Abstract

The thesis begins by providing a comprehensive introduction that focuses on the background, difficulties in-depth, and stated research objectives in the first chapter, followed by a thorough review of the literature in the second chapter. The third chapter outlined the methodological approaches used to attain the aims, as well as a quick summary of the overall research plan. Chapters 4 and 5 describe the green synthesis of monometallic, bimetallic, and quadrimetallic nanoparticles (MNP, BNP, and QMNP) using plant leaf extracts, as well as the optimization of reaction yield and comprehensive characterization. The fifth chapter discussed the effects of engineered MNP, BNP, and QMNP on the microbe-plant-soil interface. Finally, the sixth chapter summarizes the research's significant findings, as well as potential future scope and extension.

Assam's diverse plant population is a benefit for researching green synthesis approaches for nanoparticle production. The region's extensive flora, which includes a variety of habitats and species, contains bioactive chemicals such as phenolics, flavonoids, and terpenoids, which help in redox reactions as well as stabilizers in nanoparticle formation. This environmentally benign approach uses plant extracts to decrease metal ions, resulting in nanoparticles with exact properties. Assam's distinct plant species have a diverse range of phytochemicals, making them excellent for sustainable nanoparticle production. Traditional medicinal plants, such as Neem, Tulsi, and Aloe vera, are ideal for green synthesis due to their quantity of bioactive chemicals. Leveraging Assam's plant biodiversity has enormous promise for a variety of applications, including agriculture, healthcare, and environmental remediation. Integrating indigenous knowledge of plant-based remedies improves the sustainability and cultural relevance of nanoparticle synthesis methods. Quantitative and qualitative phytochemical investigations shed light on plant extracts' antioxidant capabilities and bioactive components, making them more suitable for use in green synthesis methods. Green leaves of *Peltophorum inerme* Roxb., *Polygonum microcephalum* Wall. ex D. Don., *Chrysalidocarpus lutescens* H. Wendl., *Crinum asiaticum* L., and *Aquilaria malaccensis* Lam. were collected in Tezpur, Assam, presenting an intriguing opportunity for novel nanoparticle synthesis. With a focus on sustainable farming methods and plant micronutrients, four transition metals were chosen to generate zinc-based monometallic, bimetallic, and quadrimetallic nanoparticles. This work meticulously synthesized zinc monometallic nanoparticles of exceptional purity and uniformity by exploiting the leaves' strong antioxidant properties as well as improved synthesis settings. A

close examination of the green leaves revealed important information regarding their nutritional makeup, with *Polygonum microcephalum* having a high moisture content but comparatively low fixed carbon and ash content. This work sheds insight into the leaves' potential applications in a wide range of sectors. Further examination indicated that the leaves contained a wide range of phytochemicals, including reducing sugars, flavonoids, alkaloids, tannin, terpenoids, quinones, and saponins, all of which are known to influence metal ion speciation. Tannins, for example, serve a key function in reducing metal ions and capping them in their zerovalent state, allowing for successful nanoparticle nucleation. Spectrophotometric analysis demonstrated that the leaf extracts had remarkable antioxidant capabilities, particularly reducing activity, total antioxidant capacity, and total phenolic content. This was confirmed by a change in DPPH colour from purple to yellow, indicating antioxidant activity. These findings emphasize the potential of plant-mediated green synthesis as a sustainable and efficient method for nanoparticle generation, taking advantage of the intrinsic properties of plant extracts to produce superior quality of nanomaterials with an extensive range of uses. *Polygonum microcephalum* had the maximum moisture content (89.1%), followed by *Crinum asiaticum*, however, it had lower fixed carbon and ash levels (33.54% and 1.895%, respectively). This study provides critical information about the nutritional composition of the leaves, as well as possible uses in a variety of sectors. *Chrysalidocarpus lutescens* H. Wendl has significant DPPH radical scavenging action, with a lower IC_{50} indicating a higher antioxidant potential. This assay assesses antioxidants' ability to lower the odd electron of DPPH, providing information on their scavenging capacity. The total antioxidant capacity and total phenolic content (TPC) of leaf extracts are assessed to determine their health benefits and prospective applications in various industries. Higher TPC values indicate higher phenolic component concentrations, which are related to increased antioxidant activity and health benefits. The reducing power assay indicates plant extracts' ability to donate electrons and scavenge free radicals, which is very useful in green synthesis processes compared to chemical reduction. Using bioactive chemicals for metal ion reduction in green synthesis is cost-effective, scalable, and sustainable. Synthesis success is determined by pH, temperature, and precursor concentrations, all of which influence nanoparticle size, shape, and bioactivity.

The process of optimizing synthesis parameters to regulate the size, composition, shape, and surface characteristics of nanoparticles and obtain the intended traits and performance is known as optimization. The characterization procedures are crucial in determining the characteristics and accuracy of manufactured nanoparticles. X-ray diffraction (XRD), dynamic light scattering

(DLS), transmission electron microscopy (TEM), Field Emission Scanning Electron Microscopy (FE-SEM), and Fourier-Transform Infrared Spectroscopy (FTIR) are common techniques used to characterize nanoparticles. These methods provide useful data on nanoparticle size distribution, shape, crystallinity, chemical composition, and surface chemistry. Optimization and characterization are intricately intertwined since synthesis circumstances and methodologies influence nanoparticle properties. Researchers can optimize the synthesis process to produce nanoparticles with desired qualities by systematically varying precursor content, reaction temperature, pH, and reaction duration. Researchers can then employ characterization techniques to assess the optimization outcomes and get insight into nanoparticle structure-property relationships. The DLS analyses particle size distribution using the autocorrelation function of scattered light. FTIR spectroscopy was used to analyze the functional groups of nanoparticles synthesized from *C. lutescens* leaf extract. The crystal structure is determined via X-ray diffraction (XRD) investigation using a BRUKER AXS D8 FOC instrument. SEM with Low Vacuum mode investigated nanoparticle surface shape, while EDS offered elemental composition studies. TEM examination was performed on a TECNAI G2 20 S-TWIN (200KV). BET surface area analysis determined specific surface area, while TGA-50 (Shimadzu) measured residual metal concentration in plant extract samples. For agricultural applications, one ideal configuration was chosen from each parameter group of Monometallic Nanoparticles (MNP), Bimetallic Nanoparticles (BNP), and Quadrimetallic Nanoparticles (QMNP) out of 30 possible combinations. MNP with 3% Aqueous Leaf Extract (ALE) at pH 9, BNP with 2% ALE (pH 9), and QMNP with 4% ALE (pH 9) were selected. Surface Plasmon Resonance (SPR) peaks were sharper and narrower at lower ALE concentrations and pH values, with larger peaks at higher concentrations for MNP and BNP, but QMNP showed sharper peaks at ALE concentrations and pH values. UV-visible absorption spectroscopy confirmed colloidal nanoparticle production, with the highest yields reported at specified ALE concentrations and pH values for each nanoparticle type. These selected configurations were further characterized in terms of yield (%) and SPR peak sharpness. The Polydispersity Index (PDI) of biosynthesized Monometallic Nanoparticles (MNP) was 0.312, showing monodispersed, but Bimetallic Nanoparticles (BNP) exhibited a PDI of 0.554, indicating monodispersed and increasing its potential for biological applications. However, quadrimetallic nanoparticles (QMNP) had a PDI of 1.14, indicating polydispersity. The zeta potentials for MNP, BNP, and QMNP were -11.3 mV, -17.4 mV, and -16 mV, respectively, showing stability. Field-Emission Scanning Electron Microscopy (FE-SEM) found MNP and BNP with nanocrystals ranging from 30 to 85 nm, exhibiting hexagonal Wurtzite and Zinc blende structures typical of zinc-based nanoparticles. The FTIR spectra revealed the distinctive vibrations of biomolecules found in the leaf extract used for synthesis. The TGA profiles demonstrated that the nanoparticles were thermally stable up to temperatures above 400°C, making them ideal for high-temperature applications.

Nanoparticles (NPs) are currently being used in agriculture, generating concerns about how they interact with the plant-microbe-soil interface and how they may affect ecosystem health. At the plant-microbe-soil interface, NPs can influence a variety of biological and chemical processes that are critical to ecosystem function. To begin, NPs may interact with plants after being absorbed through their roots or foliage. Once inside the plant, nanoparticles can go to many tissues, influencing plant growth, development, and physiology. They can affect nutrient intake, photosynthesis, and water relations, changing plant productivity and stress responses. Furthermore, nanoparticles can alter gene expression and signaling pathways, potentially having long-term implications on plant health and resilience. Second, NPs can interact with soil bacteria, which are critical for nutrient cycling, organic matter decomposition, and soil structure building. NPs can influence microbial abundance, diversity, and activity, affecting ecosystem services such as nutrient availability and soil fertility. Furthermore, NPs can alter microbial community makeup and dynamics, affecting symbiotic connections, disease suppression, and biogeochemical cycling processes. Third, nanoparticles can interact directly with soil components, influencing their physical, chemical, and biological properties. They may modify soil structure, porosity, and water retention, hence influencing soil aeration, drainage, and erosion. Furthermore, NPs can adsorb soil particles, altering nutrient sorption-desorption dynamics and contaminant mobility. These interactions can have a ripple impact on soil microbial communities, plant growth, and ecosystem function. The Bacterial Compatibility assay used the Agar Well Diffusion Assay (AWDA), in which test substances were introduced to wells produced in Muller-Hinton agar plates, and zones of inhibition surrounding the wells were evaluated to assess antimicrobial activity. Using AWDA, the antibacterial activity of MNPs, BNPs, and QMNPs produced from the extracted leaves of *C. lutescens* against *Rhizobium Sp*. and *Salmonella Sp*. was evaluated. Bacterial isolates were put onto agar plates for SEM analysis, nanoparticles were added, and following incubation, coverslips were removed, cleaned, and fixed to preserve morphology. Chickpea seeds were evaluated with different nanoparticle concentrations and hydroponic growth for 120 days. Germination experiments and plant growth characteristics were analyzed, revealing an EC_{50} of 500 ppm for MNP and BNP and 45 mg L^{-1} for QMNP-mediated root length suppression. Total chlorophyll

content, mineral absorption, and enzyme activity were all examined, with different responses to nanoparticle treatments. Soil characteristics and nutrient retention were evaluated, revealing impacts on soil organic carbon, nitrogen, phosphorus, and potassium. Photosynthesis and stomatal conductance were measured, and oxidative stress enzyme activities were investigated, with nanoparticle treatments having varying effects. Finally, bacterial colony-forming units were measured, revealing effects on both bacterial and fungal populations. Overall, the study found intricate interactions between nanoparticles, plants, microorganisms, and soil, which have implications for agricultural practices and ecosystem health. Because of their distinct properties and eco-friendliness, alternative green nano fertilizers play a significant part in promoting root and shoot development. Traditional fertilizers frequently contain synthetic chemicals and nutrients that can have a negative impact on soil health, water quality, and ecological balance. In contrast, green nano fertilizers use nanotechnology to supply nutrients to plants in a more focused and efficient manner, reducing waste and environmental effect. One significant advantage of green nano fertilizers is their capacity to increase nutrient uptake by plant roots. These fertilizers protect nutrients from leaching, volatilization, and runoff by encapsulating them within nanoparticles, resulting in more consistent and effective delivery to the roots. This tailored fertilizer delivery encourages robust root growth and development, allowing plants to form stronger root systems that have better access to water and nutrients in the soil. Furthermore, green nano fertilizers can promote shoot growth by improving nutrient delivery from the roots to the shoots. Nanoparticles can penetrate plant cell walls more easily than conventional fertilizers, resulting in better nutrient absorption and assimilation inside plant tissues. This better nutrient utilization promotes healthy shoot growth, which results in increased biomass output, higher crop yields, and overall plant vigor. Green nano fertilizers can improve soil fertility and the growth of bacteria, which aids root and shoot development in addition to their nutrient delivery function. Nanoparticles can interact with soil particles and organic matter, thereby enhancing soil structure, water retention, and nutrient availability. Furthermore, certain nano fertilizers may boost beneficial microbial communities in the soil, which are essential for nutrient cycling, pathogen suppression, and plant growth promotion.

Keywords: *Bioprospecting, Green Synthesis, Nanotechnology, Hydroponics, Plant-Microbe-Soil*