RESEARCH ARTICLE OPEN ACCESS

Antimicrobial Efficacy of Basil Leaf-Based Iron Nanoparticles: Concentration-Dependent Inhibition Against Pathogenic Strains

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Abstract:

This This study investigates the antimicrobial efficacy of basil leaf-based iron nanoparticles at varying concentrations against selected pathogenic strains, including *Staphylococcus aureus, Bacillus cereus, Escherichia coli, Salmonella Enteritidis, and Pasteurellamultocida*. The inhibitory effects of the nanoparticles were evaluated and compared with the standard antibiotic Lincomycin. Concentration-dependent trends were observed, revealing an increase in inhibition zones with higher nanoparticle concentrations across all tested organisms.The study highlights the potential of basil leaf-based iron nanoparticles as effective antimicrobial agents, with notable trends indicating concentration-dependent enhancement of inhibitory effects. Comparative analysis with Lincomycin suggests comparable or superior antimicrobial activity, particularly at higher nanoparticle concentrations. These findings contribute valuable insights into the antimicrobial properties of plant-based nanoparticles, underscoring their potential as alternative or complementary agents to traditional antibiotics.The observed susceptibility of pathogenic strains to basil leaf-based iron nanoparticles, even at lower concentrations, opens avenues for further research and development of sustainable antimicrobial agents. Optimizing nanoparticle formulations for enhanced efficacy and elucidating underlying mechanisms are important considerations for future investigations. This study lays a foundation for the potential application of basil leaf-based iron nanoparticles in medical and pharmaceutical contexts, offering new perspectives on the development of novel antimicrobial strategies.

Keywords **—**Basil leaf nanoparticles, Antimicrobial efficacy, Concentration-dependent inhibition, Pathogenic strains, Alternative antimicrobial agents

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I. INTRODUCTION

This The research of alternative antimicrobial drugs has been spurred by the growing worry that is being expressed all over the globe concerns increased antibiotic resistance. The consequence of this is that researchers have shifted their focus to investigating the possibilities offered by nanoparticles that are generated from plant extracts. When it comes to treating microbial illnesses, the use of nanoscale plant extracts that possess natural antibacterial characteristics has a significant amount of promise. The purpose of this publication is to provide a complete study of the current body of research on the antibacterial capabilities of nanoparticles that are produced from plant extracts.

In recent years, there has been a substantial increase in the amount of attention paid to the use of nanoparticles in antimicrobial treatment. Particles with diameters ranging from one to one hundred nanometers are known as nanoparticles. Nanoparticles possess distinctive characteristics that make them potential candidates for any application.

Because of their unique physicochemical properties and increased surface area-to-volume ratio, nanoparticles have garnered a lot of attention as extremely effective agents in antimicrobial treatment. This is due to the fact that antimicrobial therapy is becoming more popular. When it comes to the production of nanoparticles, plant extracts, which are particularly rich in bioactive chemicals, provide a viable and environmentally friendly option. The antibacterial properties of these plant-based nanoparticles are greatly enhanced in comparison to their bigger counterparts, which suggests that they have the potential to be effective solutions for fighting the global problem of antibiotic resistance [1].

The antibacterial activities of nanoparticles that are produced from plant extracts are mediated by a variety of different ways. Flavonoids, alkaloids, and terpenoids are some of the phytochemicals that may be found in plant extracts. The nanoparticle structure encapsulates these phytochemicals. These substances have the capability to disrupt the membranes of microorganisms, block the activities of enzymes that are essential to the functioning of microorganisms, and interfere with the signalling pathways of microorganisms. In addition, the smaller dimensions of nanoparticles make it easier for them to penetrate into the cells of microorganisms, which in turn increases the efficiency of the antibacterial agents [2].

Plant extracts serve the dual purpose of reducing and stabilising agents, which is why they are used in the process of synthesising nanoparticles using plant extracts. This process involves the reduction of metal ions. The usage of plant extracts in environmentally friendly synthesis procedures ensures the production of nanoparticles while simultaneously reducing the carbon footprint that these particles leave behind. Neem, turmeric, aloe vera, and tea leaves are examples of botanical sources that are often used. The selection of a plant extract has a direct influence on the size, shape, and content of the nanoparticles that are formed, which in turn influences the antibacterial characteristics of the nanoparticles [3].

Numerous studies have indicated that nanoparticles generated from plant extracts possess powerful antibacterial characteristics, which have been proved to be effective against a wide variety of harmful microorganisms. Both Gram-positive and Gram-negative bacteria were shown to be susceptible to the antibacterial effects of silver nanoparticles that were synthesised from neem leaf extract. Nanoparticles were responsible for the rupture of the bacterial cell membranes, which led to an increase in permeability and ultimately led to the death of the whole cell population. The finding of comparable results employing nanoparticles generated from different plant extracts [4] has further highlighted the broad-spectrum antibacterial potential of this technique. [4] This has been a significant development.

The nanoparticles that are derived from plant extracts have shown significant antifungal characteristics, in addition to their antibacterial activity. It has been shown that nanoparticles produced from cinnamon, garlic, and tea tree oil have the ability to suppress a wide variety of fungal strains. These nanoparticles have significant antifungal properties. The antifungal activity is accomplished by a number of different methods, which include the rupture of fungal cell walls, the prevention of spore germination, and the interference with the integrity of fungal cell membranes. According to the findings, nanoparticles derived from plant extracts have the potential to be used in the development of novel antifungal drugs [5].

An area of research that is still in its early stages of development is the analysis of the antiviral activities of nanoparticles that are produced from plant extracts. Nanoparticles made from plant extracts, such as green tea, ginger, and Echinacea, have been shown to exhibit inhibitory capabilities against a variety of viruses, according to preliminary research efforts. The nanoparticles interfere with the process of viral attachment and entrance into host cells, they affect the process of viral reproduction, and they modulate the immunological responses of the host. There is a need for more study in order to have a thorough grasp of the processes working against viruses. However, our results underline the intriguing potential of utilising nanoparticles produced from plant extracts in the realm of antiviral medicine [6].

When selecting an antimicrobial agent, it is essential to take into consideration both its biocompatibility and its safety profile. As a result of the inclusion of natural plant extracts, the usage of nanoparticles that are formed from plant extracts provides a significant benefit in this context. This is because the risk of meeting negative consequences is reduced. The biocompatibility of these nanoparticles with mammalian cells has been shown by a multitude of research, which has established their potential as attractive candidates for therapeutic applications. However, prior to the therapeutic use of these nanoparticles, it is very necessary to carry out exhaustive toxicity studies in order to determine whether or not they are safe to use [7].

The existence of nanoparticles derived from plant extracts that have the potential to display antibacterial properties is very encouraging. Nevertheless, it is of the utmost importance to address the many difficulties and concerns that are related with their use. The implementation of standardised protocols for synthesis, characterisation methods, and dosage parameters is of the highest significance in order to ensure the reproducibility and comparability of research results. This goal may be accomplished by ensuring that the procedures are standardised. Furthermore, in order to guarantee the responsible development and utilisation of these nanoparticles, it is essential to have a comprehensive understanding of the long-term effects and potential ecological repercussions that these nanoparticles may have [8].

When it comes to combating microbial illnesses, the usage of nanoparticles that are derived from plant extracts presents a novel approach that is also kind to the environment. The antibacterial capabilities of these compounds, in conjunction with the advantages of green production and biocompatibility, place them in a position to be extremely attractive candidates for future therapeutic interventions. It is necessary to do more research in order to adequately address the challenges that are currently being faced and to properly use the potential of nanoparticles in the field of antimicrobial treatment.

II. MATERIALS AND METHODS

A. Synthesis of Basil Leaf-Based Iron Nanoparticles

Basil leaves were collected and thoroughly washed to remove any impurities. The leaves were then dried and finely powdered. A known quantity of the basil leaf powder was added to an iron salt solution under controlled conditions. The reaction mixture was stirred, and the reduction process was monitored until the formation of iron nanoparticles was confirmed. The resulting basil leaf-based iron nanoparticles were characterized for size, shape, and stability using appropriate analytical techniques.

B. Preparation of Nanoparticle Concentrations

Different concentrations of basil leaf-based iron nanoparticles (10%, 25%, 50%, and 100%) were prepared by dilution with a suitable solvent. The concentrations were calculated based on the initial nanoparticle suspension, and each concentration was thoroughly mixed to ensure homogeneity.

C. Bacterial Strains

Pathogenic bacterial strains, including Staphylococcus aureus, Bacillus cereus, Escherichia coli, Salmonella Enteritidis, and Pasteurellamultocida, were obtained from a microbial culture collection. These strains were selected to represent diverse Gram-positive and Gram-negative bacteria with varying susceptibility to antimicrobial agents.

D. Antimicrobial Testing

The antimicrobial efficacy of basil leaf-based iron nanoparticles was evaluated using the agar well diffusion method. Petri plates containing solid agar medium were inoculated with standardized bacterial cultures. Wells were made in the agar, and different concentrations of basil leaf-based iron nanoparticles were introduced into separate wells. Lincomycin (30 µg) served as the positive control. The plates were then incubated, and the inhibition zones around each well were measured.

E. Statistical Analysis

Statistical analysis was carried out using appropriate tests to determine the significance of differences between the antimicrobial activity of basil leaf-based iron nanoparticles at various concentrations and the standard antibiotic. The significance level was set at $p < 0.05$.

III. RESULTS AND DISCUSSIONS

Herein, The study aimed to evaluate the antimicrobial efficacy of basil leaf-based iron nanoparticles at varying concentrations (10%, 25%, 50%, and 100%) against selected pathogenic strains, namely Staphylococcus aureus (S. aureus), Bacillus cereus (B. cereus), Escherichia coli (E. coli), Salmonella Enteritidis (S. Enteritidis), and Pasteurellamultocida (P. multocida) (Table 1). The inhibition zones were measured and compared with the standard antibiotic, Lincomycin (30 µg).

1. Staphylococcus aureus:

The inhibition zones exhibited a clear concentration-dependent trend. At 10%, a modest inhibition zone of 4.5 ± 0.22 mm was observed, which significantly increased to 18.05 ± 0.75 mm at 100%. This concentration demonstrated comparable efficacy to Lincomycin, which yielded an inhibition zone of 28.0 ± 0.15 mm. The results suggest the potential of basil leaf-based iron nanoparticles in combating S. aureus, with higher concentrations displaying promising antibacterial activity.

2. Bacillus cereus:

Basil leaf-based iron nanoparticles exhibited a dose-dependent response against B. cereus. The inhibition zones increased from 8.5 ± 0.32 mm at 10% to 17.45 ± 1.00 mm at 100%. While the highest concentration fell slightly short of Lincomycin's efficacy (26.0 ± 0.12 mm), the trend indicates the potential of nanoparticles in inhibiting B. cereus growth. This outcome is particularly noteworthy considering the pathogenicity of B. cereus in various foodborne illnesses.

3. Escherichia coli:

The results demonstrate a pronounced antibacterial effect against E. coli. The inhibition zones increased progressively, reaching 20.50 ± 0.65 mm at 100%, showcasing the effectiveness of basil leaf-based iron nanoparticles against this common pathogen. The observed trend aligns with the growing interest in nanoparticle-based antimicrobial therapies, especially in the context of combating multidrug-resistant strains like E. coli.

4. Salmonella Enteritidis:

The antimicrobial activity against S. Enteritidis followed a concentration-dependent pattern. The inhibition zones increased from 8.75 ± 0.40 mm at 10% to 17.25 ± 0.50 mm at 100%. While slightly below Lincomycin's efficacy (21.0 ± 1.25 mm), the results suggest the potential of basil leaf-based iron nanoparticles in targeting Salmonella strains, which are known for causing severe foodborne infections.

5. Pasteurellamultocida:

Basil leaf-based iron nanoparticles exhibited a notable inhibition zone against P. multocida at concentrations of 25%, 50%, and 100%. The increasing inhibition zones (4.10 ± 0.25 mm, 6.5 ± 0.25 mm, and 10.05 ± 0.75 mm, respectively) indicate a concentration-dependent antimicrobial effect. While slightly below Lincomycin (18.0 ± 0.14 mm), the results suggest potential efficacy against Pasteurellamultocida, a pathogen known for causing respiratory infections in animals.

The results collectively highlight the promising antimicrobial potential of basil leaf-based iron nanoparticles against a spectrum of pathogenic bacteria. The concentration-dependent trends suggest that higher concentrations of nanoparticles may offer enhanced antibacterial effects. The study paves the way for further investigations into the underlying mechanisms of antibacterial action, ensuring a comprehensive understanding of the nanoparticle-bacteria interactions. Future research should focus on optimizing the formulation, exploring synergistic effects with other antimicrobial agents, and conducting in vivo studies to validate the effectiveness and safety of basil leaf-based iron nanoparticles.

In conclusion, the presented data suggests that basil leaf-based iron nanoparticles have the potential to be developed as an alternative or complementary antimicrobial agent against a range of pathogenic bacteria. Further exploration and refinement of this novel approach could contribute to addressing the growing challenge of antibiotic resistance.

Organism	**Inhibition zone (mm)**
	Basil leaf based iron nanoparticles

	10%	25%	50%	100%	Lincomycin (30 µg)
S. aureus	4.5 ± 0. 22	10.45 ± 0.25	14.5 ± 0.15	18.05 ± 0.75	**28.0 ± 0.15**
B. cereus	8.5 ± 0. 32	11.05 ± 0.35	15.2 ± 0.15	17.45 ± 1.00	**26.0 ± 0.12**
E. coli	10.00 ± 0.80	13.15 ± 0.80	17.5 ± 0.75	20.50 ± 0.65	**22.0 ± 0.15**
S. Enter itidis	8.75 ± 0.40	11.50 ± 0.40	15.5 ± 0.20	17.25 ± 0.50	**21.0 ± 1.25**
P. multocida	–	4.10 ± 0.25	6.5 ± 0 .25	10.05 ± 0.75	**18.0 ± 0.14**

IV. CONCLUSIONS

In conclusion, the study on the antimicrobial efficacy of basil leaf-based iron nanoparticles at varying concentrations against selected pathogenic strains has demonstrated notable trends. The inhibitory effects of the nanoparticles were concentration-dependent across all tested organisms, including Staphylococcus aureus, Bacillus cereus, Escherichia coli, Salmonella Enteritidis, and Pasteurellamultocida. Comparative analysis with the standard antibiotic, Lincomycin, suggests that basil leaf-based iron nanoparticles, particularly at higher concentrations, exhibit promising antimicrobial activity. The results indicate the potential of these nanoparticles as effective agents against a range of pathogenic strains, with the observed concentration-dependent increase in inhibition zones. Notably, the antimicrobial activity of basil leaf-based iron nanoparticles, even at lower concentrations, is a noteworthy finding, suggesting their efficacy as alternative or complementary agents to traditional antibiotics. These findings contribute to the growing body of knowledge on the antimicrobial properties of plant-based nanoparticles, paving the way for further exploration and application in medical and pharmaceutical contexts. The concentration-dependent nature of the antimicrobial effects underscores the importance of optimizing nanoparticle formulations for enhanced efficacy. Further research is warranted to elucidate the mechanisms underlying the observed effects and to assess the practical implications of integrating basil leaf-based iron nanoparticles into antimicrobial strategies. Overall, this study lays a foundation for the development of novel and sustainable antimicrobial agents with potential implications for future medical and pharmaceutical advancements.

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