1. A Concise Description of the Project

The release of synthetic dyes and other organic contaminants from textile, pharmaceutical, agricultural, and related industries continues to threaten aquatic ecosystems and public health. Many existing wastewater treatment methods are either energy-intensive, chemically demanding, or inefficient in completely degrading persistent pollutants. Nanomaterial-based catalysis has emerged as a promising alternative due to its high surface activity and enhanced reactivity. Among these materials, silver nanoparticles (AgNPs) are particularly attractive because of their strong catalytic performance and antimicrobial properties. However, achieving stable, uniform, and reproducible AgNPs through environmentally friendly methods remains a significant challenge.

Green synthesis routes using plant-derived bioactive compounds offer a sustainable alternative to conventional chemical reduction techniques, which often rely on toxic reagents and harsh reaction conditions. Plant extracts such as japonicus and radix contain naturally occurring phytochemicals that can reduce silver ions while simultaneously stabilizing the resulting nanoparticles. Despite these advantages, green synthesis frequently suffers from poor control over particle size, aggregation, and batch-to-batch variability. These limitations largely arise from reliance on traditional one-variable-at-a-time (OVAT/OFAT) optimization strategies that fail to account for interactions among synthesis parameters.

This project proposes a comprehensive statistical modeling framework using full factorial experimental design combined with Taguchi methods to systematically evaluate the influence of critical variables, including extract concentration, silver precursor concentration, pH, temperature, and reaction time. By examining both individual and interaction effects, the study will establish predictive models that define optimal synthesis conditions. Statistical validation will include analysis of variance (ANOVA), regression modeling, response surface and contour analysis, and residual diagnostics to ensure model accuracy and robustness. The optimized nanoparticles will be characterized using advanced physicochemical techniques to assess morphology, crystallinity, particle size distribution, and colloidal stability, including microscopic imaging and zeta potential analysis. Their catalytic efficiency will be evaluated for the degradation of azo dyes as representative organic pollutants, and antimicrobial activity will also be examined to explore dual environmental applications.

Overall, this research integrates green chemistry principles with rigorous statistical design to enhance reproducibility, efficiency, and scalability in AgNP synthesis. The outcomes will contribute to the development of cost-effective, sustainable nanocatalysts for wastewater remediation and broader environmental nanotechnology applications.

Research Gap: (a) The practical application of AgNPs is often limited by particle aggregation, which reduces stability, uniformity, and catalytic performance. Despite progress in green synthesis, effective strategies to prevent agglomeration and to achieve reproducible, stable nanoparticles remain lacking. **(b)** Conventional optimization methods, such as OVAT/OFAT, do not capture interactions among multiple synthesis parameters, leading to suboptimal conditions, low reproducibility, and inefficient use of materials and time. **(c)** Although statistical tools like Taguchi design and full factorial modeling can enhance process optimization, their use in plant-mediated AgNPs synthesis remains limited. Most studies focus solely on single-response metrics, such as absorbance, without considering critical factors like particle size distribution, crystallinity, and zeta potential, which are essential for controlling nanoparticle quality, stability, and environmental applicability.

This project aims to address these gaps through systematic, multivariate optimization and thorough nanoparticle characterization.

2. Measurable Impacts and Objectives

Long-term Impact: This project seeks to advance AgNP synthesis by improving particle stability, applying robust statistical optimization, and integrating predictive modeling to enhance reproducibility and functionality. **Key Issues:** *(a)* Preventing AgNP aggregation to ensure long-term stability and consistent performance. *(b)* Overcoming limitations of OVAT methods in controlling multi-factor synthesis parameters. *(c)* Utilizing advanced statistical designs for systematic process optimization. Likely Outcomes: *(a)* Stable, uniform AgNP formulations with minimized agglomeration. *(b)* A reproducible and efficient framework for nanoparticle synthesis. *(c)* Improved control over particle size, morphology, and physicochemical properties. *(d)* Expanded applications in textiles, sensors, and antimicrobial materials. *(e)* Generation of high-quality scientific publications and potential intellectual property. Objectives: *(a)* Develop strategies to enhance AgNP stability and prevent aggregation. *(b)* Replace OVAT/OFAT with multifactorial optimization approaches. *(c)* Apply Taguchi and full factorial statistical modeling for synthesis. *(d)* Optimize key synthesis parameters affecting yield and nanoparticle quality. *(e)* Evaluate AgNP performance in functional materials applications.

3. Timeframe and Major Tasks for the Project

Week 01–12: Comprehensive literature review and knowledge advancement. Week 01–04: Investigate AgNP stabilization and strategies to prevent aggregation. Week 01–06: Identify limitations of OVAT and explore alternative optimization methods. Week 03–08: Apply Taguchi design of experiments (DoE) for systematic process optimization. Week 05–10: Perform statistical modeling and validate optimized synthesis conditions. Week 05–10: Conduct physicochemical characterization of synthesized AgNPs. Week 07–10: Evaluate applications of optimized AgNPs in dye degradation and antibacterial assays. Week 09–12: Prepare progress reports, manuscripts, and conference proceedings. A detailed description of all research tasks is provided in the *Supplementary Information*.

4. Enhancing Teaching and Research at Lincoln University

This project will offer undergraduates hands-on experience in green chemistry, nanomaterial synthesis, and environmental remediation. Research outcomes will be incorporated into chemistry and materials science courses, enhancing laboratory skills and environmental awareness while supporting future collaborations and grant proposals in sustainable technologies. *(a)* Research examples will be integrated into General and Advanced Chemistry courses to reinforce concepts in catalytic kinetics, synthesis, and structural analysis. *(b)* Undergraduates will participate in independent research, contributing to manuscripts and external grant proposals. *(c)* The project will act as a springboard for larger initiatives, expanding student opportunities in summer research programs at institutions such as UPenn and UDel under faculty mentorship. *(d)* Findings will be disseminated through seminars, workshops, and presentations, fostering interdisciplinary discussions in nanotechnology and materials science.

5. Measuring Project Success

Project success will be evaluated by: *(a)* Quality and reproducibility of data supporting external grant submissions. *(b)* Student engagement in research, resulting in presentations and co-authored publications. *(c)* Impact measured through presentations at Lincoln's Science Fair, annual meetings, and poster sessions.

6. Dissemination of Project Outcomes

(a) Where and When: Results will be presented at Lincoln University Science Fair, Faculty Development Grant seminars, and national/ international conferences. (b) With Whom: Findings will be shared with students, faculty, and the broader scientific community. (c) Publication Plan: Outcomes will be submitted to peer-reviewed journals, with student co-authors highlighting their contributions. (d) Institutional Reports: A project summary will be submitted to relevant university offices to document progress and outcomes.

[**Optional Attachment:** *Supplementary Information*]