreted by mushrooms during nanoparticle synthesis are also able to reduce the toxicity arising from it. When nanoparticle synthesis is carried out in bacterial cell the nanoparticles does not

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remain localized, instead, they interact with the bacterial cell wall and create toxicity to cells.[20,21]

A mushroom has high metal binding capacity in comparison to bacteria and hence has gained wider exposure. Various mushrooms with various types of nanoparticles produced from them have been tabulated as per Table 1.

**Table 1**. Literature survey of various edible mushrooms and nanoparticles produced from them.

| Mushrooms | Medicinal property | Type of nanoparticles | Ref. |
|---|---|---|---|
| *Pleurotussajor-caju* | Antibacterial | AgNPs | 22 |
| *Pleurotusflorida* | Antibacterial | AgNPs | 23 |
| *Agaricusbisporus* | Antibacterial | AgNPs | 24 |
| *Calocybe indica* | Antibacterial | AgNPs | |
| *Ganoderma lucidum* | Antibacterial | AgNPs | |
| *Pleurotusostreatus* | Antibacterial | AgNPs | |
| *Pycnoporussanguineus* | Antibacterial | AgNPs | 25 |
| *Schizophyllum commune* | Antibacterial | AgNPs | |
| *Pycnoporussanguineus* | Antibacterial | AgNPs | |
| *Schizophyllum commune* | Antibacterial | AgNPs | 26 |
| *Pleurotusflorida* | Antibacterial | AgNPs | 27 |
| *Ganoderma lucidum* | Antibacterial | AgNPs | 28 |
| *Pleurotus giganteus* | Antibacterial | AgNPs | 29 |
| *Pleurotusostreatus* | Antifungal | AgNPs | 30 |
| *Pleurotuscornucopiae var. citrinopileatus* | Antifungal | AgNPs | 31 |
| *Polyporus rhinoceros* | Anticancer | SeNPs | 32 |
| *Ganoderma neo-japonicum* | Anticancer | AgNPs | 33 |
| *Pleurotusdjamor var. roseus* | Anticancer | AgNPs | 34 |

## Silver Nanoparticles

Silver nanoparticles (AgNPs) are formerly used as an active drug moiety in gene therapy, targeted drug transport, and artificial implants, as well as the diagnostic agent for sensing and imaging in the early stages of various diseases.[35–38] They may be produced efficaciously via several synthesis techniques, including heating methods, ionizing radiation, laser irradiation, and radiolysis. These approaches for the processing of nanomaterials are expensive and environmentally unfriendly. The use of *Pleurotusflorida* extract, edible mushroom, and silver nitrate ($AgNO_3$) salt inthe synthesis of stable biofunctionalized AgNPs via photo-irradiation andreaction mixture exposed directly to the sunlight, is an attempt to establish an environmentally friendly process for AgNPs synthesis.[27] The mycosynthetic system usedto biosynthesize the Ag nanoparticles has numerous benefits over the chemical approaches, including higher biosafety, non-toxicity, and being eco-friendly to the environment.[39]

The *Pleurotus sp.* is among the most popular medicinal and edible mushrooms, as it comprises of several active composites. *P. ostreatus*, *P. florida*,and *P. sajorcaju* are generally used in AgNPs synthesis. The oyster mushroom engaged as first amongst the macrofungi in nanoparticle synthesis and their utilizations. Among all metallic nanoparticles, AgNPs are the most common which are synthesized from this mushroom. These silver nanoparticles exhibit inhibitory effects towards several pathogenic microorganisms, yeasts, and molds and are used to confiscate textile dyes, as well as in cancer treatment.[40]

The initial research on nanoparticle synthesis via edible mushrooms with proteins from the spent mushroom substrate to form AgNPs, which is accompanied by different extracts from mycelium and mushroom fruiting bodies. A modest application for the formation of AgNPs in core-shell via SMS (spent mushroom substrate) exposed to an organic surface, which reduces the $Ag^+$ and form the AgNPs stabilization via secreted mushroom protein. After 24 hours, the $AgNO_3$ solution incubated with SMS turned yellow, suggesting the development of stable Ag-NPs (Silver nanoparticles).[41]

Although the mechanism of AgNPs synthesis is unknown, recent researches suggest that the intracellular synthesis of silver nanoparticles is linked to nitrate reductase, which releases an electron from NADH that converts $Ag^+$ to $Ag^0$, resulting inthe creation of $NAD^+$. The extracellular synthesis of silver nanoparticles is linked to the reduction of $Ag^+$ via natural organic mycomaterials e.g., proteins, enzymes, polysaccharides, amino acids, etc.[40] as illustrated in Figure 1.

Roy et al. synthesized silver nanoparticles using the enoki mushroom water extract and integrated them with Starch/agar-based functional films for active packing applications.[42] The integration of nanoparticles showed strong antibacterial action against food-borne bacteria such as *L.monocytogenes* and *E.Coli*. Also due to the presence of silver nanoparticles, the water vapor barrier and hydrophobicity of films got enhanced.Similarly, Li et al. studied the extraction of silver nanoparticles from *Aspergillus terreus*.[43] The formation of silver nanoparticles was monitored using UV Spectroscopy as shown in Figure 2.

## Gold Nanoparticles

The synthesis of gold nanoparticles has been fascinated as a major consideration because of their incipient utilizations in various fields such as biomedicines, biosensors, and bioimaging.[44,45] Because of their high Fermi potential, metal nanoparticles, especially AuNPs have excellent catalytic properties. The yellowish color of the solution of gold ions worn as the color of mushroom stripe turned to the pinkish-redcolor, suggesting the development of intracellular gold nanoparticles(AuNPs) and the aqueous solution gradually turned out to be colorless, demonstrating no formation of extracellular gold nanoparticles.[46]

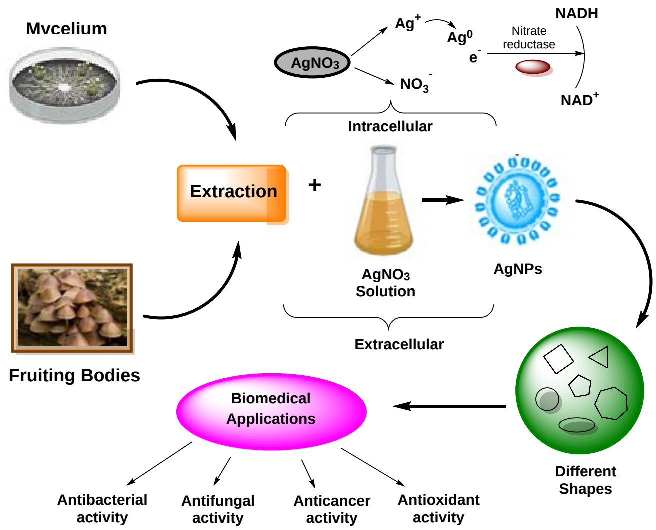


**Figure 1.** Synthesis of silver nanoparticles (AgNPs) by using the edible mushrooms.

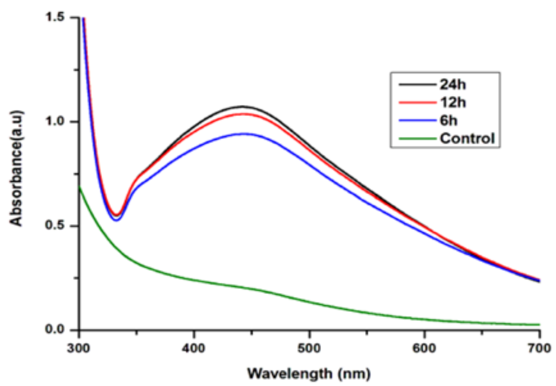


**Figure 2.**The UV-Vis spectra recorded for the reaction of fungal cell filtrate with $AgNO_3$ solution. Reproduced with permission from Ref [43](under creative common licence).

They display surface plasmon resonance (SPR), Rayleigh scattering, and surface-enhanced Raman scattering (SERS), making them useful in medicinal fields, catalysis, and optoelectronics.[47]

Mushrooms are widely recognized as a high proteinaceous food, containing more than 75% protein. Oyster mushroom(*Pleurotus Sp.*) is a virtuous source of riboflavin, in addition to proteins.[48] Riboflavin plays a vital role in bound coenzymes to form flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD), which aid as the catalysts for severaloxidation and reduction reactions. It is known that flavins (i.e., flavoproteins) existing in the extract of mushrooms are reliable for reducing Au ions into AuNPs. When exposed to sunlight, the reaction mixture absorbs the photons of energy, and flavins in the reaction mixture become excited and act as oxidizers or electron donors. This supplies a robust indication for the renovation of $Au^+$ to $Au^0$. In addition,the presence of protein isalleged to cap the AuNPs produced, making them biofunctionalized and stable.[49]

Gold nanoparticles (AuNPs) have been manufactured by the reduction of chloroauric acid with glucan, eluted from *Pleurotus florida*, an edible mushroom. Glucan serves as the stabilizing as well as the reducing agent. This synthesis specified that the size distribution of AuNPs altered with a variation in the concentration of chloroauric acid ($HAuCl_4$).[50] The representation of the pathway for gold nanoparticles (AuNPs) synthesis is shown in Figure 3.

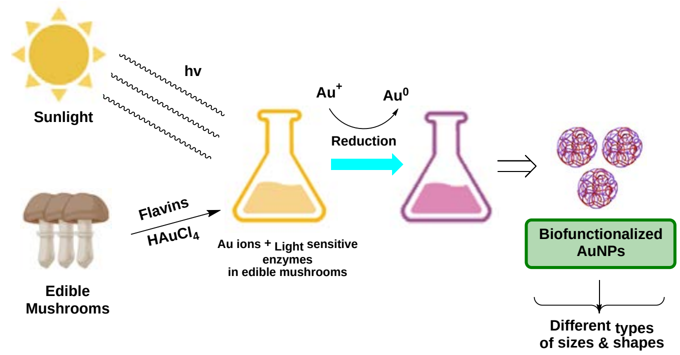


**Figure 3.** Synthesis of gold nanoparticles (AuNPs) by using edible mushrooms.

To determine the existence of Au-NPs, tinny slices of fungal mycelium have been examined underneath a field emission-scanning electron microscope (FE-SEM) with subordinate electron detectors at 15 kV voltage. The fundamental investigation of mushroom mycelia has been done by energy-dispersive X-ray spectrometry (EDS) that is coupled with scanning electron microscopy (SEM). The amount of gold deposited within mushroom mycelia is determined by inductively coupled plasma-optical emission spectrometry (ICP-OES).[51]

The core-shell morphology of Au-NPs is determined by using FTIR spectroscopy. The AFM technique is employed to investigate the surface morphology of AuNPs. The size and exact location of accumulated AuNPs in mushroom mycelium are determined via transmission electron microscopy (TEM), indicating that the formed nanoparticles are of uneven shape. The size and shape of gold nanoparticles (AuNPs) are regulated via deviations in temperature conditions and the relative concentration of extract about metal ions.[52]

## Zirconia Nanoparticles

Zirconia is a technologically significant material with excellent natural color, transformation durability, higher strength and chemical stability, corrosion resistance, and chemical, and microbial resistance. Zirconia is an amphoteric element, which means it can be both acidic and basic. The more notable feature of zirconia is its steadiness under reducing circumstances, making it a valuable material in the catalytic region.[53]

Zirconium dioxide ($ZrO_2$), also known as zirconia, is a white color powder, that exists in three different polymorphic forms i.e., monoclinic, cubic, and tetragonal. The monoclinic phase of zirconia is constant below 1170 ˚C, and exists in the tetragonal phase between 1170 ˚C and 2370 ˚C, whereas above 2370 ˚C, zirconia renovates into the cubic phase.[54] Zirconium is used in a variety of applications including, structural reinforcement, adsorption, photodegradation, and antimicrobial agents.[55] $ZrO_2$ NPs have sparked a lot of research interest among transition metal oxide nanoparticles because of their specific catalytic, thermal, electrical, mechanical, optical, sensing, and biocompatible properties.[56] They have been used in solid oxide fuel cells, solar cells, bone implants, nitrogen oxide, and oxygen gas sensors. Because of their long-term stability and strong oxygen ion transport capabilities, the stabilized zirconia nanoparticles are well-equipped for higher-temperature energy conversion systems.[53]

The usage of zirconium NPs in biological fields is rapidly growing. They are generally used as the drug delivery carriers for several medications such aspenicillin, itraconazole, alendronate, and zoledronate as well as gene delivery carriers with target specificity.[57,58] Zirconia nanoparticles have been synthesized by using several physicochemical approaches including, sol-gel synthesis, hydrothermal methods, and aqueous precipitation methods, and require the conditions of higher pressure and temperature. Biological methods for the synthesis of zirconia nanoparticles have more benefits because they use an environmentally friendly approach at mild pH, temperature, and pressure, as well as at significantly lower costs without the explosion of any toxic waste to the environment.[59]

Zirconia NPs might be formedvia challenging the fungus i.e., *Fusarium oxysporum* with aqueous $ZrF_6^{2-}$ anions; extracellularly protein-mediated hydrolysis of anionic complexes outcomes in the simplistic synthesis of nano-crystalline zirconia at room temperature.[60] Furthermore, zirconium NPs have been synthesized vialeaf extract of *Eucalyptus globulus* with spherical morphology in the range of 9-11 nm. These zirconia nanoparticles displayed a higher antioxidant potential, strong antibacterial activity against using the disc diffusion method as well as remarkable anticancer activity towardshuman lung (A-549)cancer cell lines and human colon (HCT-116)cancer cell lines by using MTT and DPPH assays, respectively.[57,61] The figurative demonstration of the pathway for zirconia nanoparticle synthesis is depicted in Figure 4.

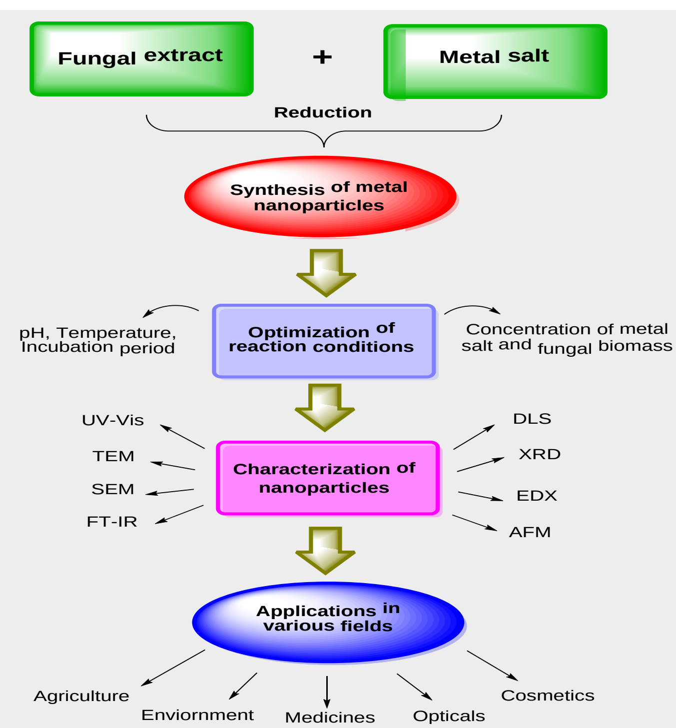


**Figure 4.** Synthesis of Zirconia nanoparticles by using edible mushrooms

## Miscellaneous Nanoparticles

The “green” methodology for the synthesis of nanoparticles, which is promptly substituting conventional chemical synthesis, is of prodigious curiosity due to its environmental-friendly nature, economical views, feasibility,and applications in numerous areas including, nano-medicines and catalysis medicines.[16]

The myogenesis of nanoparticles has been discovered to be an effective and appropriate method for the production of several nanoparticles with considerable potential and their utilities in various fields such as food, medicines, agriculture, textiles, optics, electronics, and cosmetics.[15] Since fungi and yeasts are efficient extracellular enzyme secretors and numerous varieties develop quickly; culturing and maintaining them in the laboratories is facile and simple. By using intracellular or extracellular reducing enzymes, edible mushrooms may produce metal-NPs and nanostructures.[16] Several mushroom-active materials are capable of forming the nanoparticles. Many investigators have examined several mushroom elements including, enzymes, proteins, polysaccharides, and complexes of polysaccharide-proteins as the sources for metal reduction and nanoparticle stabilization in addition to the mushroom extract.[62] Roy et al. synthesized sulfur nanoparticles from the facile acid hydrolysis process of enoki mushrooms with a size range of 20nm.[63] The nanoparticles were further integrated with the Gelatin-cellulose nanofiber for food-packing applications. The presence of sulfur nanoparticles enhanced the mechanical and UV protection activity of the film. The films were further characterized using the FESEM, FTIR, Mechanical properties, and vapor barrier activities. Green synthesis of multifunctional and spherical Palladium nanoparticles (Pd NPs) using *Agaricus bisporus* (mushroom) fungus was recently described.[64] Until a brown hue formed, indicative of the development of Pd NPs, the mushroom was mixed with Pd (II) ions at a ratio of 1:9 at room temperature to synthesize the NPs. The loss of UV/Vis absorbance at 405 nm, corresponding to Pd (II) ions, was used as evidence for the production of Pd NPs. The synthesized Pd NPs had a size of 13 nm and a zeta potential of 24.3 mV, making them very stable. Both Gram-positive Streptococcus pyogenes and Gram-negative Enterobacter aerogenes were killed by these compounds to a substantial degree. The manufactured NPs were also shown to be biocompatible with RBCs and to exhibit antioxidant and anti-inflammatory properties.

Recently, the biological synthesis of NPs has gained a lot of consideration via several biological tools like extracts of plants and microorganisms as the stabilizing and reducing agents. These synthesized nanoparticles have been characterized by using Scanning Electron Microscopy (SEM), Fourier Transform Infrared (FT-IR),Atomic Force Microscopy (AFM), Dynamic Light Scattering (DLS),and Energy Dispersive X-ray (EDX) method.

In mushroom studies, two species i.e., *Coriolus versicolor* and *Pleurotus ostratus* are utilized prominently to produce the cadmium nanoparticles(Cd-NPs). Cd-NPs are successfully formed by using a solution of extracellular biomass of *Caribena versicolor* and cadmium sulfide.[65] Selenium nanoparticles (SeNPs) have recently become a new goal of research since, they exhibit excellent bioavailability, lower toxicity, and remarkable anticancer activity.[66] Highly stable SeNPs have been efficaciously produced via mushroom polysaccharide-protein complexes (PSPs) that are eluted from the sclerotia of *Pleurotus tuber-regium.* Furthermore, these novel SeNPs are significantly inhibiting the growth of tumor progression concomitantly in patients of breast carcinoma and MCF-7 cancer cell lines by inducing apoptosis in a dose-dependent mode, without showing any cytotoxicity to the normal cells which signify that their cytotoxicity is cancer-specific.[67]

**Table 2.** Literature survey of various techniques enlisted with property to be determined for nanoparticle characterization.

| Property of Nanoparticles | Techniques employed | Ref. |
|---|---|---|
| Particle morphology | Transmission electron microscopy | 68,69 |
| | Scanning electron microscopy | 70,71 |
| | Freeze fracture electron microscopy | 72,73 |
| | High-resolution transmission electron microscopy | 74 |
| Surface hydrophilicity | Hydrophobic interaction chromatography | 75,76 |
| | Zeta potential measurement | 77,78 |
| Molecular weight and crystallinity | High-resolution mass spectroscopy | 79,80 |
| | Gas chromatography-mass spectrometry analysis | 81,82 |
| | Raman spectroscopy | 83–85 |
| | X-ray diffraction | 86,87 |
| Surface chemistry | Fourier transform infrared spectroscopy | 88 |
| | Nuclear magnetic resonance | 89,90 |
| | Mass spectroscopy | 91,92 |
| Thermal stability | Differential scanning calorimetric | 93,94 |
| | Thermogravimetric analysis | 95,96 |

## Various Applications of Nanoparticles

### Applications of Silver Nanoparticles

Silver nanoparticles derived from edible mushrooms have been used for their antibacterial and antimicrobial action. The nanoparticles derived from *Ganoderma lucidum* extract showed DNA cleavage activity.[97] It becomes determined that the silver nanoparticles have been capable of reason the single stress DNA cleavage for 30 and 60min at distinction dilutions. The nanoparticles also showed strong antibacterial action against gram-positive microbes such as *S.aureus*, *E.hirae*, and *B.cereus*. Also, it was able to inhibit the microbes belonging to the gram-negative class of bacteria and *C. albicans* fungus. Similarly, Arun et al. described the antimicrobial action of AgNPs synthesized *Schizophyllum commune* for their antimicrobial activity against the *E.Coli*, *B.subtilis*, *Klebsiella pneumoniae*, and *Pseudomonas fluorescens.*[26] The NPs were also able to inhibit the growth of *Trichophytonsimii*, *Trichophyton mentagrophytes*, and *Trichophytonrubrum* significantly.

Researchers developed silver nanoparticles from the *fomitopsis pinicola* and it was found that they possess anticancer properties.[98] The silver nanoparticles caused deformities in cellular morphology. The nucleus of cells also got disintegrated and condensed as many of the cells were found to be dead. The dose-dependent action on tumor cells was observed as confirmed by the colorimetric assay. The main reason behind the cell death can be attributed due to the presence of program cell death, as the nucleus undergoes disintegration and DNA fragments after nanoparticle introduction.[99] Sanpui et al. described the mechanism of AgNPs that it interferes with the regular activity of cells and interferes with the equilibrium of the membrane inducing the formation of apoptotic signaling genes leading to cell death. Similarly, another group of researchers also reported the anticancer application of silver nanoparticles.[100,101]

The silver nanoparticles derived from *Agaricus bisporus* fungi are also reported to possess photocatalytic, antioxidant, and anti-inflammatory activity.[102] The nanoparticles showed better anti-inflammatory activity compared to aceclofenac. The silver nanoparticles have been found to impede the growth of biofilm formation and reduce the death rate of *Ruditapes philippinarum.*[103]

Researchers synthesized silver nanoparticles derived from *Ganoderma lucidum* for the remedy of drug-resistant *E.coli* remoted from the catheter used for urinary tract infections.[104] The DPPH and ARP results showed comparable results in terms of the potency of free radical scavenging activity, in comparison to Quercetin. The AgNPs showed a reducing effect on tumor cell lines such as MDA-MB-231. Similarly, silver nanoparticles derived from *Ganoderma neo-japonicum Imazeki* showed anticancer activity.[33] Silver nanoparticles can produce Reactive oxygen species. Accumulation of a larger amount of ROS leads to oxidative damage.[105] The cells were equally treated with Doxorubicin and silver nanoparticles. As the intracellular production of ROS increased the levels of ROS generation in silver nanoparticles treated cells also increased. The results showed that ROS is an important factor for apoptosis in yeast cells. Silver nanoparticles are said to possess the antibacterial property of *S.aureus* and showed good inhibition characteristics.[24] Moreover, they also were exploited for their antibacterial and anti-inflammatory action on wounds.[106] Researchers synthesized silver nanoparticles using the *Pleurotus florida* mushroom extract.[107] The nanoparticles showed significant antibacterial activity against *Streptococcus pyogenes (22.17 ± 0.66 mm), Enterococcus faecalis (16.54 ± 0.88 mm), Klebsiella pneumoniae (26.32 ± 0.88 mm), Shigella flexneri (27.21 ± 0.66 mm), Candida albicans (15.13 ± 0.33 mm) and Aspergillus fumigatus (14.89 ± 0.33 mm).* The bactericidal activity was found to increase significantly with increasing synergistic AgNPs with mushroom extract concentration. Differences in cell wall composition explain why AgNPs have different antibacterial actions on Gram-negative and Gram-positive bacteria. Because Ag+ ions are released from NPs and interact with bacterial enzymes, AgNPs exhibited a larger zone of inhibition. By interacting with thiol, carboxyl, hydroxyl, amino, phosphate, and imidazole groups in proteins and enzymes on bacterial membranes, green-synthesized AgNPs exert antibacterial action. This results in severe structural deformation of the cell membrane. Then, the AgNPs enter the cells through the porous membranes and inactivate the enzymes, causing the cells to suffocate, stop replicating, and die.[108]

### Applications of Gold Nanoparticles

Researchers prepared gold nanoparticles from *Agaricus bisporus* mushroom.[109] The nanoparticles thus prepared were able to degrade the decolorizing activity of Methylene blue and the decrease was showing a dose-dependent effect with decolorization at 97.98%. Similarly, another group of researchers prepared nanoparticles from the mushroom. The nanoparticles were able to reduce the methylene blue dye with a decolorization efficiency of 75.35% after 4h of treatment.[110] The gold nanoparticles also showed inhibitory action against the various cancer lines such as A-549, K-562, and HeLa.[49] But no effect was observed against the Vero cell lines. Another group of researchers also showed the cytotoxic effect of mushrooms produced from *Inonotusobliquus* on the cancer cell lines such as MCF-1 and NCI-N87.[111] The anticancer activity of gold nanoparticles was also observed for the HepG2 and HCT-116 cells.[112] The nanoparticles showed alterations in the morphology of cells. The anticancer effect of AuNPs may be attributed due to irregular shape and functional groups attached to the surface. The gold nanoparticles, derived from *Pleurotus sajor-caju* showed ant proliferative properties in the case of colon cancer cell lines.[113] The nanoparticles caused morphological alterations in the HCT-116 cell lines. The cells treated showed a loss in shape and cell adhesion capacity and got shrunk. Many studies supported evidence of the antiproliferative and anticancer effects on the HeLa cells, Hep-2 cell lines, and sarcoma 180.[114–116] The nanoparticles derived from *Pleurotus florida* and *Hericium erinaceus* have been used as anticancer agents.[117]

### Applications of other metallic nanoparticles

Dias et al., synthesized zinc nanoparticles based on *Cordyceps militaris.* The nanoparticles thus obtained showed 70-90% survival rate in lethality assay and possessed α-amylase and α-glucosidase inhibitory effects. Along with this the nanoparticles also showed antibacterial action on *P.aeruginosa, Shigella flexneri, P.vulgaris.*[118] Zeng et al. studied the antiproliferative effect of selenium nanoparticles decorated with water-soluble polysaccharides of various mushrooms. The nanoparticles induced caspases and mitochondria-mediated apoptosis but doesn't affect neighboring organs.[119] Similarly, Ali et al. also decorated selenium nanoparticles using proteins derived from protein precipitation of *Lentinus edodes* mushroom. The nanoparticles showed antifibrinolytic activity *invitro*.[120] *Liu et al.* studied the antifatigue effect of selenium nanoparticles derived from polysaccharides of *Lyciumbarbarum(LBP).*[121] The effectiveness of LBP-decorated SeNPs in fighting tiredness was measured with a forced swimming test. After 30 days of storage, the findings revealed that LBP1-SeNPs maintained an average particle size of around 105.4 nm, which is lower than that of LBP2-SeNPs and LBP3-SeNPs. All LBP1-SeNPs dose groups examined had a longer fatigue swimming time compared to the control group (p 0.05), with the high-dose group's duration being even noticeably longer than the positive group. LBP1-SeNPs alleviated tiredness by boosting glycogen reserve, raising antioxidant enzyme levels, and modulating metabolic process, as evidenced by measurements of glycogen, blood urea nitrogen (BUN), blood lactic acid (BLA), superoxide dismutase (SOD), and malondialdehyde (MDA).

## Conclusion

Though the nanoparticles produced from myco-source are quite effective for their antibacterial and other medicinal action. But still,the toxicity level needs to be evaluated. There have been no extract guidelines for evaluating their effectiveness such that they can be standardized for normal human usage. Thus, there is a need to develop some regulatory framework for the development of evaluation techniques. The rate of production of nanoparticles depends on environmental factors too. One cannot say if mushrooms are grown from the same species, the place and quality of nutrition given also influences nanoparticle production. Thus, still, more clinical aspects need to be evaluated in the future time.

## Conflict of interest

The authors declare no conflict of interest in this article.

## References

1. R.K. Singla, C.S. Sai, H. Chopra, et al. Natural Products for the Management of Castration-Resistant Prostate Cancer: Special Focus on Nanoparticles Based Studies. *Frontiers in cell and developmental biology* **2021**, 9.
2. H. Bansal, R.K. Singla, S. Behzad, et al. Unleashing the Potential of Microbial Natural Products in Drug Discovery: Focusing on Streptomyces as Antimicrobials Goldmine. *Current Topics in Medicinal Chemistry* **2021**, 21 (26), 2374–2396.
3. R.K. Singla, S. Behzad, J. Khan, et al. Natural Kinase Inhibitors for the Treatment and Management of Endometrial/Uterine Cancer: Preclinical to Clinical Studies. *Frontiers in Pharmacology* **2022**, 13 (February), 1–15.
4. R.K. Singla, X. He, H. Chopra, et al. Natural Products for the Prevention and Control of the COVID-19 Pandemic: Sustainable Bioresources. *Frontiers in pharmacology* **2021**, 12.
5. H. Chopra, S. Bibi, F. Islam, et al. Emerging Trends in the Delivery of Resveratrol by Nanostructures: Applications of Nanotechnology in Life Sciences. *ene* **2022**, 4, 13.
6. I. Singh Bakshi, H. Chopra, M. Sharma, et al. Herbal bioactives for wound healing application. *Herbal Bioactive-Based Drug Delivery Systems* **2022**, 259–282.
7. H. Chopra, A.K. Mishra, A.A. Baig, et al. Narrative Review: Bioactive Potential of Various Mushrooms as the Treasure of Versatile Therapeutic Natural Product. *Journal of Fungi* **2021**, 7 (9), 728.
8. F. Islam, S. Bepary, M.H. Nafady, et al. Review Article Polyphenols Targeting Oxidative Stress in Spinal Cord Injury : Current Status and Future Vision. **2022**, 2022.
9. T. Bhattacharya, G.A.B.E. Soares, H. Chopra, et al. Applications of Phyto-Nanotechnology for the Treatment of Neurodegenerative Disorders. *Materials* **2022**, 15 (3), 804.
10. J.C. Bose, H. Chopra, S. Bibi, et al. Preparation and Evaluation of Chitosan/PVA Based Hydrogel Films Loaded with Honey for Wound Healing Application. *Gels* **2022**, 8 (2), 111.

11. H. Chopra, S. Bibi, I. Singh, et al. Green Metallic Nanoparticles: Biosynthesis to Applications. *Frontiers in Bioengineering and Biotechnology* **2022**, 0, 548.
12. J. Kour, H. Chopra, S. Bukhari, et al. Nutraceutical-A deep and profound concept. *Nutraceuticals and Health Care* **2022**, 1–28.
13. H. Chopra, A.K. Mishra, A.A. Baig, et al. Narrative review: Bioactive potential of various mushrooms as the treasure of versatile therapeutic natural product. *Journal of Fungi* **2021**, 7 (9).
14. M. Ovais, A.T. Khalil, M. Ayaz, et al. Biosynthesis of metal nanoparticles via microbial enzymes: A mechanistic approach. *Int. J. Mol. Sci*. 2018.
15. P. Khandel, S.K. Shahi. Mycogenic nanoparticles and their bio-prospective applications: current status and future challenges. *J. Nanostructure in Chemistry* **2018**, 8 (4), 369–391.
16. A.B. Moghaddam, F. Namvar, M. Moniri, et al. Nanoparticles biosynthesized by fungi and yeast: A review of their preparation, properties, and medical applications. *Molecules*. **2015**, 6540–16565.
17. M. Guilger-Casagrande, R. de Lima. Synthesis of Silver Nanoparticles Mediated by Fungi: A Review. *Front. Bioengineer. Biotechnol.* **2019**, 287.
18. H. Bahrulolum, S. Nooraei, N. Javanshir, et al. Green synthesis of metal nanoparticles using microorganisms and their application in the agrifood sector. *J. Nanobiotechnology*. **2021**, 86.
19. X. Li, H. Xu, Z.S. Chen, G. Chen. Biosynthesis of nanoparticles by microorganisms and their applications. *J. Nanomaterials*. **2011**.
20. L. Wang, C. Hu, L. Shao. The antimicrobial activity of nanoparticles: Present situation and prospects for the future. *Int. J. Nanomedicine*. **2017**, 1227–1249.
21. Y.N. Slavin, J. Asnis, U.O. Häfeli, H. Bach. Metal nanoparticles: Understanding the mechanisms behind antibacterial activity. *J. Nanobiotechnol.* **2017**, 65.
22. N. Vigneshwaran, A.A. Kathe, P. V. Varadarajan, R.P. Nachane, R.H. Balasubramanya. Silver-protein (core-shell) nanoparticle production using spent mushroom substrate. *Langmuir* **2007**, 23 (13), 7113–7117.
23. I.K. Sen, A.K. Mandal, S. Chakraborti, et al. Green synthesis of silver nanoparticles using glucan from mushroom and study of antibacterial activity. *Int. J. Biological Macromolecules* **2013**, 62, 439–449.
24. S. Mirunalini, v. Arulmozhi, k. Deepalakshmi, m. Krishnaveni. Intracellular Biosynthesis and Antibacterial Activity of Silver Nanoparticles Using Edible Mushrooms. *Notulae Scientia Biologicae* **2012**, 4 (4), 55–61.
25. Y.S. Chan, M. Mat Don. Biosynthesis and structural characterization of Ag nanoparticles from white rot fungi. *Materials Science and Engineering C* **2013**, 33 (1), 282–288.
26. G. Arun, M. Eyini, P. Gunasekaran. Green synthesis of silver nanoparticles using the mushroom fungus Schizophyllum commune and its biomedical applications. *Biotechnol. Bioprocess Engineering* **2014**, 19 (6), 1083–1090.
27. R. Bhat, R. Deshpande, S. V. Ganachari, D.S. Huh, A. Venkataraman. Photo-irradiated biosynthesis of silver nanoparticles using edible mushroom Pleurotus florida and their antibacterial activity studies. *Bioinorganic Chemistry and Applications* **2011**, 2011.
28. A. Karwa, S. Gaikwad, M. Rai. Mycosynthesis of silver nanoparticles using lingzhi or reishi medicinal mushroom, ganoderma lucidum (W. Curt.:Fr.) P. karst. and their role as antimicrobials and antibiotic activity enhancers. *International Journal of Medicinal Mushrooms* **2011**, 13 (5), 483–491.
29. G. Debnath, P. Das, A.K. Saha. Green Synthesis of Silver Nanoparticles Using Mushroom Extract of Pleurotus giganteus: Characterization, Antimicrobial, and α-Amylase Inhibitory Activity. *BioNanoScience* **2019**, 9 (3), 611–619.
30. R.S. Yehia, H. Al-Sheikh. Biosynthesis and characterization of silver nanoparticles produced by pleurotus ostreatus and their anticandidal and anticancer activities. *World Journal of Microbiology and Biotechnology* **2014**, 30 (11), 2797–2803.
31. M.N. Owaid, J. Raman, H. Lakshmanan, et al. Mycosynthesis of silver nanoparticles by Pleurotus cornucopiae var. citrinopileatus and its inhibitory effects against Candida sp. *Materials Letters* **2015**, 153, 186–190.
32. H. Wu, H. Zhu, X. Li, et al. Induction of apoptosis and cell cycle arrest in A549 human lung adenocarcinoma cells by surface-capping selenium nanoparticles: An effect enhanced by polysaccharide-protein complexes from Polyporus rhinocerus. *Journal of Agricultural and Food Chemistry* **2013**, 61 (41), 9859–9866.
33. S. Gurunathan, J. Raman, S.N. Abd Malek, P.A. John, S. Vikineswary. Green synthesis of silver nanoparticles using Ganoderma neo-japonicum Imazeki: A potential cytotoxic agent against breast cancer cells. *Int. J. Nanomedicine* **2013**, 8, 4399–4413.
34. J. Raman, G.R. Reddy, H. Lakshmanan, et al. Mycosynthesis and characterization of silver nanoparticles from Pleurotus djamor var. roseus and their in vitro cytotoxicity effect on PC3 cells. *Process Biochemistry* **2015**, 50 (1), 140–147.
35. B.S. Chhikara. Current trends in nanomedicine and nanobiotechnology research. *J. Materials NanoScience* **2017**, 4 (1), 19–24.
36. N. Gupta, C. Gupta, S. Sharma, R.K. Sharma, H.B. Bohidar. Comparative study of antibacterial activity of standard antibiotic with silver nanoparticles synthesized using ocimum tenuiflorum and garcinia mangostana leaves. *Chem. Biol. Lett.* **2015**, 2 (2), 41–44.
37. A. Albasher Omar, N. Abdurazq Ahmad, M. Moftah Rajab, et al. Biosynthesis of Silver nanoparticles using Olive Wastewater. *J. Materials NanoScience* **2021**, 8 (1), 11–15.
38. G. Saini, K. Thakur, M.D. Gnaneswari. Preparation of NanoSilver coated Cotton Fabric and its bactericidal evaluation. *J. Materials NanoScience* **2019**, 6 (1), 13–18.
39. M.N. Owaid, I.J. Ibraheem. Mycosynthesis of nanoparticles using edible and medicinal mushrooms. *Eur. J. Nanomedicine*. **2017**, 5–23.
40. M.N. Owaid. Green synthesis of silver nanoparticles by Pleurotus (oyster mushroom) and their bioactivity: Review. *Environmental Nanotechnology, Monitoring and Management*. **2019**, 100256.
41. S. Sudheer, R.G. Bai, K. Muthoosamy, et al. Biosustainable production of nanoparticles via mycogenesis for biotechnological applications: A critical review. *Environmental Research* **2022**, 204.
42. S. Roy, J.W. Rhim. Starch/agar-based functional films integrated with enoki mushroom-mediated silver nanoparticles for active packaging applications. *Food Bioscience* **2022**, 49, 101867.
43. G. Li, D. He, Y. Qian, et al. Fungus-Mediated Green Synthesis of Silver Nanoparticles Using Aspergillus terreus. *Int. J. Mol. Sci*. **2011**, 13 (1), 466–476.
44. S. Rastogi. Controlled Aqueous Phase Synthesis of Gold Nanoparticles using Fruit extract of Momordica charantia. *J. Materials NanoScience* **2016**, 3 (1), 11–13.
45. B.S. Chhikara, R. Kumar, Poonam, P. Bazard, R.S. Varma. Viral infection mitigations using advanced nanomaterials and tools: lessons from SARS-CoV-2 for future prospective interventions. *J. Materials NanoScience* **2021**, 8 (2), 64–82.
46. J. Sarkar, S. Kalyan Roy, A. Laskar, D. Chattopadhyay, K. Acharya. Bioreduction of chloroaurate ions to gold nanoparticles by culture filtrate of Pleurotus sapidus Quél. *Materials Letters* **2013**, 92, 313–316.
47. S.S. Shankar, A. Rai, B. Ankamwar, et al. Biological synthesis of triangular gold nanoprisms. *Nature Materials* **2004**, 3 (7), 482–488.
48. C. Sánchez. Cultivation of Pleurotus ostreatus and other edible mushrooms. *Applied Microbiology and Biotechnology*. **2010**, 1321–1337.
49. R. Bhat, V.G. Sharanabasava, R. Deshpande, et al. Photo-bio-synthesis of irregular shaped functionalized gold nanoparticles using edible mushroom Pleurotus florida and its anticancer evaluation. *Journal of Photochemistry and Photobiology B: Biology* **2013**, 125, 63–69.
50. I.K. Sen, K. Maity, S.S. Islam. Green synthesis of gold nanoparticles using a glucan of an edible mushroom and study of catalytic activity. *Carbohydrate Polymers* **2013**, 91 (2), 518–528.
51. K.B. Narayanan, H.H. Park, S.S. Han. Synthesis and characterization of biomatrixed-gold nanoparticles by the mushroom Flammulina velutipes and its heterogeneous catalytic potential. *Chemosphere* **2015**, 141, 169–175.
52. D. Philip. Biosynthesis of Au, Ag and Au-Ag nanoparticles using edible mushroom extract. *Spectrochimica Acta - Part A: Molecular and Biomolecular Spectroscopy* **2009**, 73 (2), 374–381.
53. A.S. Keiteb, E. Saion, A. Zakaria, N. Soltani. Structural and optical properties of zirconia nanoparticles by thermal treatment synthesis. *J. Nanomaterials*, **2016**.

54. T.Y. Luo, T.X. Liang, C.S. Li. Stabilization of cubic zirconia by carbon nanotubes. *Materials Science and Engineering A* **2004**, 366 (1), 206–209.
55. A.F.V. da Silva, A.P. Fagundes, D.L.P. Macuvele, et al. Green synthesis of zirconia nanoparticles based on Euclea natalensis plant extract: Optimization of reaction conditions and evaluation of adsorptive properties. *Colloids and Surfaces A: Physicochemical and Engineering Aspects* **2019**, 583, 123915.
56. A. Nikam, T. Pagar, S. Ghotekar, K. Pagar, S. Pansambal. A Review on Plant Extract Mediated Green Synthesis of Zirconia Nanoparticles and Their Miscellaneous Applications. *Journal of Chemical Reviews* **2019**, 1 (3), 154–163.
57. A.R. Golnaraghi Ghomi, M. Mohammadi-Khanaposhti, H. Vahidi, et al. Fungus-mediated extracellular biosynthesis and characterization of zirconium nanoparticles using standard penicillium species and their preliminary bactericidal potential: A novel biological approach to nanoparticle synthesis. *Iranian J. Pharmaceutical Res.* **2019**, 18 (4), 2101–2110.
58. S. Tanga, B. Maji. Recent trends in precision drug and gene delivery. *Applied NanoMedicine* **2022**, 22 (2), 429.
59. M. Kumaresan, K. Vijai Anand, K. Govindaraju, S. Tamilselvan, V. Ganesh Kumar. Seaweed Sargassum wightii mediated preparation of zirconia (ZrO 2 ) nanoparticles and their antibacterial activity against gram positive and gram negative bacteria. *Microbial Pathogenesis* **2018**, 124, 311–315.
60. V. Bansal, D. Rautaray, A. Ahmad, M. Sastry. Biosynthesis of zirconia nanoparticles using the fungus Fusarium oxysporum. *J. Materials Chemistry* **2004**, 14 (22), 3303–3305.
61. J.B. Fathima, A. Pugazhendhi, R. Venis. Synthesis and characterization of ZrO2 nanoparticles-antimicrobial activity and their prospective role in dental care. *Microbial Pathogenesis* **2017**, 110.
62. G.Q. Chen, Z.J. Zou, G.M. Zeng, et al. Coarsening of extracellularly biosynthesized cadmium crystal particles induced by thioacetamide in solution. *Chemosphere* **2011**, 83 (9), 1201–1207.
63. S. Roy, J.W. Rhim. Gelatin/cellulose nanofiber-based functional films added with mushroom-mediated sulfur nanoparticles for active packaging applications. *J. Nanostructure Chem.* **2022**, 12 (5), 979–990.
64. S. Mohana, S. Sumathi. Multi-Functional Biological Effects of Palladium Nanoparticles Synthesized Using Agaricus bisporus. *J. Cluster Science* **2020**, 31 (2).
65. R. Sanghi, P. Verma. Biomimetic synthesis and characterisation of protein capped silver nanoparticles. *Bioresource Technology* **2009**, 100 (1), 501–504.
66. M.P. Ganeshkar, M.R. Mirjankar, A.T. Gaddigal, et al. Selenium Nanoparticles: Synthesis using Averrhoa carambola extract, characterization and its biological applications. *Applied NanoMedicine* **2022**, 22 (1), 324.
67. D. Zeng, J. Zhao, K.H. Luk, et al. Potentiation of in Vivo Anticancer Efficacy of Selenium Nanoparticles by Mushroom Polysaccharides Surface Decoration. *J. Agricultural and Food Chemistry* **2019**, 67 (10), 2865–2876.
68. D.J. Smith. Characterization of nanomaterials using transmission electron microscopy. In *RSC Nanoscience and Nanotechnology*; Royal Society of Chemistry, **2015**; Vol. 2015-January, pp 1–29.
69. M.A. Asadabad, M.J. Eskandari. Transmission electron microscopy as best technique for characterization in nanotechnology. *Synthesis and Reactivity in Inorganic, Metal-Organic and Nano-Metal Chemistry* **2015**, 45 (3), 323–326.
70. V.D. Hodoroaba, S. Rades, T. Salge, et al. Characterisation of nanoparticles by means of high-resolution SEM/EDS in transmission mode. In *IOP Conference Series: Materials Science and Engineering*; Institute of Physics Publishing, **2016**; Vol. 109, p 012006.
71. P.J. Kempen, C. Hitzman, L.S. Sasportas, S.S. Gambhir, R. Sinclair. Advanced characterization techniques for nanoparticles for cancer research: Applications of SEM and NanoSIMS for locating au nanoparticles in cells. In *Materials Research Society Symposium Proceedings*; Materials Research Society, **2013**; Vol. 1569.
72. J.L. Carson. Fundamental technical elements of freeze-fracture/freeze-etch in biological electron microscopy. *J. Visualized Experiments* **2014**, No. 91.
73. L. Isa, F. Lucas, R. Wepf, E. Reimhult. Measuring single-nanoparticle wetting properties by freeze-fracture shadow-casting cryo-scanning electron microscopy. *Nature Communications* **2011**, 2 (1), 1–9.
74. G.C. Ruben, L.W. Hrubesh, T.M. Tillotson. High resolution transmission electron microscopy nanostructure of condensed-silica aerogels. *Journal of Non-Crystalline Solids* **1995**, 186, 209–218.
75. L.E. Crandon, K.M. Boenisch, B.J. Harper, S.L. Harper. Adaptive methodology to determine hydrophobicity of nanomaterials in situ. *PLoS ONE* **2020**, 15 (6), e0233844.
76. A. Valsesia, C. Desmet, I. Ojea-Jiménez, et al. Direct quantification of nanoparticle surface hydrophobicity. *Communications Chemistry* **2018**, 1 (1), 1–11.
77. M.K. Rasmussen, J.N. Pedersen, R. Marie. Size and surface charge characterization of nanoparticles with a salt gradient. *Nature Communications* **2020**, 11 (1), 1–8.
78. G. V. Lowry, R.J. Hill, S. Harper, et al. Guidance to improve the scientific value of zeta-potential measurements in nanoEHS. *Environmental Science: Nano* **2016**, 3 (5), 953–965.
79. S. Nicolardi, Y.E.M. Van Der Burgt, J.D.C. Codée, et al. Structural Characterization of Biofunctionalized Gold Nanoparticles by Ultrahigh-Resolution Mass Spectrometry. *ACS Nano* **2017**, 11 (8), 8257–8264.
80. C. Chang, J. Zhang, Z. Li, et al. Applications of nanoparticles in mass spectrometry for highly sensitive analysis. In *Handbook of Nanoparticles*; Springer International Publishing, **2015**; pp 1313–1337.
81. S. Patil, R. Chandrasekaran. Biogenic nanoparticles: a comprehensive perspective in synthesis, characterization, application and its challenges. *Journal of Genetic Engineering and Biotechnology*. Springer Science and Business Media Deutschland GmbH December 1, 2020.
82. V. Karthick, V.G. Kumar, T.S. Dhas, et al. Biosynthesis of gold nanoparticles and identification of capping agent using gas chromatography-mass spectrometry and matrix assisted laser desorption ionization-mass spectrometry. *J. Nanoscience and Nanotechnology* **2015**, 15 (6), 4052–4057.
83. N.C. Lindquist, C.D.L. de Albuquerque, R.G. Sobral-Filho, I. Paci, A.G. Brolo. High-speed imaging of surface-enhanced Raman scattering fluctuations from individual nanoparticles. *Nature Nanotechnology* **2019**, 14 (10), 981–987.
84. J. Lu, Z. Cai, Y. Zou, et al. Silver Nanoparticle-Based Surface-Enhanced Raman Spectroscopy for the Rapid and Selective Detection of Trace Tropane Alkaloids in Food. *ACS Applied Nano Materials* **2019**, 2 (10), 6592–6601.
85. R.E. Darienzo, J. Wang, O. Chen, et al. Surface-Enhanced Raman Spectroscopy Characterization of Breast Cell Phenotypes: Effect of Nanoparticle Geometry. *ACS Applied Nano Materials* **2019**, 2 (11), 6960–6970.
86. S. Mourdikoudis, R.M. Pallares, N.T.K. Thanh. Characterization techniques for nanoparticles: Comparison and complementarity upon studying nanoparticle properties. *Nanoscale*. **2018**, 12871–12934.
87. S.M. Londoño-Restrepo, R. Jeronimo-Cruz, B.M. Millán-Malo, E.M. Rivera-Muñoz, M.E. Rodriguez-García. Effect of the Nano Crystal Size on the X-ray Diffraction Patterns of Biogenic Hydroxyapatite from Human, Bovine, and Porcine Bones. *Scientific Reports* **2019**, 9 (1), 1–12.
88. S. Suresh, S. Karthikeyan, K. Jayamoorthy. FTIR and multivariate analysis to study the effect of bulk and nano copper oxide on peanut plant leaves. *Journal of Science: Advanced Materials and Devices* **2016**, 1 (3), 343–350.
89. T. Gutmann, G. Buntkowsky. Solid-state NMR studies of supported transition metal catalysts and nanoparticles. In *Modern Magnetic Resonance*; **2018**.
90. L.E. Marbella, J.E. Millstone. NMR techniques for noble metal nanoparticles. *Chemistry of Materials* **2015**, 27 (8), 2721–2739.
91. C.K. Chiang, W.T. Chen, H.T. Chang. Nanoparticle-based mass spectrometry for the analysis of biomolecules. *Chemical Society Reviews* **2011**, 40 (3), 1269–1281.
92. C.T. Chen, Y.C. Chen. Fe3O4/TiO2 core/shell nanoparticles as affinity probes for the analysis of phosphopeptides using TiO2 surface-assisted laser desorption/ionization mass spectrometry. *Analytical Chemistry* **2005**, 77 (18), 5912–5919.

93. F. Castelli, C. Puglia, M.G. Sarpietro, L. Rizza, F. Bonina. Characterization of indomethacin-loaded lipid nanoparticles by differential scanning calorimetry. *Int. J. Pharmaceutics* **2005**, 304 (1–2), 231–238.
94. H. Bunjes, T. Unruh. Characterization of lipid nanoparticles by differential scanning calorimetry, X-ray and neutron scattering. *Adv Drug Deliv Rev*, **2007**, 379–402.
95. K.B. Sebby, E. Mansfield. Determination of the surface density of polyethylene glycol on gold nanoparticles by use of microscale thermogravimetric analysis. *Analytical and Bioanalytical Chemistry* **2015**, 407 (10), 2913–2922.
96. E. Mansfield, K.M. Tyner, C.M. Poling, J.L. Blacklock. Determination of nanoparticle surface coatings and nanoparticle purity using microscale thermogravimetric analysis. *Analytical Chemistry* **2014**, 86 (3), 1478–1484.
97. A. Aygün, S. Özdemir, M. Gülcan, K. Cellat, F. Şen. Synthesis and characterization of Reishi mushroom-mediated green synthesis of silver nanoparticles for the biochemical applications. *Journal of Pharmaceutical and Biomedical Analysis* **2020**, 178, 112970.
98. S. Rehman, R. Jermy, S. Mousa Asiri, et al. UsingFomitopsis pinicolafor bioinspired synthesis of titanium dioxide and silver nanoparticles, targeting biomedical applications. *RSC Advances* **2020**, 10 (53), 32137–32147.
99. K. Kansara, A. Kumar, D. Bhatia. In vivo sojourn of DNA nanodevices: Taking stock of the past and perspective for future challenges & applications. *Applied NanoMedicine* **2022**, 22 (2), 337.
100. Y.H. Hsin, C.F. Chen, S. Huang, et al. The apoptotic effect of nanosilver is mediated by a ROS- and JNK-dependent mechanism involving the mitochondrial pathway in NIH3T3 cells. *Toxicology Letters* **2008**, 179 (3), 130–139.
101. S. Rehman, R. Farooq, R. Jermy, et al. A wild fomes fomentarius for biomediation of one pot synthesis of titanium oxide and silver nanoparticles for antibacterial and anticancer application. *Biomolecules* **2020**, 10 (4).
102. M. Sriramulu, S. Sumathi. Photocatalytic, antioxidant, antibacterial and anti-inflammatory activity of silver nanoparticles synthesised using forest and edible mushroom. *Advances in Natural Sciences: Nanoscience and Nanotechnology* **2017**, 8 (4).
103. L. Zhang, Y. Wei, H. Wang, et al. Green Synthesis of Silver Nanoparticles Using Mushroom Flammulina velutipes Extract and Their Antibacterial Activity Against Aquatic Pathogens. *Food and Bioprocess Technology* **2020**, 13 (11), 1908–1917.
104. M.M. Al-Ansari, P. Dhasarathan, A.J.A. Ranjitsingh, L.A. Al-Humaid. Ganoderma lucidum inspired silver nanoparticles and its biomedical applications with special reference to drug resistant Escherichia coli isolates from CAUTI. *Saudi Journal of Biological Sciences* **2020**, 27 (11), 2993–3002.
105. R. Naik, S.A. Shivashankar, P.J. Bindu. In-vitro antioxidant and anticancer activities of MnFe2O4 nanoparticles synthesized using spinach leaves extract. *Applied NanoMedicine* **2022**, 22 (1), 330.
106. M. Fu, Q. Li, D. Sun, et al. Rapid preparation process of silver nanoparticles by bioreduction and their characterizations. *Chinese Journal of Chemical Engineering* **2006**, 14 (1), 114–117.
107. K. Chandran Priyadarshni, R. Krishnamoorthi, C. Mumtha, P. Ulagan Mahalingam. Biochemical analysis of cultivated mushroom, Pleurotus florida and synthesis of silver nanoparticles for enhanced antimicrobial effects on clinically important human pathogens. *Inorganic Chemistry Communications* **2022**, 142, 109673.
108. I. Ocsoy, M.L. Paret, M.A. Ocsoy, et al. Nanotechnology in plant disease management: DNA-directed silver nanoparticles on graphene oxide as an antibacterial against Xanthomonas perforans. *ACS Nano* **2013**, 7 (10), 8972–8980.
109. M.A. Dheyab, M.N. Owaid, M.A. Rabeea, A.A. Aziz, M.S. Jameel. Mycosynthesis of gold nanoparticles by the Portabello mushroom extract, Agaricaceae, and their efficacy for decolorization of Azo dye. *Environmental Nanotechnology, Monitoring and Management* **2020**, 14, 100312.
110. M.A. Rabeea, M.N. Owaid, A.A. Aziz, M.S. Jameel, M.A. Dheyab. Mycosynthesis of gold nanoparticles using the extract of Flammulina velutipes, Physalacriaceae, and their efficacy for decolorization of methylene blue. *J. Environmental Chemical Engineering* **2020**, 8 (3), 103841.
111. K.D. Lee, P.C. Nagajyothi, T.V.M. Sreekanth, S. Park. Eco-friendly synthesis of gold nanoparticles (AuNPs) using Inonotus obliquus and their antibacterial, antioxidant and cytotoxic activities. *Journal of Industrial and Engineering Chemistry* **2015**, 26, 67–72.
112. E.B. El, E.B. El Domany, T.M. Essam, A.E. Ahmed, A.A. Farghali. Biosynthesis Physico-Chemical Optimization of Gold Nanoparticles as Anti-Cancer and Synergetic Antimicrobial Activity Using Pleurotus ostreatus Fungus. *J. Applied Pharmaceutical Sci.* **2018**, 8 (05), 119–128.
113. V.K. Chaturvedi, N. Yadav, N.K. Rai, et al. Pleurotus sajor-caju-Mediated Synthesis of Silver and Gold Nanoparticles Active against Colon Cancer Cell Lines: A New Era of Herbonanoceutics. *Molecules* **2020**, 25 (13), 3091.
114. C. Zhuang, T. Mizuno, A. Shimada, et al. Antitumor Protein-containing Polysaccharides from a Chinese Mushroom Fengweigu or Houbitake, Pleurotus sajor-caju(Fr.) Sings. *Bioscience, Biotechnology, and Biochemistry* **1993**, 57 (6), 901–906.
115. T.C. Finimundy, G. Gambato, R. Fontana, et al. Aqueous extracts of Lentinula edodes and Pleurotus sajor-caju exhibit high antioxidant capability and promising in vitro antitumor activity. *Nutrition Research* **2013**, 33 (1), 76–84.
116. C.B.S. Telles, D.A. Sabry, J. Almeida-Lima, et al. Sulfation of the extracellular polysaccharide produced by the edible mushroom Pleurotus sajor-caju alters its antioxidant, anticoagulant and antiproliferative properties in vitro. *Carbohydrate Polymers* **2011**, 85 (3), 514–521.
117. J. Raman, H. Lakshmanan, P.A. John, et al. Neurite outgrowth stimulatory effects of mycosynthesized AuNPs from Hericium erinaceus (Bull.: Fr.) Pers. on pheochromocytoma (PC-12) cells. *International Journal of Nanomedicine* **2015**, 10, 5853–5863.
118. C. Dias, M. Ayyanar, S. Amalraj, et al. Biogenic synthesis of zinc oxide nanoparticles using mushroom fungus Cordyceps militaris: Characterization and mechanistic insights of therapeutic investigation. *J. Drug Delivery Sci. Technology* **2022**, 73, 103444.
119. D. Zeng, J. Zhao, K.H. Luk, et al. Potentiation of in Vivo Anticancer Efficacy of Selenium Nanoparticles by Mushroom Polysaccharides Surface Decoration. *Journal of Agricultural and Food Chemistry* **2019**, 67 (10), 2865–2876.
120. S.M. Ali, J. Raman, H. Lakshmanan, et al. Surface Decoration of Selenium Nanoparticles by Proteins from the Culinary-Medicinal Shiitake Mushroom, Lentinus edodes (Agaricomycetes), for Enhanced Fibrinolytic Activity. *Int. J. Med. mushrooms* **2018**, 20 (11), 1021–1030.
121. G. Liu, X. Yang, J. Zhang, et al. Synthesis, stability and anti-fatigue activity of selenium nanoparticles stabilized by Lycium barbarum polysaccharides. *Int. J. Biological Macromolecules* **2021**, 179, 418–428.