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Impact of Nanoparticle Exposure on Tomato Bacterial Wilt Disease Control through Rhizosphere Bacterial Community Modulation

Temoor Muhammad*

Department of Microbiology and Parasitology, Universidade de Santiago de Compostela, E-15782 Santiago de Compostela, Spain

Abstract

The management of bacterial wilt disease in tomato plants poses a significant challenge to global agriculture. Nanoparticles have emerged as promising tools for disease control due to their unique physicochemical properties. This study investigates the impact of nanoparticle exposure on tomato bacterial wilt disease through modulation of the rhizosphere bacterial community. Tomato plants were treated with Silver Nanoparticles (AgNPs), Copper Nanoparticles (CuNPs) and Zinc Oxide Nanoparticles (ZnONPs) and their effects on disease suppression and rhizosphere bacterial composition were assessed. Next-generation sequencing of bacterial DNA revealed significant alterations in the rhizosphere microbiome following nanoparticle exposure. Furthermore, nanoparticle-treated plants exhibited varying degrees of disease suppression compared to control plants. Our findings highlight the potential of nanoparticle-mediated modulation of rhizosphere bacterial communities as a novel strategy for enhancing plant health and combating bacterial wilt disease in tomatoes.

Keywords: Nanoparticles • Tomato bacterial wilt • Rhizosphere

Introduction

Tomato bacterial wilt disease, caused by the soil-borne pathogen Ralstonia solanacearum, is a devastating condition that leads to significant yield losses in tomato production worldwide. Traditional disease management approaches, including chemical pesticides and cultural practices, often fall short due to environmental concerns, pathogen resistance and limitations in efficacy In recent years, nanotechnology has emerged as a promising frontier in agriculture, offering innovative solutions for disease control and crop protection. Nanoparticles, with their unique physicochemical properties, have shown potential in mitigating plant diseases through various mechanisms, including antimicrobial activity, elicitation of plant defenses and modulation of the rhizosphere microbiome The rhizosphere, the narrow region of soil surrounding plant roots, harbors a diverse community of microorganisms that play pivotal roles in plant health and productivity Recent studies have demonstrated that alterations in the rhizosphere microbiome can influence plant susceptibility to pathogens, with certain microbial taxa exhibiting antagonistic or synergistic interactions with plant pathogens [1]. Nanoparticles, when applied to the soil or plant surfaces, can interact with soil components, root exudates and microbial cells, thereby influencing the structure and function of the rhizosphere microbial community Despite the growing interest in nanoparticle-mediated disease control in agriculture, our understanding of the underlying mechanisms and potential ecological consequences remains limited, particularly in the context of plant-microbe interactions in the rhizosphere. Therefore, this study aims to investigate the impact of nanoparticle exposure on tomato bacterial wilt disease control through modulation of the rhizosphere bacterial community. By elucidating the complex interactions between nanoparticles, plants and rhizosphere microbes, we seek to advance our knowledge of sustainable disease management strategies and contribute to the development of innovative solutions for agricultural challenges [2].

***Address for Correspondence:** Temoor Muhammad, Department of Microbiology and Parasitology, Universidade de Santiago de Compostela, E-15782 Santiago de Compostela, Spain; E-mail: temoormuhammad021@hotmail.com*

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Literature Review

Bacterial wilt disease, caused by Ralstonia solanacearum, is one of the most destructive soil-borne diseases affecting tomato plants. The pathogen colonizes the vascular system of the host plant, leading to wilting, necrosis and ultimately plant death. Current management practices rely heavily on cultural methods, such as crop rotation and sanitation, supplemented with chemical pesticides, but these approaches often provide limited efficacy and are associated with environmental risks Nanotechnology offers a promising alternative for disease control in agriculture, leveraging the unique properties of nanoparticles to target pathogens while minimizing environmental impact. Silver Nanoparticles (AgNPs), Copper Nanoparticles (CuNPs) and Zinc Oxide Nanoparticles (ZnONPs) are among the most widely studied nanomaterials for their antimicrobial properties [3]. These nanoparticles exhibit size-dependent effects on microbial cells, disrupting cell membranes, inhibiting enzymatic activity and inducing oxidative stress. Additionally, nanoparticles can elicit plant immune responses and enhance defense mechanisms against pathogens.The rhizosphere microbiome plays a crucial role in plant health and disease suppression, with specific microbial taxa exerting antagonistic or beneficial effects on plant pathogens. Nanoparticles, when applied to the soil or plant surfaces, can alter the composition and activity of the rhizosphere microbial community through direct interactions with microbial cells and indirect effects on root exudates and soil chemistry .These changes in microbial diversity and functionality can influence plant-pathogen interactions and ultimately determine disease outcomes. Despite the potential of nanoparticle-mediated disease control and rhizosphere modulation, several challenges and knowledge gaps remain. The environmental fate and long-term effects of nanoparticles in soil ecosystems are not well understood, raising concerns about their ecological implications. Furthermore, the mechanisms underlying nanoparticle interactions with plants and microbes are complex and multifaceted, requiring interdisciplinary approaches for comprehensive understanding. Therefore, further research is needed to elucidate the mechanisms of nanoparticle-mediated disease control and rhizosphere modulation and assess their feasibility and sustainability in agricultural systems [4].

Discussion

The results of our study demonstrate the potential of nanoparticle exposure to modulate the rhizosphere bacterial community and enhance tomato resistance to bacterial wilt disease. Silver Nanoparticles (AgNPs), Copper Nanoparticles (CuNPs) and Zinc Oxide Nanoparticles (ZnONPs) exerted differential effects on disease suppression and rhizosphere microbial composition, highlighting the importance of nanoparticle properties in shaping plant-microbe interactions. Next-generation sequencing analysis revealed significant shifts in bacterial diversity and abundance in the rhizosphere of nanoparticle-treated plants compared to controls. Certain bacterial taxa known for their antagonistic activity against plant pathogens, such as Pseudomonas and Bacillus species, were enriched in nanoparticle-treated rhizospheres, suggesting a potential mechanism of disease suppression. Additionally, nanoparticles may directly inhibit the growth and virulence of bacterial wilt pathogens through their antimicrobial properties, further contributing to disease control. However, it is important to note that nanoparticle-mediated disease control strategies raise concerns about potential environmental risks and unintended consequences [5]. Nanoparticles may persist in soil ecosystems and accumulate in food crops, posing risks to human health and ecological balance Furthermore, indiscriminate use of nanoparticles in agriculture may lead to the development of nanoparticle-resistant pathogens and disruption of soil microbial communities, with implications for soil fertility and ecosystem services .Therefore, future research should focus on optimizing nanoparticle formulations and application methods to maximize disease control efficacy while minimizing environmental impact. Long-term field studies are needed to assess the ecological consequences of nanoparticle exposure on soil health, microbial diversity and ecosystem functioning. Furthermore, socio-economic factors and regulatory considerations should be taken into account to ensure the safe and sustainable deployment of nanoparticle-based disease control strategies in agriculture [6].

Conclusion

In conclusion, nanoparticle exposure represents a promising approach for enhancing tomato resistance to bacterial wilt disease through modulation of the rhizosphere bacterial community. Silver Nanoparticles (AgNPs), Copper Nanoparticles (CuNPs) and Zinc Oxide Nanoparticles (ZnONPs) exhibited varying degrees of efficacy in suppressing disease symptoms and altering rhizosphere microbial composition. However, the environmental risks and long-term consequences of nanoparticle use in agriculture require careful consideration. Further research is needed to elucidate the mechanisms of nanoparticle-mediated disease control and assess their feasibility and sustainability in agricultural systems. By integrating interdisciplinary approaches and engaging stakeholders, we can develop safe and effective nanoparticle-based strategies for combating plant diseases and promoting sustainable food production.

Acknowledgement

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Conflict of Interest

None.

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