CHAPTER

24

Mycogenic-assisted synthesis of nanoparticles and their efficient applications

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24.1 Introduction

Nanotechnology's tremendous impact on almost all life forms has intrigued researchers all over the world. It focuses on creating and controlling matter at the molecular level at the nanoscale (1−100 nm). Professor Richard Feynman for the first time presented the theoretical concept of miniaturization in 1959, which provided a glimpse into nanotechnology. Some novel properties of nanoparticles (NPs) are governed by their size, shape, and size distribution, including their physicochemical, magnetic, and optical properties (Husen and Siddiqi, 2014; Husen and Iqbal, 2019a,b; Husen and Jawaid, 2020; Husen, 2020; Joudeh and Linke, 2022). In most cases, the differences in properties are primarily due to the NPs extremely small size and large surface area to volume ratio viz, catalytic activity, mechanical properties, melting point, optical absorption, thermal and electrical conductivity (Das et al., 2017; Kalpana and Rajeswari, 2018; Siddiqi Husen, 2020). As a result of these unique physicochemical and optoelectronic properties, NPs are particularly interesting for a variety of uses including chemical sensors, catalysts, electronic components,

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medical diagnostic imaging, pharmaceutical products, and medical treatment. In biomedical applications, gold NPs have been extensively used in disease diagnostics, separation sciences, and pharmaceuticals. Several studies have successfully reported that silver NPs have antibacterial and anti-inflammatory properties which promote wound healing at a phenomenal rate (Siddiqi et al., 2018; Paladini and Pollini, 2019; Chinnasamy et al., 2021). These beneficial properties have led to the incorporation of silver NPs into commercially available wound dressings, pharmaceuticals, and cosmetics (Gade et al., 2010; Mishra et al., 2018; Jin-Chul et al., 2021). Platinum NPs are of extensive use in biomedical applications, whether they are in pure form or alloyed with other NPs whereas palladium NPs play a pivotal role in chemical sensors, antibacterial, optoelectronics, catalysis, and electrocatalysis applications (Siddiqi and Husen, 2016a; Yaqoob et al., 2020). Moreover, copper, iron, selenium, and zinc oxide NPs have also been extensively used in cosmetics, medical treatments, and antibacterial applications (Siddiqi et al., 2016, 2018; Joshi et al., 2019; Bachheti et al., 2020; Siddiqi and Husen, 2020; Jin-Chul et al., 2021; Husen, 2022; Islam et al., 2022).

For the facile synthesis of NPs, there are two basic approaches usually employed "bottom-up" and "top-down" (Husen and Siddiqi, 2014). The "top-down" approach involves assembling NPs from bulk material (larger ones) to facilitate assembly. However, the "bottomup approach" involves starting at the atomic level and controlling molecular structure accurately to build larger and more complex systems. The above-mentioned basic approaches for the fabrication of NPs have been accomplished by different physical, chemical, and biological methods (Durán et al., 2007). In response to the growing demand for metallic and nonmetallic NPs, numerous physical and chemical methods have been developed to fabricate NPs of various shapes, sizes, and structures. Traditional methods for the fabrications of NPs viz. physical and chemical methods were costly as well and used toxic chemicals which pose potential harmful effects such as carcinogens, cytotoxicity, and ecological toxicity Therefore, it is of utmost importance to develop a technique that efficiently controls the shape, size, stability, and physicochemical properties of NPs is at the forefront of NPs synthesis research. This is why researchers have shown keen interest in developing green synthetic methods which are clean, reliable, eco-friendly, and biocompatible (Fig. 24.1).

FIGURE 24.1 Biological sources of nanoparticles.

The affiliation between Nanotechnology and biology has brought into existence a new field of science that is, "Nanobiotechnology" that takes advantage of biological life forms like plants, bacteria, fungi, algae, yeasts, actinomycetes, and viruses in numerous biochemical and biophysical processes. Nanobiotechnology is of great importance due to the widespread of plants and the diversity of microorganisms. With the rich biodiversity of microbes, nanoparticle synthesis can be enhanced as well as the properties can also be improved (Shah et al., 2015). Since it is critical to developing eco-friendly methods of producing NPs, researchers are increasingly relying on microorganisms that possess the ability to reduce metal ions into metallic NPs. However, the manufacture of NPs by fungi has greater practicality than the production of NPs by bacteria, algae, viruses, yeasts, and plants (Dhillon et al., 2012). The use of fungi in Nanobiotechnology for the synthesis of NPs is termed "Mycosynthesis" or "Myconanotechnology." Mycology is the branch of biology that deals with fungi on the other hand nanotechnology deals with the engineering of materials at the nanoscale level, the interface between these two studies is called myconanotechnology. Thus, several biotechnological processes have been developed using various strains of fungi use of waste mycelium could provide feasible and cost-efficient biosynthesis of NPs (Siddiqi and Husen, 2016b; Bachheti et al., 2021). Several fungal species are used for NPs syntheses such as *Fusarium* sp., *Aspergillus* sp., *Trichothecium* sp., *Cladosporium* sp., *Trichoderma* sp., and *Penicillium* sp. More frequently, silver and gold NPs have been synthesized from *Aspergillus flavus*, *Aspergillus niger*, *Bjerkandera adusta*, *Colletotrichum* sp., *Cladophialophora bantiana, Ganoderma enigmaticum*, *Fusarium* sp., *Penicillium* sp., *Trametes ljubarskyi*, *Trametes versicolor*, *Trichoderma martiale*, *Umbelopsis isabellina*, etc. (Shankar et al., 2003; Vigneshwaran et al., 2007; Gade et al., 2008; Kathiresan et al., 2009; Omran et al., 2020; Yousef et al., 2020; Krishna et al., 2021; Rai et al., 2021; Alves and Murray, 2022). Moreover, yeasts have also been explored for various metal and metal-oxide NPs syntheses. For instance, *Candida glabrata*, *Schizosaccharomyces pombe*, *Saccharomyces cerevisiae*, and *C. glabrata* (Dameron et al., 1989; Cuevas et al., 2015; Zhang et al., 2016; Zamani et al., 2020) are some of the common yeast reported for the synthesis of NPs. Taken together, the main of this chapter is to highlight the key strategies involved in the synthesis of NPs by fungi while discussing briefly the intracellular and extracellular mechanisms. Moreover, the significance of fungal nanobiotechnology in escalating NPs potential and its applications in diverse fields such as agriculture, antimicrobial, environmental and other sectors.

24.2 The superiority of fungi over other microbes

Kingdom fungi contain a wide range of heterotrophic multicellular eukaryotic organisms. The role of these microbes is particularly important in nutrient-cycling paradigms, in diverse ecosystems. They are capable of reproducing by both sexual and asexual means. Fungi groups mostly consist of mold, mildew, rust, yeast, and, mushrooms. Fungi release high levels of extracellular enzymes that facilitate the bioreduction and stabilization of NPs synthesis. Several advantages of the use of fungi in NPs synthesis over other microorganisms have been illustrated in Fig. 24.2. In the reductive state, fungi use enzymes, proteins, and membrane-bound molecules for electron donation, which results resulting in the precipitation of metal

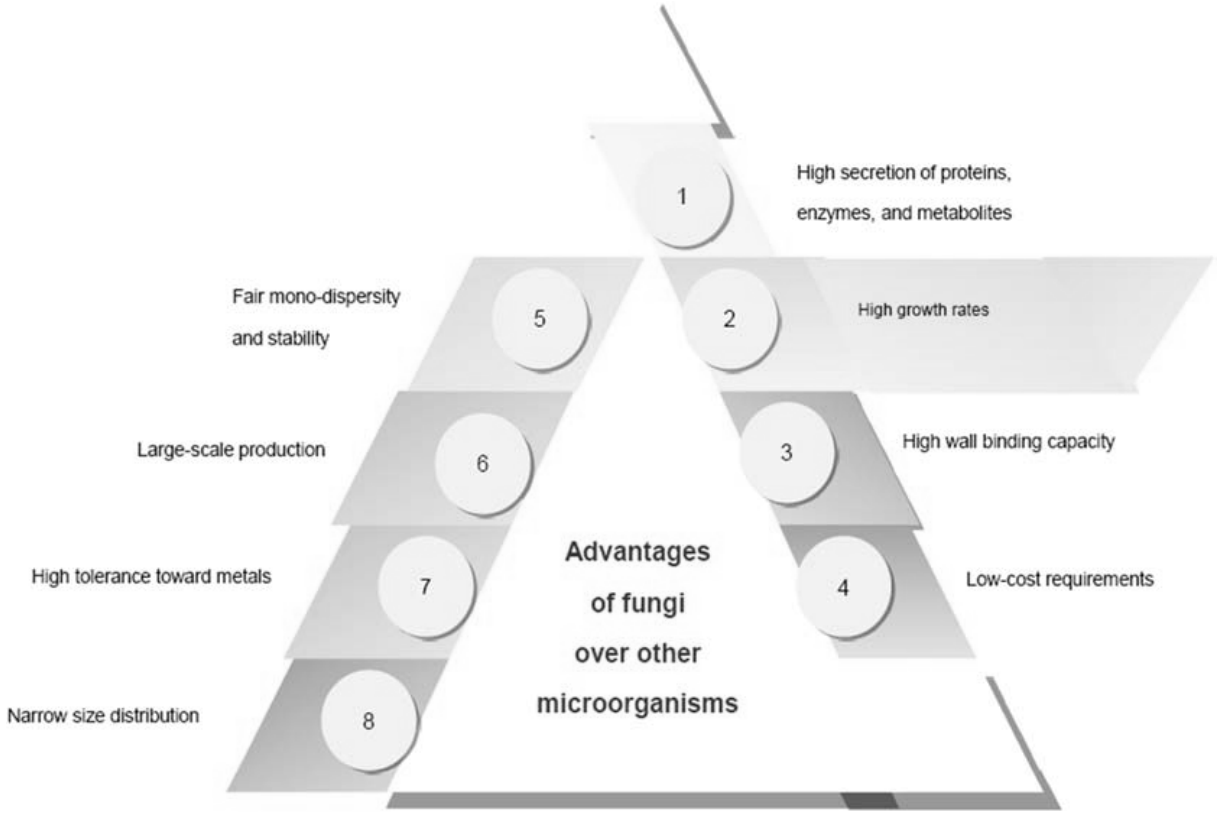

FIGURE 24.2 Advantages of fungi over other microorganisms.

NPs either intracellularly or extracellularly, depending on how the process was carried out (Guilger-Casagrande and Lima, 2019). Fungi provide effective hold ability in bioreactors, as well as in high flow pressure and agitation. It is generally believed that microorganisms that would be used for nanobiotechnology applications must be GRAS (generally recognized as safe) without controversies. In nanobiotechnology, the characteristic of fungi is the GRAS status meaning that regardless of the fungi's enzyme, habitat, or biology, they are generally safe. Interestingly, NPs produced by fungi are of GRAS status. In comparison to other plants and microbes, fungi have high metal-binding abilities, since metal ions containing a positive charge readily bind with a negative charge on the fungal cell surface via electrostatic interactions or receptor-specific interactions (Siddiqi et al., 2016b; Adebayo et al., 2021). When fungi are exposed to large concentrations of toxic metals, they tend to transform into a form that can tolerate high concentrations of metal ions due to their inherent ability to produce higher levels of proteins that promote the reduction of toxic metal ions to less toxic forms. Moreover, bacteria, algae, and viruses do not produce a high titer of proteins and are hence unable to do such action (Priyadarshini et al., 2021). However, the viruses and algae have not been thoroughly explored for their potential to produce NPs. In addition, viruses, require an expression host, which does not seem feasible as compared to the simple culturing protocols for fungi. These unique properties make fungal an ideal candidate for facile synthesis of NPs which exhibited splendid properties for instance sensing, medicine, catalysis, and food packaging.

Moreover, they have shown excellent biocompatibility, photostability, and adequate near-infrared light absorption. While NPs synthesized by nonbiogenic methods require an additional step of coating their surfaces with polymers or surfactants. This process, known as functionalization, involves the anchoring of biomolecules on the surfaces of NPs to achieve desired results (Mout et al., 2012). As part of biogenic synthesis assisted by fungi, the capping occurs simultaneously in the course of the formation of the NPs, so, there are no additional steps are required to make functionalization (Chowdhury et al., 2014). Interestingly, fungal excretes consist of proteins, enzymes, free amino groups, or cysteine residues which bears the ability to bind with metal ions and acts as a capping agent which prevents the segregation of NPs hence the stability of NPs improved significantly. The stabilization can also occur through the actions of mycelial cell wall enzymes present in the filtrate by electrostatic attraction provided by their negative carboxyl groups.

24.3 Mechanisms of fungi-derived nanoparticles

It has been successfully reported that the enzymes, proteins, and other compounds produced by microbes play an important role in the biogenic synthesis process but the exact mechanism involved in the synthesis of NPs remains unclear and still needs to be explored (Hulkoti and Taranath, 2014). In the intracellular synthesis mechanism of NPs, microbes and ions play a significant role, Microbial cells have unique ion transport mechanisms involving enzymes, coenzymes, etc. The cell walls of microbes consist of polysaccharides and proteins which act as active sites for metal ion binding. Interestingly, all microbes do not show the ability to synthesize metal and metal oxide NPs. It has been reported in the presence of heavy metal ions microbe's behavior changes they respond by gripping or trapping the ions on cell walls through electrostatic interactions and hence impair the applied action (Yusof et al., 2019). Usually, the metal ions are attracted to the negatively charged carboxylate groups (specifically polypeptides, enzymes, and cysteine) present on the cell wall. Afterward, the NADH-dependent reductase, which acts as an electron carrier embedded within the plasma membrane, initiates the reduction of the trapped metal ions into the elemental atom by transferring electrons from NADH and the nuclei grow into NPs, which accumulate in the cytoplasm or the cell wall (periplasm). While on the other hand, it is the amino acids, peptides, and proteins especially, cysteine, tyrosine, and tryptophan that exist inside the cells that are found to be responsible for stabilizing NPs as shown in Fig. 24.3A and B. In the extracellular biological synthesis of metal NPs, fungal cell membranes play a pivotal role as they contain many biologically active compounds, including proteins, peptides, polysaccharides, quinones, and oxidoreductases that are involved in the metal reduction and precipitation (Alghuthaymi et al., 2015). In extracellular mode, the enzyme is either released to the growth medium as an extracellular enzyme or located on the cell membrane. A nitrogen cycle enzyme known as nitrate reductase is responsible for converting nitrate to nitrite. As an example, Zn^{2+} is reduced by NADH-dependent reductase, which acts as an electron carrier during electron transfer from NADH to Zn^{2+}. As a result, Zn^{2+} was reduced to ZnO. This caused Zn^{2+} to acquire electrons and subsequently reduce to ZnO. Fig. 24.3B reveals a schematic mechanism for the extracellular synthesis of NPs.

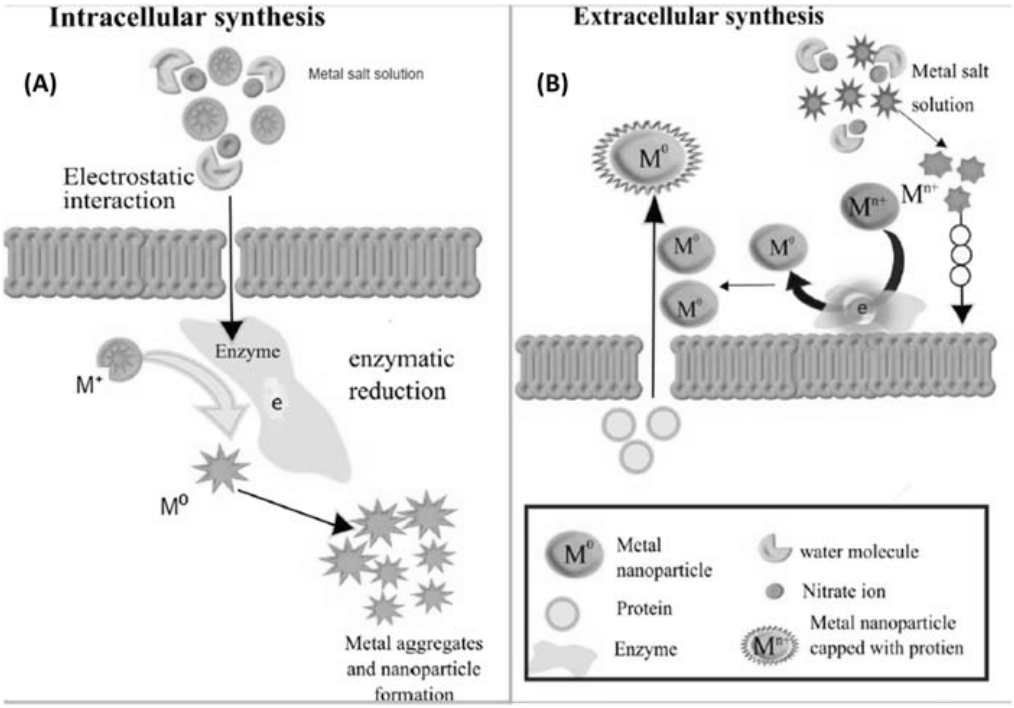

FIGURE 24.3 (A) Schematic presentation of intracellular and (B) extracellular mechanism of nanoparticle formation.

24.4 Synthesis of fungal-mediated nanoparticles

The use of microbial cells for the synthesis of metal NPs has increased over the past few decades. Several fungal strains can be used to produce NPs. A letter in Nature in 1989 gave rise to the first detailed discussion and analysis of using fungi to biosynthesize NPs, reporting that *Candida albicans* could produce CdSe NPs (Ahmad et al., 2002; Rai et al., 2021). Since then, several attempts have been made to biosynthesize different metal NPs by using fungi. As mentioned, there are two basic approaches for the synthesis of metal NPs via fungi extracellular and intracellular as illustrated in Fig. 24.3. In the extracellular mode of synthesis, the microorganisms are cultured for 1−2 days in a rotatory shaker underoptimum conditions (including pH, medium components, temperature, etc.) and the biomass is removed from the medium culture by centrifugation. The supernatant obtained is incubated for a second time in a filter-sterilized metal salt solution. The progress of the reaction is monitored by noticing a difference in the color of the culture medium; for example, silver NPs turn to deep brown color, whereas gold NPs from deep purple or ruby-red color solution. Fatima et al. (2015) have successfully reported for facile synthesis of gold and silver NPs by the fungus *Bipolaris tetramera* and found out that on adding 1 mM of gold tetrahydrate and silver nitrate salt solution to fungal filtrate the color of the solution mixture changed to brown indicating the formation of gold NPs whereas formation of silver NPs was confirmed by the appearance of pinkish violet color. Next, incubation is the centrifugation of the reaction mixture at different speeds to draw out any large

particles or medium components. Finally, the NPs are centrifuged at high speed and washed properly with water or solvent (methanol/ethanol), and are obtained as pellets. Clarance et al. (2020) used endophytic strain *Fusarium solani* (ATLOY-8, obtained from the plant *Chonemorpha fragrans*) and produced gold NPs and characterizations of these particles were made by UV-Vis, FTIR, SEM and XRD. Gold NPs formation was confirmed by pink-ruby red colors and an absorbance band was noticed between 510 and 560 nm, and they were 40−45 nm in size. Joseph et al. (2018) reported silver NPs synthesis via xylanases of *Trichoderma longibrachiatum* and *A. niger* and characterization was made using UV-Vis spectroscopy, TEM and FTIR. They found that the synthesized particles varied from spherical, cylindrical, and oval; and had to size ranges between 15.21 and 77.49 nm. Silver NPs were fabricated using the fungus *Verticillium* sp (Mukherjee et al., 2001). They suggested that the enzymes present on the cell wall membrane of the fungus *Verticillium* sp act as a reducing agent. Very recently, Nejad et al. (2022) synthesized extracellular gold NPs using *Phoma* sp. as an endophytic fungus (Fig. 24.4A). The UV−Vis spectroscopy FTIR investigation revealed the absorbance peak at 526 nm, while the XRD and TEM images showed the formation of spherical gold NPs with sizes in the range of 10−100 nm. In another experiment, Xue et al. (2016) reported the biogenic synthesis of silver NPs *Arthroderma fulvum* (Fig. 24.1B). The UV− Vis range exhibited a single peak at 420 nm, which corresponded to the surface plasmon absorbance of silver NPs. Arun et al. (2015) have successfully investigated mushroom *Schizophyllum commune*-assisted synthesis of silver NPs via both intracellular as well as extracellular approaches. The synthesis was carried out by adding 1 mM silver nitrate solution to cell-free culture filtrate and also to mycelium; a change in color from pale yellow to brown for the broth and the mycelium was observed, indicating extracellular and intracellular synthesis of silver NPs. The presence of silver NPs was confirmed by studying its surface resonance absorption band which appeared at 440 nm, characteristic of the silver NPs in the visible wavelength. Arun et al. (2015) found that the size of silver NPs fabricated from the cell-free filtrate was 51 $\sim$ 93 nm. In an experiment, silver NPs were synthesized using *Alternaria tenuissima* (AUMC 13621) isolated from *Ruta graveolens* plant, and characterized using UV−Vis, FTIR, DLS and TEM. TEM showed the spherical shape of silver NPs with an average size of 9.8 nm. FTIR revealed the presence of proteins and biomolecules (Yousef et al., 2020). Further, Yousef et al. (2020) suggested that pH 12, temperature 70°C and $AgNO_3$ concentration (1 mM) were very much suitable for silver NPs formation. Furthermore, various other fungal species are studied for NPs synthesis. For instance, gold and silver NPs formation from fungal strains namely *A. flavus*, *A. niger*, *B. adusta*, *Colletotrichum* sp., *C. bantiana*, *G. enigmaticum*, *Fusarium* sp., *Penicillium* sp., *T. ljubarskyi*, *T. versicolor*, *T. martiale*, *U isabellina*, etc. (Shankar et al., 2003; Vigneshwaran et al., 2007; Gade et al., 2008; Kathiresan et al., 2009; Omran et al., 2020; Yousef et al., 2020; Krishna et al., 2021; Rai et al., 2021; Alves and Murray, 2022). Other investigations such as Binupriya et al. (2010) silver NPs fabrication from nitrate reductase and phytochelatin of *Rhizopus stolonifera*; Chuhan et al. (2011) gold NPs from the cytosolic extract of *C. albicans*, and Gade et al. (2014) silver NPs from the filtrate of *Phoma glomerata*.

Bhardwaj et al. (2020) adopted an extracellular route for the facile synthesis of CdS quantum dots (QDs) using *Phanerochaete chrysosporium*, a white rot fungus. Upon the optimum condition of reaction, interestingly mycelial pellets began to turn yellow after 12 hour which indicates the formation of CdS QDs. A possible mechanism for the biosynthesis of CdS QDs was suggested. The presence of toxic metal ions causes stress which

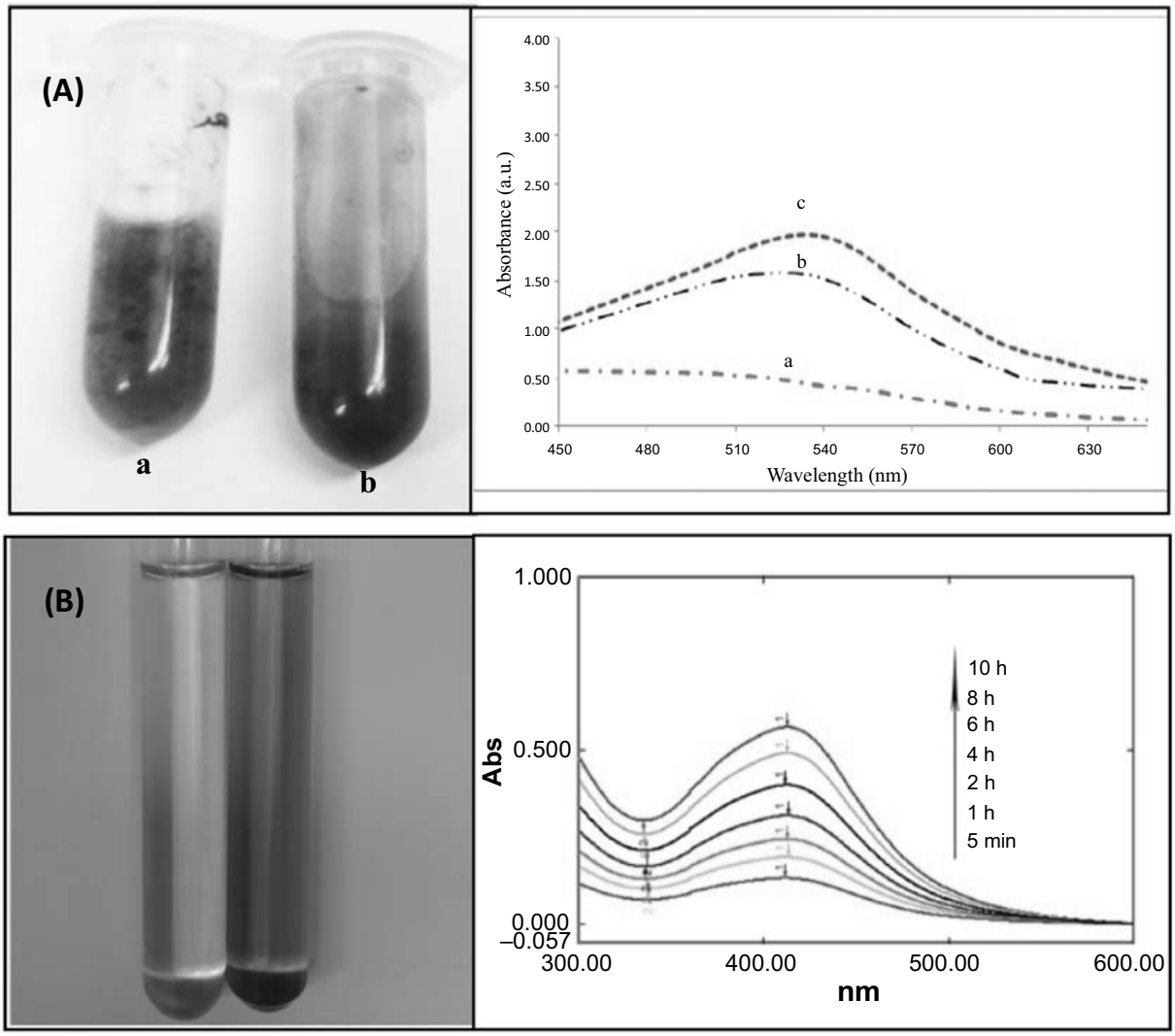

FIGURE 24.4 (A) Fabrication of Au NPs in a colloidal dispersion by *Phoma* sp. Mycelia biomass before (A) and after (B) exposure to $HAuCl_4$ after 48 h and UV−Vis spectra of Au NPs at different times: a, b and c control, 24 h and 48 h respectively (B) The cell filtrate of *Arthroderma fulvum* without $AgNO_3$ (*left*) and with $AgNO_3$ and UV−visible absorption spectrum display formation of AgNPs with different time intervals (Xue et al., 2016; Nejad et al., 2022). *Source: (A) Adopted from Nejad, M.S., Najafabadi, N.S., Aghighi, S., Pakina, E., Zargar, M., 2022. Evaluation of Phoma sp. Biomass as an endophytic fungus for synthesis of extracellular gold nanoparticles with Antibacteria L and antifungal properties.Molecules.27, 1181. https://doi.org/10.3390/molecules27041181. (B) Adopted from Xue, B., He, D., Gao, S., Wang, D., Yokoyama, K., Wang, L. 2016. Biosynthesis of silver nanoparticles by the fungus Arthroderma fulvum and its antifungal activity against genera of Candida, Aspergillus and Fusarium. Int. J. Nanomed.11, 1899−1906. https://doi.org/10.2147/IJN.S98339.*

facilitates white fungus to release cysteine and other proteins, the thiol group of this protein can make chelate with cadmium ions which leads to the formation of CdS QDs. In other studies, *Fusarium oxysporum* with a mixture of $CdCl_2$ and $SeCl_2$ was incubated at room temperature and highly luminescence CdSe QDs were noticed (Kumar et al., 2007).

Kumar et al. (2017) use *S. cerevisiae* (brewer yeast) for the extracellular synthesis of ZnO NPs and discuss the role of yeast in the facile synthesis of ZnO NPs. An adequate amount of fungal biomass was mixed with Zinc acetate solution and incubated for 48 hours at 150 rpm at 28°C. While as a control, a sample devoid of fungal biomass was also used to monitor the role of fungal biomass in mycosynthesis, the appearance of white suspension confirmed the formation of ZnO NPs. Afterward resulting filtrate was then centrifuged to obtain pure ZnO precipitate, which was characterized further. Additionally, the FTIR data confirmed that ZnO NPs were stabilized by proteins released by *S. cerevisiae*. Kalpana and Rajeswari (2018) used *A. niger* for the eco-friendly synthesis of ZnO NPs. For the facile synthesis of ZnO NPs; an adequate amount of fungal biomass was mixed with a 5 mM solution of zinc nitrate and the resultant solution was incubated for 2 days at 32°C. Upon completion of the reaction, a visual color change was observed which confirmed the formation of ZnO NPs and displayed a characteristic peak in the ZnO UV-Vis spectrum at 320 nm. Ganesan et al. (2020) reported *Periconium* sp. extract-mediated sol-gel synthesis of ZnO NPs; and they were characterized by XRD, FTIR, SEM, and TGA/DTA. XRD exhibited that the ZnO-NPs exist in hexagonal wurtzite while size lies between 16 and 78 nm when observed underTEM. Vijayanandan and Balakrishnan (2018) also observed that *Aspergillus nidulans* and endophytic fungi, biomass mixed with cobalt acetylacetone solution, showed visual changes in color in the resultant solution mixture; from pink to orange, which confirmed the formation of cobalt oxide NPs. Afterward, the NPs were further characterized by various analytical techniques. The NPs exhibited distinguished UV-Vis absorption at 315 nm, which is typical of cobalt oxide NPs and possessed an average particle size of 25 ± 5 nm. The authors concluded that sulfur-bearing proteins, which act as stabilizing agents, were responsible for stabilizing cobalt oxide NPs. Cuevas et al. (2015) used *Stereum hirsutum* used for copper/copper oxide NPs fabrication under various pH levels and by using three different ($CuCl_2$, $CuSO_4$, and $Cu(NO_3)_2$ copper salts. It was found that with 5 mM $CuCl_2$ under alkaline conditions NPs were higher. Further, TEM showed that NPs were spherical with sizes 5−20 nm. FTIR revealed the presence of an amine group attached to synthesize NPs.

Chatterjee et al. (2020) reported superparamagnetic iron oxide NPs (Fe_3O_4) of 20−40 nm size which was obtained by *A. niger* BSC-1. Due to unparalleled and distinguished applications of iron-oxide NPs, Mahanty et al. (2019) screened three species of fungi, *Trichoderma asperellum, Phialemoniopsis ocularis and Fusarium incarnatum;* the adequate amount of fungal biomass facilitates mycoreduction of iron chloride salt mixture produced monodisperse and stable iron oxide NPs with a range between 25 and 3.94 nm, 13.13 and 4.32 nm and 30.56 and 8.68 nm using *T. asperellum*, *P. ocularis*, and *F. incarnatum*, respectively. Interestingly, Iron oxide NPs synthesized by using *T. asperellum*, *P. ocularis* showed crystalline nature whereas the iron oxide NPs generated using *F. incarnatum* possess amorphous. The possible mechanism for facile synthesis of iron NPs using these fungal species may be due to the active bioactive molecules present in the fungal culture filtrate (FCF) which mediate the extracellular mycosynthesis and stabilization of iron oxide NPs. Because of the long incubation period of the fungi, more extracellular protein is produced in FCF, which increases the hydrolysis potential of iron chloride complexes and speeds up the extracellular formation of NPs. Iron oxide NPs may be formed by the reduction of iron chloride complex by FCF in three simple steps. The first step involves the release of

chloride ions from the iron-chlorine complex immediately after placing it in the solution. Afterward; several extracellular fungal bioactive molecules, including proteins, polysaccharides, enzymes, and polyphenols, provided a hydrolyzing effect on the solution and may have formed partial bonds with metal ions, which subsequently transforms into iron oxide NPs.

In the intracellular synthesis of NPs, the microorganism is cultured for a definite optimal growth period and is centrifuged to collect the biomass followed by thorough washing and dissolving in sterile water with a filter-sterilized metal salt solution (Narayanan and Sakthivel, 2010). Just like extracellular synthesis, after the incubation period, the reaction mixture is visually monitored for color change and subsequently washed, centrifuged, and ultrasonically separated, resulting in the release of NPs, as these steps help break downthe cell wall. In the end centrifugation, washing, and collecting of the mixture are carried out. Compared to intracellular synthesis, extracellular synthesis has proven to be more advantageous. As a result of its simple downstream processing, it eliminates various steps of synthesis, as well as easy separation and industrialization. To obtain purified NPs through intracellular synthesis, additional steps such as cell harvesting through centrifugation and ultrasonication cycles for cell disruption are required (Singh et al., 2016). Table 24.1 summarizes several of NPs mediated via fungi including their precursor salt, synthesis condition, size, and shape. Moreover, yeasts (eukaryotic, single-celled microorganisms belonging to the fungus kingdom) have also been used for various metal and metal-oxide NPs synthesis. For instance, silver NPs have been obtained from yeast extract (Shu et al., 2020). In this experiment, SEM images showed that particles were spherical and had fine size ($\sim$ 13.8 nm) (Fig. 24.5A). EDX exhibited an optical absorption peak at $\sim$3 keV, which was assigned as a typical optical absorption peak of Ag nanocrystallites for SPR (Fig. 24.5B). Although, minor amounts of oxygen and carbon were ascribed to the thin layer of organic capping on the synthesized silver NPs. Shu et al. (2020) have reported that the reaction of $AgNO_3$ solution with NaOH leads to the formation of a small amount of Ag_2O. Therefore, a small amount of O was also ascribed to the presence of Ag_2O. HRTEM studies revealed particle diameter ranged from 10.3 to 18.9 nm (Fig. 24.5C) and had an average size of 13.8 nm (Fig. 24.5D). UV-Vis studies exhibited a peak of absorption at 418 nm (Fig. 24.6A) and yellow solution (Fig. 24.6B) which was considered for silver NPs synthesis and or formation. XRD exhibited the presence of crystalline nature of the synthesized silver NPs. XRD pattern showed four peaks at 77.36, 64.30, 43.52 and 38.16 degrees corresponding to the (311), (220), (200) and (111) planes for silver, respectively (Fig. 24.6C). However, FTIR showed the presence of biomolecules namely, reductive amino acids, alpha-linolenic acid and carbohydrates in yeast extract and considered that they had an important role in silver NPs formation (Fig. 24.6D) (Shu et al., 2020).

There are several factors that direct mycosynthesis, viz; temperature, pH, time, the parent compound, amount of biomass produced by the fungus, and colloidal interaction that determines the size, shape, and position of the NPs. It is well established that fungi and their environment interact continuously and environmental conditions play a significant impact on organism growth and development. Fungi produce enzymes in response to the environment in which they are cultivated. Optimization studies will therefore support both growth and product yield (Qamar and Ahmad, 2021). As reported earlier, Xue et al. (2016) have successfully produced silver NPs using *A. fulvum*. In this experiment, XRD

TABLE 24.1 Use of various fungal strains for nanoparticle synthesis.

Fungus (common name)	Metal precursor	Synthesis condition	Shape and size	Key reference
Alternaria alternate (Black spot)	$ZnSO_4$	An appropriate amount of Zinc sulfate was added to the fungal culture filtrate and the resultant mixture was agitated for 24 h, afterwards color changed from light yellow to yellowish green, which indicates the formation of ZnO NPs.	Most particles were spherical, triangular and hexagonal with an average size of 45–150 nm.	Sarkar et al. (2014)
Aspergillus aculeatus (black spores)	$NiCl_2$	An appropriate amount of $NiCl_2$ was added to the dead, dried, and live biomass of *A. aculeatus*, and the mixture was maintained at pH4.0 at 30°C and agitated at 150 rpm which results in the formation of NiO NPs.	Most particles were spherical and the average size lies between 10 ± 3.0 nm	Salvadori et al. (2014)
Schizophyllum commune (split-gill)	$AgNO_3$	An adequate amount of $AgNO_3$ solution was added to the culture filtrate of *S. commune* and resultant was set on a rotary shaker at 120 rpm until the color changed from pale yellow to brown; which confirms the formation of Ag NPs.	Most particles were spherical and bear an average particle size between 54 and 99 nm.	Arun et al. (2015)
Stereum hirsutum (false turkey tail)	$CuCl_2$, $Cu(NO_3)_2$, and $CuSO_4$	50 mL of *S. hirsutum* extract was gradually added into a 0.5 mL solution of different copper salts, namely, $CuCl_2$, $Cu(NO_3)_2$, and $CuSO_4$, afterwards, the flasks were incubated for 7 days on an orbital shaker (100 rpm) at 25°C in the dark.	Most particles were regular and spherical and the average particle size lies between 5 and 20 nm.	Cuevas et al. (2015)
Arthroderma fulvum	$AgNO_3$	For the synthesis of Ag NPs, 1 mM of silver nitrate solution was added to the culture filtrate of *A. fulvum* and the mixture was incubated at an ambient temperature of 28°C for 48 h.	Particles were spherical and bear an average particle size of 15 ± 3 nm.	Xue et al. (2016)
Duddingtonia flagrans (worm-eating)	$AgNO_3$	An adequate amount of $AgNO_3$ solution was added to the fungal filtrate was mixed and resultant was set at two different temperatures 30°C and 60°C and also at different pHs 5 and 10 respectively.	Particles were monodisperse and quasispherical and possess an average size between 11 and 38 nm.	Silva et al. (2017)

(*Continued*)

TABLE 24.1 (Continued)

Fungus (common name)	Metal precursor	Synthesis condition	Shape and size	Key reference
Aspergillus nidulans	Cobalt(II) acetylacetonate	An adequate amount of fungal biomass was mixed with 2 mM of Cobalt (II) acetylacetonate solution and resultant mixture was kept for stirring at 115 rpm in a rotatory shaker.	Most particles were regular and spherical in shape and average particle size of 20 ± 3 nm.	Vijayanandan and Balakrishnan (2018)
Cordyceps militaris (Caterpillar fungi)	$Zn(NO_3)_2$	An appropriate amount of fungal extract was mixed with a 0.1 mM $Zn(NO_3)_2$ solution. Afterward, the mixture was stirred continuously for 2 h, which resulted in the appearance of milky white color. It indicates the formation of ZnO NPs.	Particles were flower shaped and bear an average particle size of 10 ± 2 nm.	Li et al. (2019)
Aspergillus niger (black mold)	$CuSO_4$	An appropriate amount of fungal extract was added to the copper sulfate solution and the final solution was incubated for 24 h at 30°C until the solution changed to blue color, which indicates the formation of Cu NPs.	Particles were polydisperse with a size of 500 nm, and a Z-average of 398.2 nm.	Noor et al. (2020)
Rhizopus oryaze (Black fungus)	Mg $(NO_3)_2$	The desired amount of know concentration of $Mg(NO_3)_2$ is gradually mixed with fungal extract and the resultant solution was incubated until the formation of a white precipitate which was further calcined at 400°C for 3 h to obtain Mg NPs.	Particles were polydisperse and spherical with an average of 20 ± 9 nm.	El-Din Hassan et al. (2021)
Phoma species (coelomycetous soil fungi)	Auric Chloride ($HAuCl_4$)	An adequate amount of Auric chloride solution was gradually mixed with fungal biomass. Subsequently, the mixture was vigorously agitated in an incubator at ambient temperature until red color appeared indicating the formation of Au NPs.	Particles were uniform and spherical with an average size of 10−100 nm.	Nejad et al. (2022)

and TEM images showed that the biosynthesized silver NPs were crystalline with an average diameter of 15.5 ± 2.5 nm. Further, they examined numerous factors that affect the process of biosynthesis, and suggested that substrate concentration of 1.5 mM, alkaline

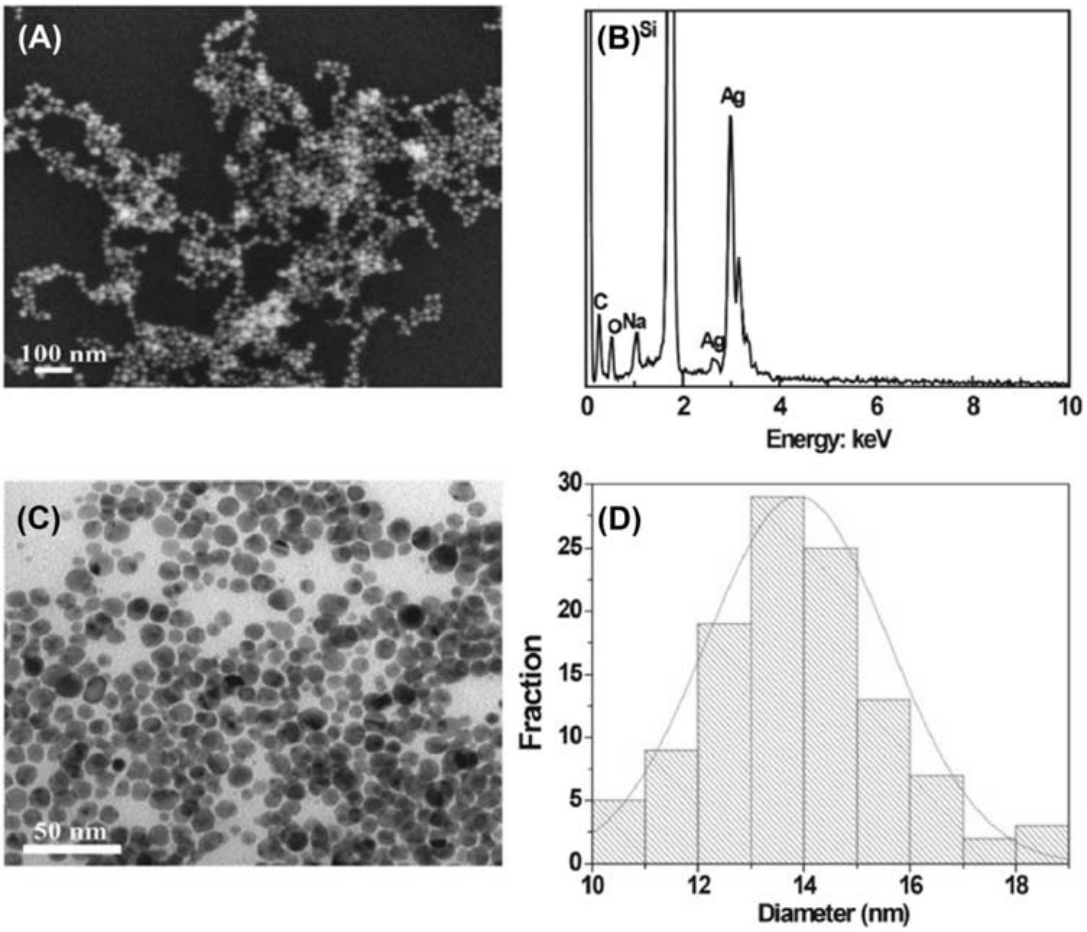

FIGURE 24.5 (A) SEM image, (B) EDX spectrum, (C) TEM image and (D) size distribution pattern of Ag-NPs. *Source: Adopted from Shu, M., He, F., Li, Z., Zhu, X., Ma, Y., Zhou, Z., et al., 2020. Biosynthesis and antibacterial activity of silver nanoparticles using yeast extract as reducing and capping agents. Nanoscale Res. Lett. 15, 14.*

pH, reaction temperature of 55°C, and reaction time of 10 hours were the optimum conditions for silver NPs biosynthesis (Fig. 24.7A–C). Silver NPs were homogenous and showed significant order of stability. The distribution and size of the silver NPs did not significantly change after 2 months, indicating reasonable stability of the biosynthesized silver NPs.

Temperature also plays a significant role during the synthesis of metal NPs as it can affect the reduction rate, size, and stability of the NPs. Tyagi et al. (2019) successfully optimized different physicochemical parameters for silver NPs synthesis using *Beauveria bassiana* and found that maximum yield occurred at 30°C followed by 25°C and 35°C with lower production rates (57.8% and 39.06%) at 15°C and 40°C. The optimal pH for the reduction of Ag^{+1} to Ag^{0} was observed to be at pH 6. Further, upto 66.9% reduction in the biosynthesis of silver NPs was observed with acidic supernatant. The possible reason for low conversion efficiency at acidic pH is the slow rate of nucleation process for the formation of nanocrystal leading to large NPs. Several other optimization conditions and

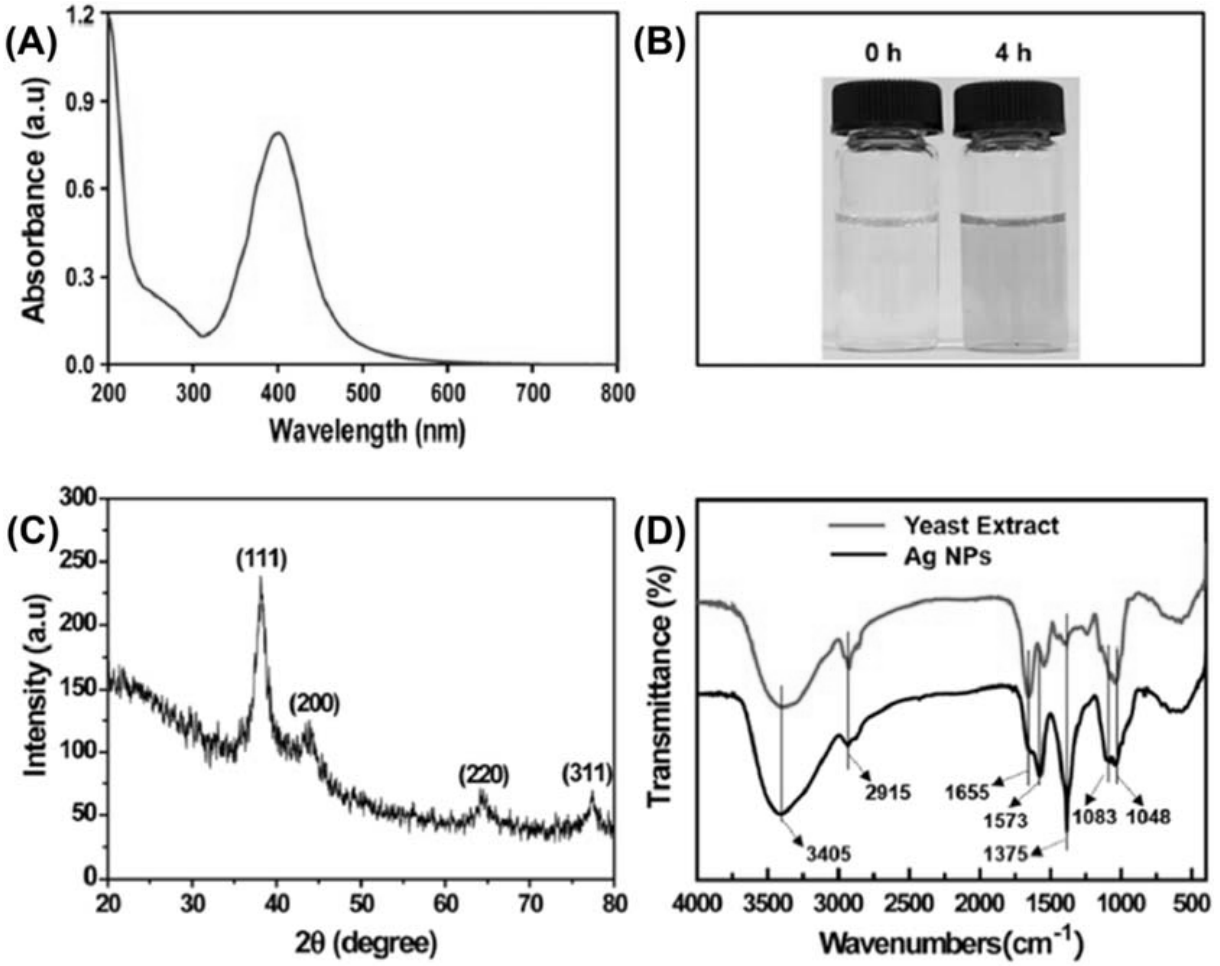

FIGURE 24.6 (A) UV-Vis spectrum of Ag-NPs, (B) synthesized Ag-NPs, (C) XRD pattern and (D) FTIR spectrum of Ag-NPs and yeast extract. *Source: Adopted from Shu, M., He, F., Li, Z., Zhu, X., Ma, Y., Zhou, Z., et al., 2020. Biosynthesis and antibacterial activity of silver nanoparticles using yeast extract as reducing and capping agents. Nanoscale Res. Lett. 15, 14.*

associated details are presented in Table 24.2. In general, NPs of small size are highly reactive, unstable, and prone to aggregation, which alters their physicochemical properties and reactivity. With the fabrication of organic stabilizers, NPs of desirable size and shape can be obtained. The extracellular proteins produced by fungi can act as capping agents and crystal growth regulators for NPs, minimizing their aggregation and controlling their formation.

24.5 Applications of nanoparticles

Numerous metal and metal-oxide NPs have gained enormous attention due to their wide applications in several disciplines of science and technology (Husen and Siddiqi,

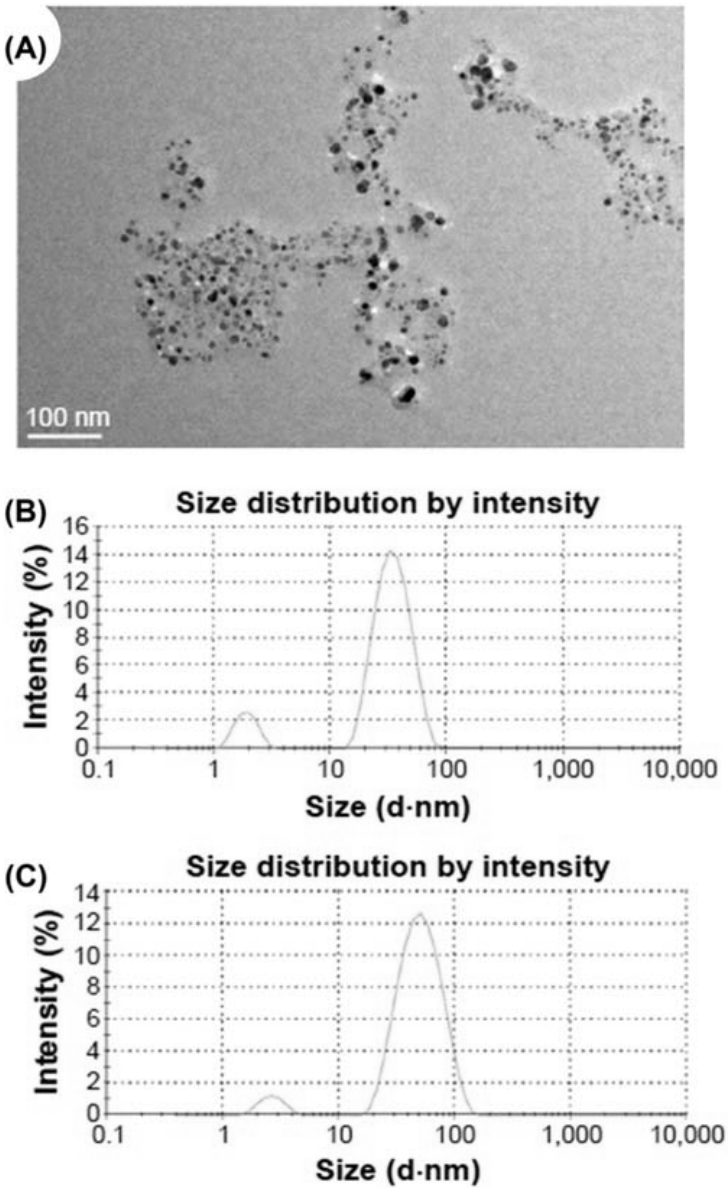

FIGURE 24.7 (A) TEM images and size distribution of silver NPs (B) and (C) show zeta potential for *Arthroderma fulvum*, assisted synthesized silver NPs 10 h and 2 months, respectively. *Source: Adopted from Xue, B., He, D., Gao, S., Wang, D., Yokoyama, K., Wang, L. 2016. Biosynthesis of silver nanoparticles by the fungus Arthroderma fulvum and its antifungal activity against genera of Candida, Aspergillus and Fusarium. Int. J. Nanomed.11, 1899–1906. https://doi.org/10.2147/IJN.S98339.*

2014; Husen and Iqbal, 2019b; Husen and Jawaid, 2020; Jin-Chul et al., 2021; Sharma et al., 2021; Kumar et al., 2021a,b; 2022; Husen, 2022) (Fig. 24.8). Table 24.3 provides an overview of some selected applications of NPs.

24.5.1 Antimicrobial applications

Microbial infections have become a major health concern in recent decades due to their continuously evolving nature and potential for developing resistance against existing treatments. It is, therefore, necessary to search for a strong alternative candidate that can kill or inhibit multidrug-resistant microbes. Due to the strong oxidative effects of metal NPs and

TABLE 24.2 Some studies involving different fungal species and different optimization conditions resulted in nanoparticles synthesis.

Fungus	Nanoparticles	Type of parameter	Optimization condition	Shape and size	References
Aspergillus flavus	Ag NPs	pH Temperature Incubation	6.2 37°C 5 days	Monodisperse 8 ± 2 nm	Vigneshwaran et al. (2007)
Alternaria alternate	Ag NPs	Concentration Culture media Temperature	1 mM $AgNO_3$ Potato dextrose 25°C	Spherical 20–60 nm	Gajbhiye et al. (2009)
Alternaria alternate	Au NPs	Concentration pH Culture media Temperature Incubation	1 mM, 0.3 and 0.5 mMchloroaurate solution 4.0 Potato dextrose 25°C 3 day	Quasi-spherical and spherical with a size range of about 7–13 and 15–18 nm	Dhanasekar et al. (2015)
Aspergillus terreus	CuO NPs	Concentration pH Incubation	0.1 mM 7.4 35–48 h	–	Mani et al. (2021)
Saccharomyces cerevisia	ZnO NPs	Concentration pH Temperature Incubation	0.3 mM Zinc acetate 7.8 28°C ± 1°C 48 h	The spherical and homogenous bear range between 5 and 25 nm	Kumar et al. (2017)
Penicillium oxalicum	Ag NPs	Concentration Temperature Incubation	1 mM $AgNO_3$ 37°C. 72 h	Spherical 60 to 80 nm	Feroze et al. (2020)
Aspergillus niger	ZnO NPs	Concentration Temperature Incubation	1 mM Zin acetate 150°C 48 h	Most particles were assembled into rod shape and cluster form and a size range between 80 and 130 nm	Gao et al. (2019)
Rhizopus oryzae	MgO NPs	Concentration pH Temperature Incubation	4 mM of precursor 8 35°C 36 h	Spherical with an average size of 20 ± 10 nm	Hassan et al. (2021)

their photodynamic effects, metal NPs are known to have potent antimicrobial properties against a wide range of microorganisms (Husen and Siddiqi, 2014; Siddiqi and Husen, 2016b,c; Siddiqi, et al., 2018; Siddiqi and Husen 2018). Mohamed et al. (2015) evaluated the antimicrobial activity of iron NPs employing the fungus *Alternaria alernata*. As antibacterial agents, Fe NPs were effective against both Gram-positive (*Bacillus subtilis* and *Staphylococcus aureus*) and Gram-negative bacteria (*Escherichia coli* and *Pseudomonas aeruginosa*). But, the antimicrobial activity of these NPs was better against *B. subtilis* than against *P. aeruginosa, S. aureus*, and *E. coli*. Balakumaran et al. (2016) and colleagues synthesized silver and gold NPs from the fungi *Aspergillus terreu* to control seven types of human

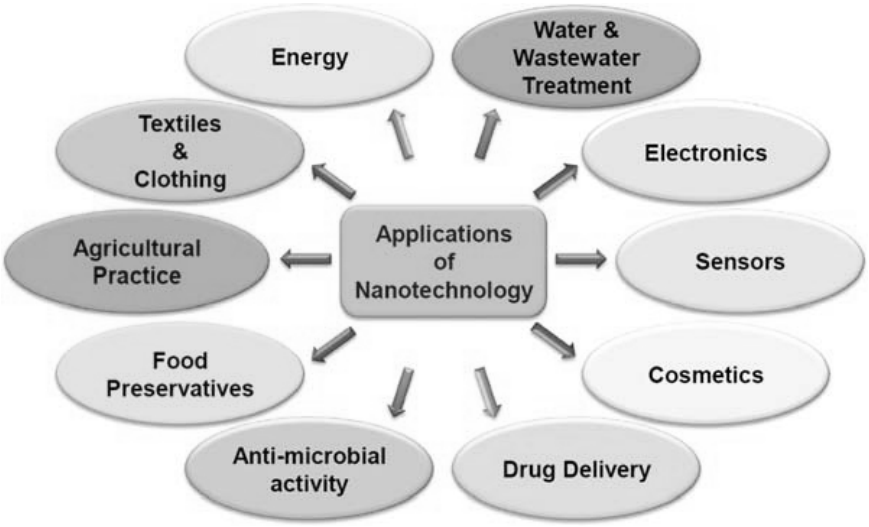

FIGURE 24.8 Application of nanotechnology in various disciplines of science and technology.

pathogenic bacteria *E. coli, P. aeruginosa, Klebsiella pneumonia* (Gram-negative), *Enterococcus faecalis, B. subtilis, S. aureus*, *S. aureus* (Gram-positive) and a yeast pathogen, *C. albicans*. In conclusion, silver NPs showed excellent antimicrobial activity against all of the tested bacteria, probably due to the proteins or other biocompatible materials adsorption on their surfaces, which subsequently increased their antimicrobial properties. Durán et al. (2007) have demonstrated that extracellular produced silver or gold NPs from *F. oxysporum* can be embedded in different types of materials, such as cloths. These clothes are sterile and possess antibacterial properties, making them suitable for hospitals. To minimize infection with pathogenic bacteria, such as *S. aureus*. Silver NPs are known to have antimicrobial activity by inactivating sulfhydryl groups in the cells and disrupting membrane-bound enzymes and lipids which results in lysis of the cells. Moreover, silver NPs could also bind to proteins outside the cells to form pores that interfere with DNA replication, creating superoxide anions, hydrogen peroxide, and hydroxyl radicals (ROS). Similarly, ZnO NPs synthesized from white-rot fungus *P. chrysosporium* were tested for antibacterial activity Sharma et al. (2021) against two major medically important bacteria, that is, *E. coli* (Gram-negative pathogen) and *S. aureus* (Gram-positive pathogen). Inhibition of bacterial growth by ZnO NPs at minimum concentration was more towards *S. aureus* compared to *E. coli*. In the case of *E. coli*, the zone of inhibition of ZnO NPs was 18−22 mm, while *S. aureus* showed a zone of inhibition of ZnO NPs was 11−23 mm in the range under different concentrations of ZnO NPs. The variation in resistance including its bacterial strains may be due to the structure, and morphology of the cell wall membrane between *S. aureus* and *E. coli*. The cell wall provides a protective surface that prevents or slows down the penetration of antimicrobials that can destroy or cause bacterial damage. There are several possible bactericidal mechanisms of ZnO NPs. The release of zinc from ZnO NPs is one of them, which is known to inhibit many bacterial functions, including active transport, metabolism, and enzyme activity. Subsequently, the toxicity properties of Zn^{2+} on the bacterial cell biomolecules induced the cell to death.

TABLE 24.3 Selected applications of nanoparticles.

Fungus	Metal NPs	Activity	Key reference
Aspergillus terreus	Au NPs	Gold NPs exhibited selective bactericidal activity against gram-negative bacteria *Escherichia coli*	Priyadarshini et al. (2014)
Bipolaris tetramera	Ag NPs	Higher concentrations of silver NPs showed effective antimicrobial activity against *Staphylococcus aureus, Bacillus cereus*, *Trichoderma* sp., and *Enterobacter aeroginosa*	Fatima et al. (2015)
Penicillium decumbens	Ag NPs	Biosynthesized silver NPs exhibited considerable anticancer activity against the A-549 human lung cancer cell line	Majeed et al. (2016)
Agaricus bisporus	MgO NPs	The results demonstrated that smaller-size MgO NPs promoted the growth and development of peanut seeds	Jhansi et al. (2017)
Aspergillus niger	ZnO NPs	NPs of ZnO showed antimicrobial activity against *E. coli* and *S. aureus*. A 100 μL solution of ZnO NPs decolored Bismarck brown dye 90%	Kalpana and Rajeswari (2018)
Penicillium oxalicum	Ag NPs	Ag-NPs exhibited excellent antibacterial activity with a maximum zone of inhibition for *S. aureus*, *Shigella dysenteriae* (17.5 ± 0.5 mm), and (18.3 ± 0.60 mm) for *Salmonella typhi*	Feroze et al. (2020)
Flammulina filiformis	Ag NPs	Silver NPs were also found to degrade indigo carmine dye by 98.2% within 140 min.	Faisal et al. (2021)
Phanerochaete chrysosporium	ZnO NPs	Fungus-mediated ZnO NPs demonstrated remarkable antibacterial activity against *S. aureus* and *E. coli*.	Sharma et.al. (2021)
A. terreus	MgO NPs	MgO-NPs efficiently decolorized (96.8 ± 1.7%) and removed chromium ions (97.5%) from the tanning effluent and greatly decrease chemical parameters including TSS, TDS, BOD, COD, and conductivity with percentages of 98.04, 98.3, 89.1, 97.2, and 97.7%, respectively.	Saied et al. (2021)
Alternaria alternata	Ag NPs	Silver NPs inhibited the growth of *B. cereus* followed by *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *E. coli*, *S. aureus*, and *Proteus mirabilis*	Govindappa et. al. (2022)

24.5.2 Environmental applications

Advances in nanotechnology have led to new possibilities for various environmental applications (Martínez et al., 2020; Raja and Husen, 2020; Saravanan et al., 2020; Khan et al., 2022). The photocatalytic activity of CdS NPs synthesized with fungi *Trichoderma harzianum*, was assessed via methylene blue degradation by Bhadwal et al. (2014). The photocatalytic activity of the NPs was evaluated by degrading methylene blue dye in a photocatalytic reactor and monitoring the residual concentration with UV-Vis spectroscopy. The degradation response of the CdS NPs after 60 minutes of illumination was found to be 37.15% after 60 minutes of illumination. Using metabolites secreted by a strain of *A. niger*, Fouda et al. (2021) synthesized highly adsorbent MgO NPs to determine their photocatalytic activity and potential to be reused more than once in textile wastewater

treatment. Catalytic degradation and decolorization analyses were performed in sunlight and darkness. The decolorization percentages at 0.25 mg/mL NPs concentration were 35.9% and 26.8% respectively. While, the decolorization at 1.0 mg/mL was the highest in the presence of sunlight with percentages of 92.8%, 93.5%, and 94.5% after 180 and 240 minutes respectively. While, in dark conditions, the percentages were 45.3% and 46.7%, respectively. The prevalent heavy metals in tannery effluent are highly adsorbed by MgO NPs with removal percentages of 94, 63.4, 72.7, 74, and 70.8 for Cr, Co, Pb, Cd, and Ni, respectively. A similar approach was utilized by Gupta and Chundawat (2019) for the production of platinum NPs by the fungus *F. oxysporum* to evaluate the photocatalytic degradation of methyl orange when kept undersolar illumination with continuous stirring for 70 minutes. They investigated the effects of different concentrations of platinum NPs in a solution containing methyl orange dye, ranging from 0.2 to 0.6 mg/mL. The degradation rate for methyl orange was observed to increase with increasing catalyst concentration. Results were not satisfactory using 0.2 mg/mL concentration of catalyst, but 0.4 mg/mL and above concentrations gave better results, thus selecting 0.4 mg/mL as the minimum concentration. Jain et al. (2014) synthesized protein-capped ZnO NPs with sizes predominantly between 80 and 120 nm without any aggregation using *Alternaria alternata* and investigated their photocatalytic performance. It was found that as-synthesized protein-capped ZnO NPs degraded MB dye more efficiently than commercially available bare NPs. MB degradation was significantly increased twofold times due to a charge transfer from zinc oxide NPs to the attached proteins, which reduced electron-hole recombination, therefore contributing to enhanced photocatalytic properties of protein-capped ZnO NPs.

24.5.3 Agricultural applications

Myconanofabrications have a wide range of agricultural applications, including nanofungicides, nanopesticides, nanoinsecticides, and nanofertilizers, in addition to serving as antimicrobial agents (Husen and Iqbal, 2019a; Kumar et al., 2021a,b, 2022; Siddiqi and Husen, 2021; Sharma et al., 2021; Husen, 2022). The use of fungi in nanobiotechnology can result in nanobiosensors, which are said to be a new class of biosensor. Nanobiosensors detect biological agents such as antibodies, nucleic acids, pathogens, and metabolites. A variety of nanobiosensors can be used for sensing fertilizers, herbicides, pesticides, pathogens, moisture, and soil pH. Recent reports have outlined some of the prominent applications of fungal nanobiotechnology in several agriculture sectors. Using Copper NPs (Cu NPs) synthesized from the fungi *A. flavus* to interact with selected fungal crop pathogens, such as *F. oxysporum* and *Fusarium graminearum*, was investigated by Shende et al. (2021). It was noted that amongst the tested plant pathogenic fungi, for myco-fabricated Cu NPs, *A. niger* (ZOI mean diameter 27.67 ± 0.58 mm) was found to be the most sensitive followed by *A. alternate* (ZOI mean diameter 22 mm) and *F. oxysporum* (ZOI mean diameter 16.67 ± 1.15 mm). The probable antifungal action of Cu NPs was hypothesized, Cu NPs have an antifungal effect by inhibiting chitin, mannan, glucans, and glycoproteins in the fungal cell wall, which is essential for the adhesion and pathogenesis of fungi and also functions as a protective barrier, limiting molecules from reaching the outer plasma membrane. There is also inhibition of nucleic acids, proteins, and microtubule synthesis. Many

studies have also documented the combination of biogenic NPs with conventional biocides. Young-Ki Jo et al. (2009) evaluated the efficacy of silver NPs using *A. alternata* in combination with fluconazole, an antifungal compound widely used against fungal infections. The antifungal activity of fluconazole was evaluated with these NPs against *P. glomerata*, *Phoma herbarum*, *Fusarium semitectum*, *Trichoderma* sp, and *C. albicans*. Fluconazole was significantly more effective in the presence of Ag-NPs. Among the tested fungi, *C. albicans* exhibited the highest level of antifungal activity followed by *Trichoderma sp*. and *P. glomerata*. However, no improvement in antifungal activity was observed in the cases of *F. semitectum* and *P. herbarium*. Similarly, Kaur et al., 2018 tested the antifungal ability of biosynthesized silver NPs produced by *Pseudomonas sp*. and *Achromobacter sp*. against *F. oxysporum* infection in chickpeas. It was found that biosynthesized silver NPs showed very strong antifungal activity against *F. oxysporum* in vivo and in vitro pot experiments. NPs can therefore serve as effective fungicides to treat fungal diseases in plants. Toxicity and dose of NPs, however, remain major obstacles to commercializing NPs as fungicides. Kumaran et al. (2020) compared the antifungal activity of mycosynthesized silver NPs with gold NPs, both of which were biosynthesized by the same fungus *A. terreus* against several plant pathogens, including *Curvularia lunata*, *Colletotrichum* sp, *A. flavus*, and *Penicillium* sp. With increasing concentrations of NPs, antifungal activity was observed to increase. In their study, however, only silver NPs showed antifungal activity, and gold NPs showed no effect. At 50 μg/mL, silver NPs showed the maximum antifungal index against *Penicillium sp*. (60.16%) followed by *A. flavus* (49.91%) and *C. lunata* (47.24%); the least index was observed against *Colletotrichum sp*. (39.98%). In another work by Jhansi et al. (2017) concluded that MgO NPs synthesized using mushroom extract have the potential for peanut seed germination. The results demonstrated that with a decrease in the crystalline size of MgO NPs there was a significant increase in seed germination, due to the penetration of MgO NPs into the seed coat where it supports water uptake. This activated water uptake process could be responsible for the significantly faster germination rates and higher biomass production for the plants that were exposed to small-sized 16.5 and 15 nm of MgO NPs (0.5 mg/L). The MgO NPs had a positive effect on the seed germination of peanut plants and can have significant economic importance in agriculture.

24.5.4 Miscellaneous applications

Many other significant applications have been noticed (Boroumand Moghaddam et al., 2015; Siddiqi and Husen, 2016a,b; Bachheti et al., 2021). For example, silver NPs obtained by *A. tenuissima* exhibited remarkable antioxidant activity, just like standard ascorbic acid (Yousef et al., 2020). Ganesan et al. (2020) reported that ZnO NPs obtained from *Periconium* sp. showed also antioxidant properties with 85.52% free radical quenching for 100 μg/mL. Further, gold NPs obtained from *F. solani* were examined for their cytotoxicity activity against cervical cancer cells (He La) and human breast cancer cells (MCF-7). These particles had shown significant cytotoxicity activity in a dose-dependent manner (Clarance et al., 2020). IC50 value was 0.8 ± 0.5 μg/mL on MCF-7 cell line and was found to be 1.3 ± 0.5 μg/mL on MCF-7 cell lines. It has been noticed that the NPs biocompatibility is very important for their biomedical application. Accordingly, the biocompatibility NPs obtained from yeast were examined on the cell viability of Cos-7 cells by the MTS assay.

The Cos-7 cells were incubated with silver NPs at various concentrations for 24 hours. It has been noticed that the impact of silver NPs was negligible in terms of cytotoxicity and good biocompatibility with Cos-7 cells (Shu et al., 2020). In another experiment, Husseiny et al. (2015) examined the antitumor potential of silver NPs as obtained from *F. oxysporum*. They were effective in controlling *S. aureus* and *E. coli*, as well as a tumor cell line. A low IC50 value (121.23 $\mu g\ cm^3$) for MCF-7 cells (human breast adenocarcinoma) was noticed following exposure of the cells to the NPs, exhibiting high cytotoxicity and the potential for tumor control. Bagur et al. (2022) also explore the therapeutic potential of biogenic synthesized silver NPs using endophytic fungus extract as isolated from *Tinospora cordifolia*. They have reported their antiproliferative activity in cervical and breast cancer cells. Bagur et al. (2022) have also suggested silver NPs cytocompatibility and hemocompatibility.

24.6 Conclusion

Recent studies have demonstrated that the biogenic synthesis of NPs by fungi offers many advantages including a dual role, as the functional groups could act as reducing and also play a role as stabilizing agents, which provide an easy route to the stable synthesis of NPs of controlled size and shape, downstream processing, and economic viability. The chapter gives the detail of how the fungi possess the unchecked potential to produce different metal, and metal-oxide NPs at optimum conditions viz, concentration, pH, temperature and incubation time, and there are important parameters for facile synthesis and optimum yield of NPs. It has been discussed that fungi excrete cysteine, proteins, minerals, and some other important biomolecules in ample amounts involved in NPs formation but the exact mechanism is still needed to be explored. The chapter also explores the use of NPs in some of the specific disciplines of science and technology.

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