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Importance of Green Synthesis Silver Nanoparticles in Forestry and Their Effect on *Pterocarpus santalinus*

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Pterocarpus santalinus L., commonly known as Red Sanders, is an economically and ecologically important forest tree species of southern India. Its regeneration is often limited by poor and irregular seed germination, making the development of effective seed-treatment techniques important for nursery production and conservation. Silver nanoparticles (AgNPs) have gained attention in forestry because of their unique physicochemical and antimicrobial properties and their potential application in seed priming. Green synthesis of AgNPs using plant extracts offers an eco-friendly approach for producing nanoparticles and has been successfully investigated using *P. santalinus* leaf extract. Recent studies have also evaluated AgNPs as presowing treatments for Red Sanders seeds, examining their effects on germination and early seedling growth. Parameters such as germination percentage, mean germination time, root length, shoot length, seedling dry weight and seedling vigour can be used to assess their effectiveness. Although existing studies indicate that nanoparticle treatments can influence seed quality, the response depends on nanoparticle concentration and treatment duration. Therefore, further research is required to determine suitable AgNP concentrations and priming conditions for *P. santalinus*. Such studies may contribute to improved nursery production, successful regeneration and conservation of this valuable forest tree species.

Introduction

Pterocarpus santalinus L.,commonly known as Red Sanders or Red Sandalwood, is an economically and ecologically important tree species of southern India. It is highly valued for its reddish heartwood and has faced considerable pressure from exploitation. Natural and artificial regeneration can be difficult because seed germination is generally low and is affected by factors such as the hard seed coat and seed dormancy. Therefore, improving seed germination and production of healthy seedlings is important for nursery management, plantation establishment and conservation of the species. Nanotechnology has gained importance in modern forestry because nanoparticles can be investigated for applications in seed treatment, plant growth, disease management and sustainable nursery production. Among different nanoparticles, silver nanoparticles (AgNPs) are of particular interest because of their antimicrobial properties and their potential role in seed treatment.

Green Synthesis of Silver Nanoparticles

An important concept for research on silver nanoparticles is green synthesis. Conventional nanoparticle production may involve chemical reducing or stabilizing agents, whereas green synthesis uses biological materials such as plant extracts. *Pterocarpus santalinus* leaves contain several phytochemical groups, including phenolic compounds, flavonoids, tannins and other constituents that can participate in nanoparticle formation. A published study reported spherical AgNPs produced using P. santalinus leaf extract and demonstrated their

antibacterial activity. Another study reported AgNPs produced from *P. santalinus* leaf broth with particle sizes of approximately 5–15 nm and spherical morphology, along with antibacterial and antioxidant activity. This makes *P. santalinus* particularly interesting for a plant-based nanoparticle research system, because the plant can be both the source of phytochemicals used for nanoparticle synthesis and the target species for investigating nanoparticle-mediated seed responses.(Vaishnavi*et al*.,2020)

Importance of silver nanoparticles in forestry

Silver nanoparticles may have several potential applications in forestry. Their antimicrobial properties make them useful for investigating the reduction of microbial contamination associated with seeds and plant materials. Green-synthesized AgNPs are particularly attractive because plant extracts can act as natural reducing and stabilizing agents, providing an alternative to some conventional chemical synthesis approaches. For *P. santalinus*, this approach is especially relevant because AgNPs have already been successfully synthesized using its leaf extract. Researchers reported that phytochemicals present in the leaf extract helped in the formation of spherical silver nanoparticles, which demonstrated antibacterial activity against Gram-positive and Gram-negative bacteria. (Gopinath*et al*., 2013)

Effect of silver nanoparticles on *Pterocarpus santalinus* seeds

A 2024 study directly investigated green-synthesized AgNPs and ZnNPs as presowing treatments for Red Sanders seeds. The experiment used a completely randomized design with three replications and included AgNP treatment at 1000 ppm for 24 hours. Germination and seedling-quality parameters were evaluated. The study showed that nanoparticle-based seed treatment is a promising area for improving the quality of *P. santalinus* planting material. However, it is important to note that AgNPs were not the best treatment in that particular experiment. ZnNPs at 2000 ppm for 24 hours produced the highest germination (56%), root length, shoot length, dry weight and Seedling Vigour Index-I. The untreated control had only about 31% germination. (Jaibheem*et al*.,2024). A subsequent 2025 study further examined green-synthesized AgNPs and ZnNPs prepared using guava leaf extract and tested different concentrations and treatment durations in Red Sanders seeds. AgNPs were characterized using UV–Vis spectroscopy, particle-size analysis and SEM, while seed priming treatments included concentrations from 500 to 2000 ppm and 12- or 24-hour durations. Again, ZnNP treatment at 2000 ppm for 24 hours gave the strongest seed-quality response in that study.(Jaibheem*et al*.,2025).

Effect on Improving Seed Quality

AgNP treatment can be investigated in relation to several important seed-quality parameters:

- Germination percentage – indicates the proportion of seeds that successfully germinate.
- Mean germination time – indicates how quickly the seed lot germinates.
- Speed of germination – helps assess uniformity and rapidity of emergence.
- Root length – indicates early root development.
- Shoot length – reflects early shoot development.
- Seedling dry weight – provides an estimate of biomass accumulation.
- Seedling Vigour Index – combines germination and seedling growth to assess overall seedling quality.

These parameters are particularly useful in forestry because rapid and uniform establishment can improve nursery production and facilitate the production of quality seedlings.

Importance for nursery and forest regeneration

Improving seed germination and early seedling growth has direct importance for forestry. Healthy and vigorous seedlings have better potential for successful establishment after planting. Therefore, research on AgNP seed treatment could contribute to developing improved nursery practices *for P. santalinus*. Parameters such as germination percentage, mean germination time, speed of germination, root length, shoot length, seedling dry weight

and seedling vigour index can be used to evaluate treatment effects. At the same time, AgNP applications need careful evaluation because the response of plants can vary with nanoparticle characteristics, concentration and exposure conditions. Consequently, identifying an appropriate treatment rather than assuming that a higher concentration will always produce better growth is important.

Green synthesis and sustainability

Green synthesis of AgNPs using plant extracts has an additional importance for sustainable forestry research. *P. santalinus* leaf extract has been demonstrated as a biological source for synthesizing AgNPs, with reported nanoparticles showing antibacterial activity. Another study reported AgNPs synthesized from *P. santalinus* leaf broth with particle sizes of approximately 5–15 nm and demonstrated antibacterial and antioxidant activities. Thus, research involving AgNPs and *P. santalinus* connects nanotechnology, seed science, nursery management and forest conservation. It may provide useful information for improving propagation techniques while also supporting further investigation into environmentally responsible nanoparticle applications.

Conclusion

Silver nanoparticles have considerable research importance in forestry, particularly in relation to seed treatment, microbial management and production of quality planting material. In *Pterocarpus santalinus*, direct studies have shown that AgNPs can be evaluated as a presowing treatment, while green synthesis using plant extracts provides an environmentally oriented approach. Current evidence does not establish AgNPs as the best treatment for Red Sanders seeds, but it demonstrates that nanoparticle seed priming is a promising research area. Further studies using different AgNP concentrations and treatment conditions are needed to determine their effects on germination, seedling growth and vigour. Such research could contribute to improved nursery production and long-term conservation of this valuable forest tree species.

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