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Role of Microbial Nanoparticles in Plant Diseases

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ABSTRACT: Severe plant diseases make food scarcity worse, which has increased interest in environmentally friendly ways to control these diseases. Nanotechnology has gained significant attention in agriculture, with microorganisms being potential candidates for synthesizing metallic nanoparticles. Microorganisms, including bacteria, fungi, and photosynthetic microorganisms can control these nanoparticles. Bacteria can generate extracellular enzymes that reduce metal ions into nanoparticles, while fungi are economically efficient and adaptable. Microalgae, photosynthetic microorganisms can convert metal ions into nanoparticles using internal or extracellular enzymes, making copper nanoparticles a viable and environmentally sustainable solution. Nanoparticles can improve disease control and biocidal capabilities by causing DNA damage and cell death in pathogens and stimulating systemic resistance in plants. Green silver nanoparticles were produced using *B. rhodesiae*, while bio-engineered chitosan-magnesium nanocomposites reduced biomass in *Alternaria solani* in 7 days. Biogenic nanoparticles can indirectly manage plant diseases by enhancing growth and productivity, inhibiting pathogen proliferation and stimulating the generation of reactive oxygen species and plant hormones, which are crucial for plant defense mechanisms against pathogens.

Keywords: Diseases, nanoparticles, bacteria, fungi and photosynthetic microorganisms.

INTRODUCTION

The global issue of food scarcity has been exacerbated by the advent of severe plant diseases, leading to a continuing growth in this problem (Seppelt *et al.*, 2022). Therefore, it is crucial to increase global food production by a significant margin of 70% by the year 2050 in order to adequately fulfill the nutritional needs of the rapidly growing worldwide population (Bindraban *et al.*, 2018). In recent times, there has been a concerted effort within the scientific community to develop effective alternatives to remote methods in order to enhance food production while minimizing the adverse effects on the environment and agricultural soil qualities (Adisa *et al.*, 2019). Therefore, it is imperative to implement environmentally sustainable methods aimed at enhancing agricultural production and effectively controlling plant diseases as viable alternatives to conventional procedures (Ahmed *et al.*, 2022). In recent times, nanotechnology has garnered significant attention due to its extensive utilization in the field of agriculture, namely in the application of nanoparticles (NPs) with sizes less than 100 nm for the purposes of soil conditioning and the management of plant diseases (Elmer *et al.*, 2018). Multiple studies have documented that the utilization of nanoparticles (NPs) has a substantial impact on the enhancement of plant growth and development. Several studies in the literature have demonstrated that the chemical creation of nanoparticles (NPs) has deleterious effects on plant, soil, and environmental systems (Handy *et al.*, 2007; Hu *et al.*, 2010; Korani *et al.*, 2015). The aforementioned hazards underscore the importance of conducting careful evaluation and implementing effective management strategies when utilizing chemically synthesized nanoparticles in plant disease mitigation methods.

On the other hand, the utilization of microorganisms for the synthesis of nanoparticles (NPs) has significant advantages in terms of their non-toxic nature, scalability, long-term stability, and environmental friendliness, as compared to NPs produced using chemical and physical means (Li *et al.*, 2011). The process of synthesizing nanoparticles by the use of microorganisms and several methodologies, including green synthesis, bio reduction, and extracellular synthesis, is employed to create nanoparticles with favorable characteristics (Reddy *et al.*, 2022). These non-pathogenic organisms have demonstrated promising outcomes in the management of a diverse array of plant diseases caused by different pathogens, such as *Fusarium oxysporum*, *Alternaria solani* and *Xanthomonas oryzae*. Previous research has indicated that microbe-mediated nanoparticles (NPs) exhibit reduced toxicity towards non-target organisms and display decreased environmental persistence compared to chemical pesticides (Koul *et al.*, 2021; Raj *et al.*, 2021). The aforementioned advantages have motivated researchers to conduct investigations into the possibility of microbe-mediated nanoparticles as a viable and environmentally acceptable solution for the management of plant diseases.

MICROORGANISMS IN THE SYNTHESIS OF METALLIC NANOPARTICLES

A range of conventional chemical and physical methodologies has synthesized Nanoparticles, including the solvent evaporation process, vapor condensation, physical fragmentation, sol-gel process, precipitation from micro emulsion, and interferometry lithography (Agarwal *et al.,* 2018; Radzimska *et al.,* 2014). These methodologies entail the utilization of perilous and noxious compounds, which add to the presence of environmental pollutants. In addition, it is important to note that these harmful compounds have the potential to form bonds with plants, leading to the accumulation of nanoparticles (NPs) within the food chain through eating.

Nevertheless, the utilization of microorganisms for the production of nanoparticles presents numerous advantages compared to conventional chemical methods. These include their environmentally benign nature, cost-effectiveness, and compatibility with biological systems (Shinde *et al.,* 2022). The utilization of different microorganisms, including bacteria, fungi, yeast, and microalgae, for the synthesis of nanoparticles by microbial processes presents a viable and advantageous method. This strategy holds great potential due to the intrinsic capability of microbes to generate nanoparticles that exhibit exceptional stability (Ali *et al.,* 2020). In addition, the process of microbial synthesis offers a means of achieving meticulous regulation over the dimensions, morphology, and chemical makeup of nanoparticles (NPs), thereby exerting a substantial influence on their characteristics and prospective uses (Kaur *et al.,* 2022). The efficiency of biogenic nanoparticles is significantly influenced by factors such as particle size, dispersion, and stability (Kumar *et al.,* 2021). In addition, the enduring antibacterial activity of these nanoparticles is attributed to the stability imparted by the capping agents synthesized by microorganisms.

A. Bacterial Nanoparticles

The utilization of bacteria for the synthesis of nanoparticles (NPs) is a viable and environmentally sustainable strategy for the manufacture of NPs that find many applications within the agricultural industry (Hulkoti *et al.,* 2014). Bacteria have been employed for the purpose of synthesizing nanoparticles (NPs) due to their capacity to generate extracellular enzymes capable of reducing metal ions into their respective NPs (Ibrahim *et al.,* 2019). The production of nanoparticles (NPs) utilizing bacteria can be accomplished by different processes, including intracellular biosynthesis, extracellular biosynthesis and bioaccumulation (Alfryyan *et al.,* 2022; Yang *et al.,* 2022). Within the context of intracellular biosynthesis, bacteria have the ability to manufacture nanoparticles (NPs) within their cellular structures. The process entails the internalization of metal ions into the bacterial cells, followed by the enzymatic reduction of these ions to nanoparticles within the cellular environment. Bacterial organisms are employed in the process of extracellular biosynthesis to create nanoparticles (NPs) externally to their cellular structures. The process entails the excretion of extracellular enzymes, which have the capability to convert metal ions into their respective nanoparticles. Several researches in the literature have documented the utilization of microorganisms for the green synthesis of metallic nanoparticles (Noman *et al.,* 2020b; Noman *et al.,* 2020). The biogenesis of silver nanoparticles (NPs) through the utilization of *Bacillus cereus* for the purpose of managing the rice bacterial pathogen was elucidated by Ahmed *et al.* (2020). Previously; NPs were utilized for the production of microbe-mediated NPs (Hussain *et al.,* 2023; Khan *et al.,* 2016; Selbarajan *et al.,* 2013; Singh *et al.,* 2013).

B. Fungal Nanoparticles

Fungi represent a heterogeneous collection of organisms that have been extensively employed in the production of nanoparticles (NPs) owing to their capacity to generate a wide range of extracellular enzymes and metabolites capable of reducing metal ions into their respective NPs (Guilgar *et al.,* 2019; ai *et al.,* 2021). The synthesis of nanoparticles (NPs) derived from fungus can be achieved through different methods, such as intracellular and extracellular biosynthesis, as well as fungal biomass (Mistry *et al.,* 2021). Numerous studies have documented the various benefits associated with the fungal-mediated synthesis of nanoparticles (NPs), including the convenience of growing, the ability to achieve large production rates, and the cost-effectiveness of the process (Qamar *et al.,* 2021; Qu *et al.,* 2019). In a manner consistent with other microorganisms, yeasts have also been widely utilized for the large-scale production of nanoparticles (Apte *et al.,* 2013; Karthik *et al.,* 2014; Mourato *et al.,* 2011). In aggregate, the utilization of fungi to facilitate the synthesis of nanoparticles presents a viable, economically efficient, and adaptable method for the environmentally conscious production of nanoparticles possessing distinctive characteristics and advantageous applications within the realm of agriculture (Ahmed *et al.,* 2022).

C. Algal Nanoparticles

The biosynthesis of nanoparticles (NPs) derived from microalgae offers numerous advantages, including simplicity of growing, high production rate, and cost-effectiveness (Chan *et al.,* 2022). Microalgae are easily harvestable and can be processed for NP synthesis, making them environmentally sustainable. They can convert metal ions into nanoparticles using internal or extracellular enzymes (Aboelfetoh *et al.,* 2017). Studies have shown the potential of utilizing microalgae for nanoparticle synthesis, with studies examining silver chloride nanoparticles using Chlorella vulgaris and zinc, iron, and silver nanoparticles using *Galdieria* sp (da Silva *et al.,* 2017). NPs can be characterized using conventional material characterization techniques, such as UV-Vis spectroscopy and FTIR. Nano pesticides, which incorporate nanomaterial as active components, have shown significant effectiveness as antibacterial agents against plant diseases due to their outstanding microcidal action. Nanoparticle-based interventions focusing on microorganisms present a new and innovative strategy for mitigating plant illnesses caused by pathogens (Chhipa *et al.,* 2017; Devi *et al.,* 2019; Kovendan *et al.,* 2018). These nanoparticles can be manipulated to target specific phytopathogens, making them highly effective and discerning. Metallic nanoparticles, such as silver, gold, manganese, zinc, copper, and titanium, have been extensively researched. Further investigation is needed to comprehensively understand the fundamental mechanisms and enhance the effectiveness and safety of nanoparticle-based strategies for the control and treatment of plant diseases (Salas-Herrera *et al.,* 2019)

PATHOGEN INTERACTIONS

Microorganisms have demonstrated potential in directly engaging with plant pathogens, impeding their proliferation, and mitigating the severity of diseases. The physical and chemical features of biogenic nanoparticles have been identified as one of the methods by which they interact with plant pathogens (Noman *et al.,* 2022; Xu *et al.,* 2021). These noun phrases (NPs) may consist of substances that have the potential to interfere with the integrity of the pathogen's cell membrane, resulting in cell lysis and a decrease in the pathogen's capacity to survive. Furthermore, the generation of reactive oxygen species (ROS) such as hydrogen peroxide, superoxide anions, and hydroxyl radicals following nanoparticle (NP) exposure induces DNA damage, hence impeding mRNA and protein synthesis, finally resulting in the demise of pathogens (Ogunsona *et al.,* 2020). Multiple studies have indicated that the antibacterial properties of biogenic nanoparticles (NPs) can be greatly enhanced by their vast surface area, nanoscale size, and ability to easily penetrate cells, among other distinctive qualities (Ali *et al.,* 2020). The regulated discharge of metal ions, specifically Cu2+, Ag+, Ti4+, and Zn2+, that are encapsulated by proteins. Antimicrobial processes involving nanocrystals have been hypothesized in previous studies (Ahmed *et al.,* 2021; Al-Khattaf *et al.,* 2021). Therefore, the interaction between nanoparticles (NPs) and microbial cells results in the disruption of the cellular membrane structure, depletion of antioxidants, and interference with nutrition intake by microorganisms. Chen *et al.* (2020) demonstrated significant antimicrobial efficacy exhibited by green magnesium oxide nanoparticles (MgO-NPs) against *Thielaviopsis basicola* and *Phytophthora nicotianae*. Additionally, it was revealed that the direct contacts between nanoparticles (NPs) and fungal cells resulted in the generation of reactive oxygen species (ROS) as a consequence of the damage inflicted on the fungal cells by the NPs. Additionally, the ultrastructural micrographs revealed the absence of plasmalemma, partial damage to the cell wall, and disarrayed cytoplasm. In a similar vein, Ahmed *et al.,* (2019) conducted a study that revealed the potent inhibitory properties of green magnesium oxide nanoparticles (MgO-NPs) against *A. oryzae* The researchers conducted a transmission electron microscopy (TEM) investigation to examine the effects of the antifungal compound on *Aspergillus oryzae*. The results revealed a significant disruption in the integrity of the cell membrane, accompanied by DNA damage and the release of cytoplasmic contents, ultimately leading to bacterial cell death. In a recent investigation, nanoparticles (NPs) manufactured using green methods were subjected to testing in order to evaluate their efficacy against the fungal infection. The impact of *Fusarium graminearum* on cell wall structures and hyphal morphology was investigated by electron microscopy techniques such as scanning electron microscopy (SEM) and transmission electron microscopy (TEM) (Ibrahim *et al.,* 2020). The present study investigates the comparable impacts of bio-engineered chitosan-magnesium nanocomposites on the rice fungal pathogen *R. solani* and *A. oryzae* was also noted. The utilization of nanopesticides resulted in observable damage to the cell membrane and cell wall of pathogens, as well as the impairment of cellular organelles and the release of cytoplasmic components, as evidenced by microscopic photographs. In a prior investigation, Hossain *et al.,* (2019) presented evidence of the inhibitory efficacy of silver nanoparticles (AgNPs) mediated by *P. rhodesiae* in eradicating *Dickeya dadantii*, a pathogen responsible for soft rot. In a recent study conducted by Ibrahim *et al.* (2019), it was discovered that green silver nanoparticles were produced utilizing the bacterium *B. siamensis* shown a notable bactericidal efficacy against the rice pathogen *Xanthomonas oryzae pv. oryzae* is a bacterial pathogen that is capable of inducing bacterial leaf blight, a disease that affects rice plants. In a separate investigation, documented the fungicidal impact of silver nanoparticles (NPs) that were generated using biological means. The study revealed that these NPs effectively inhibited spore germination and resulted in a complete reduction of biomass in *Alternaria solani* over a period of 7 days. In a similar vein, another study conducted in a live organism demonstrated the inhibitory impact of three metal oxide nanoparticles (MgO, ZnO, and MnO_2) that were biologically generated by *Paenibacillus polymyxa*. These nanoparticles exhibited inhibitory effects against *Xanthomonas oryzae pv. oryzae*, the pathogen responsible for rice bacterial leaf blight (Ogunyemi *et al.,* 2020). In recent times, numerous investigations have also ascertained the utilization of nanoparticles (NPs) for the management of viral illnesses. An investigation was conducted wherein silver nanoparticles derived from *Pseudomonas fluorescens* were employed to manage the tobacco mosaic virus in tobacco plants (Ahsan *et al.,* 2020). However, it is vital to conduct thorough research in order to advance our comprehension of the target specificity of biogenic nanoparticles through the evaluation of their impact on advantageous bacteria.

PLANT DEFENSE MECHANISMS

Microorganisms have demonstrated the potential to indirectly manage plant diseases by influencing plant development and defense processes through the use of microbe-mediated nanoparticles (NPs). For instance, several types of NPs have demonstrated the ability to enhance the absorption and use of nutrients in plants, resulting in enhanced growth and productivity (Chakraborty *et al.*, 2022). This phenomenon can result in the synthesis of phytohormones, enzymes, and various defense chemicals that impede the proliferation of pathogens and enhance the plant's ability to resist infections. An additional way via which biogenic nanoparticles indirectly regulate plant disease is by influencing plant defense mechanisms (Jiang *et al.*, 2022; Noman *et al.*, 2023). Certain types of NPs have demonstrated the ability to stimulate the generation of reactive oxygen species (ROS) within plants, hence initiating defensive mechanisms and mitigating the severity of diseases (Yan *et al.*, 2022). Furthermore, it has been observed that NPs have the ability to induce the synthesis of plant hormones, including salicylic acid and jasmonic acid, which are known to be crucial for plant defense mechanisms against pathogens (El-chetehy *et al.*, 2021; Luo *et al.*, 2023). Numerous prior research have shown evidence of the potential efficacy of biogenic nanoparticles (NPs) in the management of plant diseases (Nandini *et al.*, 2023; Omran *et al*., 2022).

For example, the utilization of biogenic copper nanoparticles (NPs) has exhibited promising results in the mitigation of bacterial fruit blotch in watermelon. This is attributed to their inherent antibacterial properties, which directly combat the bacterial pathogens responsible for the disease. Watermelon has the potential to elicit active immunity (Noman *et al.*, 2023b). In a similar vein, the addition of Cu nanoscale additions at a concentration of 250 mg L^{-1} had a strong suppressive effect on soybean sudden death syndrome. This suppression was achieved through the activation of plant immunity mechanisms and the enhancement of phytohormone content, photosynthetic endpoints, antioxidant enzymes, and nutritional status (Ma *et al.*, 2020). Biogenic nanoparticles have the ability to interact with soil and rhizosphere microorganisms, so exerting indirect control over plant disease, in addition to their direct impacts on plant growth and defense mechanisms (Abd Alamer *et al.*, 2021; Pnichikkal *et al.*, 2019). In addition, the application of chitosan-iron nanocomposites (BNCs) has exhibited encouraging outcomes in the management of bacterial leaf blight disease in rice due to its inhibitory effects on *Xanthomonas oryzae pv. oryzae.* The growth and enhancement of plant resistance can be achieved by manipulating antioxidant enzymes, defense-related genes, and the plant's microbiome (Ahmed *et al.*, 2022). Furthermore, it has been observed that nanoparticles (NPs) possess antibacterial characteristics, which can effectively impede the proliferation of harmful microorganisms within the soil environment. This, in turn, contributes to a decrease in the likelihood of illness occurrence (Hussain *et al.*, 2023). In a recent study conducted by Noman *et al.* (2023a), it was demonstrated that biogenic manganese nanoparticles (MnNPs) produced by *Bacillus megaterium* NOM14 exhibit the capacity to effectively mitigate watermelon *Fusarium* wilt. This suppression is achieved through a combination of mechanisms, including the inhibition of pathogen growth, augmentation of the host defense response, and modulation of the soil microbial community. In general, the utilization of biogenic nanoparticles presents a potentially effective strategy for the indirect management of plant diseases through the augmentation of plant development and defensive mechanisms. However, additional research is required in order to comprehensively comprehend the safety and environmental implications of these technologies, as well as to enhance their efficacy in the field of agriculture.

CONCLUSIONS

Microorganism-derived nanoparticles (NPs) can mitigate drawbacks of conventional chemical-based pesticides by selectively targeting specific diseases, reducing pesticide usage and environmental damage. However, there are challenges in optimizing synthesis, ensuring stability and bioavailability, and transporting NPs to specific areas. Addressing ecological and safety concerns is crucial. Pioneering efforts are needed to optimize biological synthesis methods, promote environmentally sustainable practices, facilitate efficient upscaling processes, and enhance cost-effectiveness. Integrating NPs with precision agriculture and gene editing can help farmers maximize pesticide efficacy. Establishing a comprehensive regulatory framework and conducting field experiments to assess the effectiveness of nanoparticle impacts in real agricultural settings is essential. Further research is needed to fully unlock the potential of microbe-mediated nanoparticles and contribute to sustainable agricultural systems.

REFERENCES

Abd Alamer, I. S., Tomah, A.A., Ahmed, T., Li, B. and Zhang, J. (2021). Biosynthesis of silver chloride nanoparticles by rhizospheric bacteria and their antibacterial activity against phytopathogenic bacterium *Ralstonia solanacearum. Molecules, 27*(1), 224.

Aboelfetoh, E.F., El-Shenody, R. A. and Ghobara, M. M. (2017). Eco-friendly synthesis of silver nanoparticles using green algae (*Caulerpa serrulata*): reaction optimization, catalytic and antibacterial activities. *Environ Monit Assess., 189*, 1–15.

Adisa, I. O., Pullagurala, V. L. R., Peralta-Videa, J. R., Dimkpa, C. O., Elmer, W. H., Gardea-Torresdey, J. L. and White, J. C. (2019). Recent advances in Nano enabled fertilizers and pesticides: a critical review of mechanisms of action. *Environ Sci Nano., 6*(7), 2002–2030.

Agarwal, H., Menon, S., Kumar, S.V. and Rajeshkumar, S. (2018). Mechanistic study on antibacterial action of zinc oxide nanoparticles synthesized using green route. *Chem Biol Interact., 286*, 60–70.

Ahmed, T., Noman, M., Jiang, H., Shahid, M., Ma, C., Wu, Z., Nazir, M. M., Ali, M. A., White, J. C. and Chen, J. (2022). Bioengineered chitosan-iron nanocomposite controls bacterial leaf blight disease by modulating plant defense response and nutritional status of rice (*Oryza sativa* L.). *Nano Today, 45*, 101547.

Ahmed, T., Noman, M., Luo, J., Muhammad, S., Shahid, M., Ali, M. A., Zhang, M. and Li, B. (2021). Bioengineered chitosan-magnesium nanocomposite: a novel agricultural antimicrobial agent against *Acidovorax oryzae* and *Rhizoctonia solani* for sustainable rice production. *Int J Biol Macromol., 1*, 3.

Ahmed, T., Noman, M., Ijaz, M. and Manzoor, N. (2022). Microbe-mediated nanoparticle intervention for the management of plant diseases. *Crop Health, 168*, 834 - 845.

Ahmed, T., Shahid, M., Noman, M., Niazi, M.B.K., Zubair, M., Almatroudi, A., Khurshid, M., Tariq, F., Mumtaz, R. and Li, B. (2020). Bioprospecting a native silver-resistant *Bacillus safensis* strain for green synthesis and subsequent antibacterial and anticancer activities of silver nanoparticles. *J Adv Res., 24*, 475–83.

Ahmed, T., Wu, Z., Jiang, H., Luo, J., Noman, M., Shahid, M., Manzoor, I., Alle- mailem, K. S., Alrumaihi, F. and Li, B. (2021) Bioinspired green synthesis of zinc oxide nanoparticles from a native *Bacillus cereus* strain RNT6: characterization and antibacterial activity against rice panicle blight pathogens *Burkholderia glumae* and *B. gladioli*. *Nanomaterials, 11*(4), 884.

Ahsan, T. (2020). Biofabrication of silver nanoparticles from Pseudomonas fluorescens to control tobacco mosaic virus. *Egypt J Biol Pest Control, 30*(1), 66.

Al-Khattaf, F. S. (2021). Gold and silver nanoparticles: green synthesis, microbes, mechanism, factors, plant disease management and environmental risks. *Saudi J Biol Sci., 28*(6), 3624–3631.

Alfryyan, N., Kordy, M. G., Abdel-Gabbar, M., Soliman, H. A. and Shaban, M. (2022). Characterization of the biosynthesized intracellular and extracellular plasmonic silver nanoparticles using Bacillus cereus and their catalytic reduction of methylene blue. *Sci Rep., 12*(1), 12495.

Ali, M., Ahmed, T., Wu, W., Hossain, A., Hafeez, R., Islam, Masum M., Wang, Y., An, Q. and Sun G, Li B. (2020). Advancements in plant and microbe-based synthesis of metallic nanoparticles and their antimicrobial activity against plant pathogens. *Nanomaterials, 10*(6), 1146.

Apte, M., Sambre, D., Gaikawad, S., Joshi, S., Bankar, A., Kumar, A.R. and Zinjarde, S. (2013). Psychrotrophic yeast *Yarrowia lipolytica* NCYC 789 mediates the synthe- sis of antimicrobial silver nanoparticles via cell-associated melanin. *AMB Express, 3*(1), 32.

Bindraban, P.S., Dimkpa, C.O., Angle, S. and Rabbinge, R. (2018). Unlocking the multiple public good services from balanced fertilizers. *Food Secur., 10*(2), 273–285.

Chakraborty, S., Singh, A. and Roychoudhury, A. (2022). Biogenic nanoparticles and generation of abiotic stress-resilient plants: a new approach for sustain- able agriculture. *Plant Stress, 6*, 100117.

Chan, S. S., Low, S. S., Chew, K. W., Ling, T. C., Rinklebe, J. and Juan, J. C. (2022). Ng EP, Show PL. Prospects and environmental sustainability of phyconanotechnology: a review on algae-mediated metal nanoparticles synthesis and mechanism. *Environ Res., 212*, 113140.

Chen, J., Wu, L., Lu, M., Lu, S., Li, Z. and Ding, W. (2020). Comparative study on the fungicidal activity of metallic MgO nanoparticles and macroscale MgO against soilborne fungal phytopathogens. *Front Microbiol., 11*, 365.

Chhipa, H. (2017). Nanofertilizers and nanopesticides for agriculture. *Environ Chem Lett., 15*(1), 15–22.

da Silva, Ferreira, V., Conz Ferreira, M. E., Lima, L.M.T., Frasés, S., de Souza, W. and Sant,' Anna, C. (2017). Green production of microalgae-based silver chloride nanoparticles with antimicrobial activity against pathogenic bacteria. *Enzyme Microb Technol., 97*, 114–21.

Devi, P. V., Duraimurugan, P. and Chandrika, K. (2019). *Bacillus thuringiensis*-based nanopesticides for crop protection. In: Nanobiopesticides today and future perspectives. Cambridge: Academic Press, 249–260.

El-Shetehy, M., Moradi, A., Maceroni, M., Reinhardt, D., Petri-Fink, A., Rothen-Rutishauser, B., Mauch, F. and Schwab, F. (2021). Silica nanoparticles enhance disease resistance in Arabidopsis plants. *Nat Nanotechnol., 16*(3), 344–53.

Elmer, W. and White, J. C. (2018). The future of nanotechnology in plant pathology. *Annu Rev Phytopathol., 56*, 111–33.

Handy, R. D. and Shaw, B. J. (2007). Toxic effects of nanoparticles and nanomaterials: implications for public health, risk assessment and the public perception of nanotechnology. *Health Risk Soc., 9*(2), 125–144.

Hossain, A., Hong, X., Ibrahim, E., Li, B., Sun, G., Meng, Y., Wang, Y. and An Q. (2019). Green synthesis of silver nanoparticles with culture supernatant of a bacterium *Pseudomonas rhodesiae* and their antibacterial activity against soft rot pathogen *Dickeya dadantii. Molecules., 24*(12), 2303.

Hu, C., Li, M., Cui, Y., Li, D., Chen, J. and Yang, L. (2010). Toxicological effects of TiO_2 and ZnO nanoparticles in soil on earthworm *Eisenia foetida*. *Soil Biol Bio-chem., 42*(4), 586–591.

Hulkoti, N.I. and Taranath, T. (2014). Biosynthesis of nanoparticles using microbes—a review. *Colloids Surf B Biointerfaces., 121*, 474–483.

Hussain, M., Shakoor, N., Adeel, M., Ahmad, M. A., Zhou, H., Zhang, Z., Xu, M., Rui, Y. and White, J. C. (2023). Nano enabled plant microbiome engineering for disease resistance. *Nano Today, 48*, 101752.

Husseiny, M., Abd El-Aziz, M., Badr, Y. and Mahmoud M. (2007). Biosynthesis of gold nanoparticles using *Pseudomonas aeruginosa*. *Spectrochim Acta A Mol Biomol Spectrosc., 67*(3–4), 1003–6.

Ibrahim, E., Fouad, H., Zhang, M., Zhang, Y., Qiu, W., Yan, C., Li, B., Mo, J. and Chen, J. (2019). Biosynthesis of silver nanoparticles using endophytic bacteria and their role in inhibition of rice pathogenic bacteria and plant growth promotion. *RSC Adv., 9*(50), 29293–29299.

Ibrahim, E., Luo, J., Ahmed, T., Wu, W., Yan, C. and Li, B. (2020). Biosynthesis of silver nano- particles using onion endophytic bacterium and its antifungal activity against rice pathogen *Magnaporthe oryzae*. *J Fungi., 6*(4), 294.

Jiang, L., Xiang, S., Lv, X., Wang, X., Li, F., Liu, W., Liu, C., Ran, M., Huang, J. and Xu, X. (2022). Biosynthesized silver nanoparticles inhibit *Pseudomonas syringae* pv. *tabaci* by directly destroying bacteria and inducing plant resistance in *Nicotiana benthamiana*. *Phytopathol Res., 4*(1), 43.

Kah, M. and Hofmann, T. (2014). Nanopesticide research: current trends and future priorities. *Environ Int., 63*, 224–35.

Karthik, L., Kumar, G., Kirthi, A.V., Rahuman, A., Rao, K. B. (2014). Streptomyces sp. LK3 mediated synthesis of silver nanoparticles and its biomedical application. *Bioprocess Biosyst Eng., 37*(2), 261–267.

Ke, M., Qu, Q., Peijnenburg, W., Li, X., Zhang, M., Zhang, Z., Lu, T., Pan, X. and Qian, H. (2018). Phytotoxic effects of silver nanoparticles and silver ions to *Arabidopsis thaliana* as revealed by analysis of molecular responses and of metabolic pathways. *Sci Total Environ., 644,* 1070–1079.

Khan, R. and Fulekar, M. (2016). Biosynthesis of titanium dioxide nanoparticles using *Bacillus amyloliquefaciens* culture and enhancement of its photocatalytic activity for the degradation of a sulfonated textile dye Reactive Red 31. *J Colloid Interface Sci., 475*, 184–191.

Korani, M., Ghazizadeh, E., Korani, S., Hami, Z. and Mohammadi-Bardbori, A. (2015). Effects of silver nanoparticles on human health. *Eur J Nanomed., 7*(1), 51–62.

Koul, B., Poonia, A. K., Yadav, D. and Jin, J. O. (2021). Microbe-mediated biosynthesis of nanoparticles: applications and future prospects. *Biomolecules., 11* (6), 886.

Kovendan, K., Chandramohan, B., Govindarajan, M., Jebanesan, A., Kamala- kannan, S., Vincent, S. and Benelli G. (2018). Orchids as sources of novel nanoinsecticides? Efficacy of *Bacillus sphaericus* and *Zeuxine gracilis*-fabricated silver nanoparticles against dengue, malaria and filariasis mosquito vectors. *J Cluster Sci., 29*(2), 345–357.

Li, X., Xu, H., Chen, Z. S. and Chen G. (2011). Biosynthesis of nanoparticles by microorganisms and their applications. *J Nanomater,* 1–16.

Luo, X., Wang, Z., Wang, C., Yue, L., Tao, M., Elmer, W. H., White, J. C., Cao, X. and Xing B. (2023). Nanomaterial size and surface modification mediate disease resistance activation in cucumber (*Cucumis sativus*). *ACS Nano., 17*(5), 4871–4885.

Ma, C., Borgatta, J., Hudson, B. G., Tamijani, A. A., La, T. D., Zuverza- Mena, N., Shen, Y., Elmer, W., Xing, B. and Mason, S. E. (2020). Advanced material modulation of nutritional and phytohormone status alleviates damage from soybean sudden death syndrome. *Nat Nanotechnol., 15*(12), 1033–1042.

Mistry, H., Thakor, R., Patil, C., Trivedi, J. and Bariya, H. (2021). Biogenically proficient synthesis and characterization of silver nanoparticles employing marine procured fungi *Aspergillus brunneoviolaceus* along with their antibacterial and antioxidative potency. *Biotech Lett., 43,* 307–316.

Mourato, A., Gadanho, M., Lino, A. R. and Tenreiro, R. (2011). Biosynthesis of crystalline silver and gold nanoparticles by extremophilic yeasts. *Bioinorg Chem Appl.,* 546074.

Nandini, B., Krishna, L., Jogigowda, S.C., Nagaraja, G., Hadimani, S., Ali, D., Sasaki, K. and Jogaiah, S. (2023). Significance of *Bryophyllum pinnatum* (Lam.) for green synthesis of antibacterial copper and selenium nanoparticles and their influence on soil microflora. *Appl Nanosci.,13,* 1–15.

Noman, M., Ahmed, T., Ijaz, U., Hameed, A., Shahid, M., Azizullah, Li, D. and Song F. (2022). Microbe-oriented nanoparticles as phytomedicines for plant health management: An emerging paradigm to achieve global food security. *Crit Rev Food Sci Nutr.,* 1–21.

Noman, M., Ahmed, T., Ijaz, U., Shahid, M., Nazir, M. M., White, J. C., Li, D. and Song F. (2023). Bio-functionalized manganese nanoparticles suppress Fusarium wilt in watermelon (*Citrullus lanatus* L.) by infection disruption, host defense response potentiation, and soil microbial community modulation. *Small., 19*(2), 2205687.

Noman, M., Ahmed, T., White, J. C., Nazir, M. M., Li, D. and Song F. (2023). *Bacillus altitudinis*- stabilized multifarious copper nanoparticles prevent bacterial fruit blotch in watermelon (*Citrullus lanatus* L.): direct pathogen inhibition, in plant particles accumulation, and host stomatal immunity modulation. *Small., 19*(15), 2207136.

Noman, M., Shahid, M., Ahmed, T., Niazi, M. B. K., Hussain, S., Song, F. and Manzoor, I. (2020). Use of biogenic copper nanoparticles synthesized from a native *Escherichia* sp. as photocatalysts for azo dye degradation and treatment of textile effluents. *Environ Pollut., 257*, 113514.

Noman, M., Shahid, M., Ahmed, T., Tahir, M., Naqqash, T., Muhammad, S., Song, F., Abid, H.M.A. and Aslam Z. (2020). Green copper nanoparticles from a native *Klebsiella pneumoniae* strain alleviated oxidative stress impairment of wheat plants by reducing the chromium bioavailability and increasing the growth. *Ecotoxicol Environ Saf., 192*, 110303.

Ogunsona, E. O., Muthuraj, R., Ojogbo, E., Valerio, O. and Mekonnen, T. H. (2020). Engineered nanomaterials for antimicrobial applications: a review. *Appl Mater Today., 18,* 100473.

Ogunyemi, S. O., Zhang, M., Abdallah, Y., Qiu, W., Ahmed, T., Ali, M. A., Yan, C., Yang, Y., Chen, J. and Li, B. (2020). The biosynthesis of three metal oxide nanoparticles (ZnO, MnO_2, and MgO) and their antibacterial activity against the bacterial leaf blight pathogen. *Front Microbiol., 11*, 3099.

Omran, B. A. and Baek, K. H. (2022). Control of phytopathogens using sustainable biogenic nanomaterials: recent perspectives, ecological safety, and challenging gaps. *J Clean Prod., 372*, 133729.

Panichikkal, J., Thomas, R., John, J. C. and Radhakrishnan, E. (2019). Biogenic gold nanoparticle supplementation to plant beneficial Pseudomonas monteilii was found to enhance its plant probiotic effect. *Curr Microbiol., 76*, 503–509.

Ponmurugan, P., Manjukarunambika, K, Elango, V. and Gnanamangai, B.M. (2016). Antifungal activity of biosynthesized copper nanoparticles evaluated against red root-rot disease in tea plants. *J Exp Nanosci., 11*(13), 1019–1031.

Qamar, S. U. R. and Ahmad, J. N. (2021). Nanoparticles: Mechanism of biosynthesis using plant extracts, bacteria, fungi, and their applications. *J Mol Liq., 334*, 116040.

Qu, Y., Li, X., Lian, S., Dai, C., Jv, Z., Zhao, B. and Zhou, H. (2019). Biosynthesis of gold nanoparticles using fungus Trichoderma sp. WL-Go and their catalysis in degradation of aromatic pollutants. IET *Nanobiotechnol., 13*(1), 12–17.

Radzimska, A. K. and Jesionowski, T. (2014). Zinc oxide-from synthesis to application: a review. *Materials., 7*(4), 2833–2881.

Rai, M., Bonde, S., Golinska, P., Trzcińska-Wencel, J., Gade, A., Abd-Elsalam, K. A., Shende, S., Gaikwad, S. and Ingle, A. P. (2021). Fusarium as a novel fungus for the synthesis of nanoparticles: mechanism and applications. *J Fungi., 7*(2), 139.

Raj, N., Swamy, M., Purushotham, B. and Sukrutha, S. (2021). Applications of microbe-based nanoparticles in agriculture: present state and future challenges. *Microb Nanobiotechnol Princ Appl.,* 343–382.

Rajesh, S. and Sivapriya, D. (2020). Fungus-mediated nanoparticles: characterization and biomedical advances. *Nanoparticles Med.*, 185–199.

Reddy, K. V., Sree, N. R. S., Kumar, P. S. and Ranjit, P. (2022). Microbial enzymes in the biosynthesis of metal nanoparticles. In: Ecological interplays in microbial enzymology. Singapore: *Springer Nature.,* 329–350.

Salas-Herrera,G.,González-Morales, S., Benavides-Mendoza,A.,Castañeda-Facio, A. O., Fernández-Luqueño, F. and Robledo-Olivo, A. (2019). Impact of microalgae culture conditions over the capacity of copper nanoparticle biosynthesis. *J Appl Phycol., 31*(4), 2437–2447.

Seppelt, R., Klotz, S., Peiter, E. and Volk, M. (2022). Agriculture and food security under a changing climate: an underestimated challenge. *Iscience., 25,* 105551.

Singh, R., Wagh, P., Wadhwani, S., Gaidhani, S., Kumbhar, A., Bellare, J. and Chopade, B. A. (2013). Synthesis, optimization, and characterization of silver nanoparticles from Acinetobacter calcoaceticus and their enhanced antibacterial activity when combined with antibiotics. *Int J Nanomed., 8,* 4277.

Xu, L., Zhu, Z. and Sun, D. W. (2021). Bioinspired nanomodification strategies: moving from chemical-Based agrosystems to sustainable agriculture. *ACS Nano., 15*(8), 12655–86.

Yan, X., Chen, S., Pan, Z., Zhao, W., Rui, Y. and Zhao, L. (2022). AgNPs-triggered seed metabolic and transcriptional reprogramming enhanced rice salt tolerance and blast resistance. *ACS Nano., 17,* 492–504.

Yang, Y., Waterhouse, G. I. and Chen, Y. (2022). Sun-Waterhouse D, Li D. Microbial-enabled green biosynthesis of nanomaterials: current status and future prospects. *Biotechnol Adv., 55*, 107914.

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