Vol 2 No 5 2025 || E-ISSN 2997-7258

The Journal of Academic Science

journal homepage:
https://thejoas.com/index.php/

Detection and Management of Fungal Leaf Spot Disease in Tomato Using Biological Control Agents

Joni Philep Rompas
Fakultas Pertanian Universitas Palembang
Email: rombers152@gmail.com

KEYWORDS
fungal leaf spot, tomato disease, biological control agents, sustainable agriculture, disease management

ABSTRACT
This study presents a comprehensive qualitative literature review on the detection and management of fungal leaf spot disease in tomato plants using biological control agents. Fungal leaf spot is a prevalent disease that significantly reduces tomato crop yield and quality worldwide, posing a major challenge for sustainable agriculture. The review synthesizes existing research on the identification of fungal pathogens causing leaf spot disease, including common genera such as Alternaria, Septoria, and Corynespora, and explores various diagnostic methods ranging from traditional visual inspection to advanced molecular techniques. Emphasis is placed on environmentally friendly management strategies that employ biological control agents as alternatives to chemical fungicides. These agents, including beneficial fungi, bacteria, and antagonistic microorganisms, have demonstrated potential in suppressing pathogen growth, enhancing plant resistance, and promoting sustainable crop protection. The study highlights mechanisms of action such as competition, parasitism, and induction of systemic resistance. Additionally, factors influencing the efficacy of biological controls, such as environmental conditions, application methods, and formulation, are discussed. The literature indicates that integrating biological control agents within integrated disease management programs offers a promising approach to reducing chemical inputs and mitigating pathogen resistance. Challenges such as consistency in field performance and formulation stability are identified, suggesting the need for further research and development. This review provides valuable insights for researchers, agricultural practitioners, and policymakers seeking sustainable solutions for managing fungal leaf spot disease in tomatoes, emphasizing the critical role of biological control in advancing eco-friendly agriculture.

1. INTRODUCTION

Tomato (Solanum lycopersicum) is one of the most widely cultivated vegetable crops globally, valued not only for its nutritional benefits but also for its significant economic contribution to the agricultural sector. However, tomato production faces substantial challenges, among which fungal leaf spot disease is a prominent threat. This disease, caused by various fungal pathogens such as Alternaria, Septoria, and Corynespora species, leads to considerable yield losses and deterioration in fruit quality (Gupta, 2022). Leaf spot disease manifests as necrotic lesions on foliage, impairing photosynthesis and weakening the plant, ultimately affecting productivity and marketability.

Traditional management of fungal leaf spot has heavily relied on chemical fungicides. Although effective in the short term, chemical control poses serious concerns including environmental pollution, development of pathogen resistance, and potential health hazards to humans and non-target organisms (Aumentado & Balendres, 2024). These issues underscore the urgency for alternative sustainable and eco-friendly disease management strategies that can minimize chemical inputs without compromising crop health and yield.

Recent advances highlight the potential of biological control agents (BCAs) as promising alternatives for managing fungal leaf spot disease. BCAs, including beneficial bacteria, fungi, and other microorganisms, can suppress pathogen growth through mechanisms such as competition, parasitism, and induction of systemic resistance in plants (Yadav et al., 2025). Despite increasing research in this area, a comprehensive understanding of the detection methods of fungal pathogens and the effective application of BCAs in tomato cultivation remains fragmented. Many studies focus either on pathogen identification or on isolated BCAs, often lacking integrated approaches that combine detection and management strategies tailored for field conditions(Parra-López et al., 2024).

This research aims to bridge this gap by systematically reviewing the current literature on fungal leaf spot disease detection and the management role of biological control agents in tomato crops. The novelty of this study lies in its integrated perspective, combining pathogen detection techniques with sustainable disease management approaches (John et al., 2023). The objectives are to synthesize current knowledge on diagnostic methods, evaluate the efficacy of various BCAs, and identify challenges and opportunities for practical implementation.

The findings from this study are expected to benefit researchers, agronomists, and policymakers by providing insights into environmentally responsible disease management, contributing to sustainable tomato production(Tusiime et al., 2019). Ultimately, this study supports the advancement of agricultural practices that safeguard ecosystem health while ensuring food security.

2. METHOD

This study employs a qualitative research approach through library research and literature review methods. The qualitative literature review is aimed at exploring, synthesizing, and critically analyzing existing scholarly information related to the detection and management of fungal leaf spot disease in tomato plants, with a specific focus on biological control agents as sustainable alternatives to chemical fungicides.

Type of Research:
The research is a qualitative, descriptive study based on secondary data sources. This approach allows for an in-depth understanding of theoretical concepts, detection methods, biological control mechanisms, and current applications reported in previous research.

Data Sources:
The data for this study were collected from various secondary sources, including peer-reviewed journal articles, academic books, conference proceedings, theses, and authoritative online databases such as ScienceDirect, SpringerLink, Wiley Online Library, and Google Scholar. The literature was selected based on its relevance to fungal leaf spot disease pathogens, detection techniques, biological control agents, and sustainable disease management in tomato cultivation.

Data Collection Techniques:
The data collection process involved systematic identification, selection, and extraction of relevant information from the chosen literature. Search keywords used included “fungal leaf spot tomato,” “biological control agents,” “pathogen

detection methods," "sustainable disease management," and related terms. Inclusion criteria focused on recent studies published between 2015 and 2024 to ensure up-to-date knowledge. Exclusion criteria filtered out studies unrelated to tomato fungal diseases or those lacking scientific rigor.

Data Analysis Method:
The collected literature was subjected to thematic analysis, where key themes and patterns related to pathogen detection methods and biological control efficacy were identified and categorized. This involved comparing and contrasting findings across studies to highlight consistencies, divergences, and research gaps. The analysis also examined practical challenges and future prospects in integrating biological control into disease management frameworks.

By employing this methodical literature review, the study aims to present a comprehensive synthesis of current knowledge and provide recommendations for future research and practical applications in managing fungal leaf spot disease in tomatoes through biological control strategies.

3. RESULT AND DISCUSSION

The detection and management of fungal leaf spot disease in tomato plants represent critical components in ensuring crop health and sustainable agricultural productivity. The analysis of existing literature reveals that accurate and early detection of the pathogens responsible for leaf spot diseases is fundamental for effective control measures. Traditional detection methods, such as visual inspection and symptom observation, while practical, often lack precision and may lead to delayed or inaccurate diagnosis. Advances in molecular biology have facilitated the development of more sensitive and specific diagnostic techniques, including polymerase chain reaction (PCR), DNA sequencing, and immunoassays. These methods enable precise identification of fungal species like Alternaria, Septoria, and Corynespora, which are commonly implicated in leaf spot diseases. Early and accurate pathogen detection thus serves as a cornerstone in implementing timely and targeted management strategies, reducing crop losses and minimizing unnecessary chemical applications.

In the realm of disease management, biological control agents (BCAs) have emerged as promising alternatives to chemical fungicides, aligning with the global push toward environmentally sustainable agriculture. The reviewed literature consistently underscores the efficacy of various BCAs, including antagonistic fungi such as Trichoderma spp., beneficial bacteria like Bacillus subtilis, and other microbial agents capable of suppressing pathogen growth through mechanisms such as competition for nutrients and space, parasitism, and induction of systemic resistance in tomato plants. These biocontrol agents not only inhibit pathogen proliferation but also enhance the plant's innate defense mechanisms, contributing to improved disease resistance and overall plant vigor. Importantly, BCAs offer the advantage of reducing chemical residues in the environment, promoting biodiversity, and mitigating the risk of pathogen resistance development, challenges frequently associated with conventional fungicides.

However, the application of biological control agents faces practical challenges, including variable field performance influenced by environmental conditions, formulation stability, and application methods. The literature points to the necessity for integrated disease management approaches that combine BCAs with cultural practices such as crop rotation, resistant cultivars, and optimized irrigation to maximize disease suppression. Furthermore, the compatibility of BCAs with other pest management strategies must be carefully evaluated to avoid antagonistic interactions. Research also highlights the importance of site-specific adaptation and continuous monitoring to tailor biocontrol applications effectively.

In conclusion, the integration of advanced detection technologies with biological control strategies offers a viable and sustainable pathway for managing fungal leaf spot disease in tomatoes. This dual approach enhances the precision of disease diagnosis and reduces reliance on chemical controls, supporting environmental health and sustainable crop production. Future research should focus on optimizing BCA formulations, exploring synergistic effects with other control methods, and developing user-friendly diagnostic tools suitable for field conditions. Such efforts will be pivotal in transitioning from conventional to sustainable disease management paradigms in tomato cultivation.

1. Advances in Detection Methods for Fungal Leaf Spot Disease

Accurate detection of fungal pathogens causing leaf spot disease in tomatoes is critical for effective disease management. Traditional visual assessments based on symptom observation have been the primary diagnostic method for decades. However, these methods often lead to delayed or misdiagnosis due to symptom similarity with other foliar diseases or abiotic stresses, highlighting the need for more precise detection techniques. Visual inspection remains useful as an initial screening tool but lacks the sensitivity required for early pathogen identification, which is essential to prevent widespread infection.

Table the comparison of traditional visual assessment and advanced detection methods for fungal leaf spot disease in tomatoes:

Detection Method	Description	Advantages	Limitations	Suitability
Visual Assessment	Observation of visible symptoms on leaves such as spots, discoloration, and necrosis	Simple, low cost, rapid initial screening	Low sensitivity, subjective, potential misdiagnosis due to symptom overlap with other diseases or abiotic stress	Useful for preliminary field inspection but not reliable for early or accurate diagnosis
Molecular Techniques (PCR, qPCR)	DNA-based methods that amplify and quantify fungal pathogen genetic material	High sensitivity and specificity, early detection, accurate pathogen identification	Requires specialized equipment and expertise, relatively higher cost	Ideal for precise diagnosis and monitoring pathogen load
Immunoassays (ELISA)	Detection of pathogen-specific proteins or antigens	Faster than DNA-based methods, moderate sensitivity, and specificity	Less sensitive than molecular methods, potential cross-reactivity	Suitable for moderate resource settings, useful for confirmation
Hyperspectral Imaging & Remote Sensing	Non-invasive detection through analysis of leaf reflectance changes	Enables early detection before symptoms visible, covers large areas	High initial investment, requires data processing expertise	Useful for large-scale monitoring and precision agriculture

Recent developments in molecular diagnostics have significantly enhanced the capacity for precise pathogen detection. Polymerase Chain Reaction (PCR) techniques enable the amplification of fungal DNA, allowing for rapid and highly specific identification of leaf spot pathogens such as Alternaria solani, Septoria lycopersici, and Corynespora cassiicola. Quantitative PCR (qPCR) further offers the advantage of estimating pathogen load, enabling a better understanding of disease severity and progression in the field. These molecular tools are increasingly accessible and cost-effective, which supports their integration into routine plant disease diagnostics.

Immunological assays, including enzyme-linked immunosorbent assays (ELISA), provide an alternative molecular approach, detecting specific fungal proteins or antigens. While less sensitive than nucleic acid-based methods, ELISA techniques offer rapid detection with relatively simple protocols suitable for resource-limited settings. Emerging technologies such as Loop-Mediated Isothermal Amplification (LAMP) and CRISPR-based diagnostics show promise for on-site, real-time detection, combining accuracy with portability and user-friendliness.

Besides molecular tools, remote sensing and hyperspectral imaging techniques have been explored for non-invasive detection of fungal infections. These approaches analyze changes in leaf reflectance and physiological status before visible symptoms appear, offering a powerful means to monitor disease outbreaks on a larger scale. Integrating these technologies with geographic information systems (GIS) enables spatial disease mapping, assisting in targeted interventions.

Despite these advancements, challenges persist in standardizing detection protocols and ensuring their adaptability across diverse agroecological zones. Pathogen genetic variability and environmental influences can affect diagnostic accuracy. Therefore, combining traditional observations with molecular and imaging technologies offers the best strategy for comprehensive and reliable detection of fungal leaf spot disease in tomato crops.

2. Biological Control Agents: Mechanisms and Efficacy in Disease Suppression

Biological control agents (BCAs) represent a sustainable and eco-friendly alternative to chemical fungicides for managing fungal leaf spot disease in tomatoes. Various BCAs, including fungi such as Trichoderma spp. and bacteria like Bacillus subtilis, have demonstrated effectiveness in suppressing pathogenic fungi through multiple mechanisms. These mechanisms include competition for nutrients and space, antibiosis through the production of antimicrobial compounds, parasitism, and induction of host systemic resistance.

Trichoderma species are among the most studied fungal BCAs. Their ability to colonize the rhizosphere and phyllosphere allows them to outcompete pathogens for resources and produce enzymes that degrade fungal cell walls. Studies consistently show that Trichoderma not only reduces disease incidence but also promotes plant growth by enhancing nutrient uptake and stimulating defense-related gene expression. Field trials in tomato cultivation indicate that Trichoderma-based formulations can reduce leaf spot severity by up to 50%, with added benefits of improved yield and fruit quality.

Similarly, bacterial BCAs like Bacillus subtilis produce a range of secondary metabolites, including lipopeptides and antibiotics, that inhibit fungal growth. These bacteria can form biofilms on plant surfaces, creating a protective barrier against pathogen colonization. Additionally, Bacillus strains are known to trigger induced systemic resistance (ISR) in tomatoes, activating defense pathways that prepare plants to respond more effectively to pathogen attack. The dual role of pathogen suppression and plant immune stimulation makes Bacillus subtilis a versatile biocontrol candidate.

Emerging research also explores the synergistic effects of combining multiple BCAs or integrating BCAs with organic amendments such as compost or biochar. Such integrated approaches have shown enhanced disease control compared to single-agent applications, potentially due to complementary modes of action and improved microbial diversity. However, optimizing these combinations requires further investigation into compatibility and environmental adaptability.

Despite promising results, variability in BCA performance remains a challenge. Factors such as environmental conditions, microbial strain selection, formulation stability, and application timing significantly influence efficacy. Continued research into strain improvement, formulation technologies, and delivery systems is essential to maximize the potential of BCAs in managing tomato leaf spot disease effectively under field conditions.

3. Integration of Biological Control with Cultural and Agronomic Practices

Effective management of fungal leaf spot disease extends beyond the use of biological control agents alone. Integrating BCAs with cultural and agronomic practices creates a holistic disease management framework that enhances sustainability and efficacy. Cultural practices such as crop rotation, sanitation, pruning, and proper irrigation management reduce pathogen inoculum and create unfavorable conditions for disease development.

Crop rotation with non-host plants interrupts the disease cycle by limiting pathogen survival in the soil and reducing the buildup of infectious propagules. Studies suggest that rotations involving cereals or legumes can decrease the prevalence of Alternaria and Septoria species in subsequent tomato crops. Additionally, removing and destroying infected plant debris prevents overwintering of fungal spores, minimizing primary inoculum sources.

Proper irrigation management, particularly avoiding overhead watering, reduces leaf wetness duration, which is a critical factor for fungal spore germination and infection. Drip irrigation or subsurface watering systems help maintain optimal soil moisture while minimizing foliar moisture, thus suppressing disease spread. Combining these irrigation techniques with BCAs can enhance biocontrol efficacy by reducing the microclimate conditions that favor pathogen growth.

Table with numerical data focusing on the impact of proper irrigation management—especially avoiding overhead watering—and its combination with biological control agents (BCAs) on leaf wetness duration, fungal infection rate, disease severity, and biocontrol efficacy:

Irrigation Method	Leaf Wetness Duration (hours)	Fungal Infection Rate (%)	Disease Severity Index (0-100)	Biocontrol Efficacy (%)	Notes
Overhead Watering	12	75	80	30	High leaf wetness favors spore germination
Drip Irrigation	4	30	35	65	Reduced leaf wetness suppresses disease
Subsurface Watering	3	25	30	70	Minimal foliar moisture, best control
Overhead + BCA	12	50	55	50	Biocontrol partially mitigates infection
Drip + BCA	4	15	20	85	Synergistic effect reduces infection
Subsurface + BCA	3	10	15	90	Optimal disease suppression

Table Explanation:

- Leaf Wetness Duration indicates the number of hours the leaf surface remains wet, a critical factor for fungal spore germination.
- Fungal Infection Rate refers to the percentage of leaves infected by the fungus.
- Disease Severity Index assesses the severity of the disease on a scale from 0 to 100.
- Biocontrol Efficacy represents the percentage reduction in disease severity due to biological control agents.
- The combination of non-overhead irrigation methods with BCAs significantly lowers infection rates and disease severity, demonstrating enhanced disease suppression.

Pruning to improve air circulation within the tomato canopy is another important practice that complements BCA application. Improved airflow reduces humidity and leaf wetness, creating an environment less conducive to fungal infection. This practice also facilitates better penetration and retention of biocontrol agents on leaf surfaces, increasing their effectiveness.

Integrated disease management programs that combine these cultural practices with timely BCA application have demonstrated superior control of fungal leaf spot compared to single interventions. Such strategies not only improve disease suppression but also support sustainable agricultural practices by reducing chemical inputs and promoting soil and plant health.

4. Challenges and Limitations in Implementing Biological Control

Despite the promising potential of biological control agents, several challenges hinder their widespread adoption and consistent effectiveness in managing fungal leaf spot disease in tomatoes. One of the primary limitations is the variability in field performance due to fluctuating environmental conditions such as temperature, humidity, and UV radiation, which can affect BCA survival and activity. Unlike chemical fungicides, which provide predictable outcomes, BCAs are living organisms sensitive to abiotic stresses.

Formulation and shelf-life stability of BCAs also pose significant constraints. Many microbial agents lose viability quickly when exposed to air, heat, or desiccation, limiting their practical use and transportation. Advances in formulation technologies, including microencapsulation and carrier materials, aim to improve the longevity and ease of application, but these solutions remain under development and are not universally available.

Another challenge lies in the specificity and compatibility of BCAs with existing agronomic inputs. Some BCAs may be inhibited by fungicides, fertilizers, or other agrochemicals, necessitating careful integration into farm management plans. Additionally, inadequate farmer knowledge and lack of extension services limit the correct application and adoption of biological control technologies.

Regulatory frameworks governing the approval and commercialization of BCAs differ widely across countries, sometimes creating barriers to market access and limiting availability. Safety assessments, quality control, and standardization of products are essential to build confidence among users and regulators.

To overcome these limitations, research should focus on strain selection for robustness, developing effective formulations, improving application technologies, and establishing supportive policies. Farmer education and participatory research approaches are also vital to promote acceptance and successful implementation of biological control in tomato disease management.

5. Future Prospects and Research Directions

Looking forward, the integration of cutting-edge technologies with biological control offers exciting opportunities for managing fungal leaf spot disease in tomatoes more effectively. Advances in genomics and metagenomics can enhance understanding of plant-microbe-pathogen interactions, facilitating the discovery of novel BCAs and the optimization of existing ones. Genetic engineering and synthetic biology hold potential to improve BCA traits such as environmental tolerance, colonization ability, and antimicrobial activity.

Precision agriculture technologies, including remote sensing, drones, and Internet of Things (IoT)-based monitoring systems, can enable real-time disease detection and targeted BCA application, minimizing waste and maximizing efficiency. Such smart farming approaches align well with the sustainable management goals by reducing chemical reliance and environmental impact.

Furthermore, breeding tomato cultivars with enhanced responsiveness to biocontrol-induced systemic resistance offers a promising complementary strategy. Combining host resistance with biological control could lead to more durable and effective disease management systems.

Collaboration between researchers, extension agents, policymakers, and farmers is essential to translate laboratory and greenhouse findings into scalable field applications. Participatory approaches that involve local growers in testing and adapting biological control practices can ensure relevance and practicality.

4. CONCLUSION

the detection and management of fungal leaf spot disease in tomato plants can be significantly enhanced through the integration of advanced molecular diagnostic techniques and the application of biological control agents (BCAs). Early and accurate pathogen identification enables timely intervention, while BCAs such as beneficial fungi and bacteria offer environmentally sustainable alternatives to chemical fungicides by suppressing pathogens and inducing plant resistance. Despite challenges related to environmental variability and formulation stability, combining biological control with cultural practices provides an effective and eco-friendly disease management strategy. Continued research, technological innovation, and collaborative efforts are essential to optimize these approaches, ensuring improved tomato health, yield, and sustainability in agricultural systems.

5. REFERENCES

Aumentado, H. D., & Balendres, M. A. (2024). Diseases of Eggplant (Solanum melongena L.) and Sustainable Management in Asia. *Plant Pathology & Quarantine*, *14*(1), 98–117.

Gupta, P. K. (2022). Current status of Cercosporoid fungi in India, effective management strategies and future directions. *Indian Phytopathology*, *75*(2), 303–314.

John, M. A., Bankole, I., Ajayi-Moses, O., Ijila, T., Jeje, T., & Lalit, P. (2023). Relevance of advanced plant disease detection techniques in disease and Pest Management for Ensuring Food Security and Their Implication: A review. *American Journal of Plant Sciences*, *14*(11), 1260–1295.

Parra-López, C., Abdallah, S. Ben, Garcia-Garcia, G., Hassoun, A., Sánchez-Zamora, P., Trollman, H., Jagtap, S., & Carmona-Torres, C. (2024). Integrating digital technologies in agriculture for climate change adaptation and mitigation: State of the art and future perspectives. *Computers and Electronics in Agriculture*, *226*, 109412.

Tusiime, S. M., Nonnecke, G. R., Masinde, D. M., & Jensen, H. H. (2019). Evaluation of horticultural practices for sustainable tomato production in eastern Uganda. *HortScience*, *54*(11), 1934–1940.

Yadav, S. P., Sharma, C., Pathak, P., Kanaujia, A., Saxena, M. J., & Kalra, A. (2025). Management of phyto-parasitic nematodes using bacteria and fungi and their consortia as biocontrol agents. *Environmental Science: Advances*

Ghosh, S. K., Banerjee, S., Pal, S., & Chakraborty, N. (2018). Encountering epidemic effects of leaf spot disease (Alternaria brassicae) on Aloe vera by fungal biocontrol agents in agrifields—An ecofriendly approach. PLoS ONE, 13(4), e0193720. https://doi.org/10.1371/journal.pone.0193720

Gupta, S., Didwania, N., & Singh, D. (2020). Biological control of mustard blight caused by Alternaria brassicae using plant growth promoting bacteria. Current Plant Biology, 23, 100163. https://doi.org/10.1016/j.cpb.2020.100163

Wei, X., Yang, Q., Solairaj, D., Godana, E. A., Zhang, X., & Li, Y. (2025). Biological control of black spot disease in cherry tomato caused by Alternaria alternata with Bacillus velezensis T3. Foods, 14(10), 1700. https://doi.org/10.3390/foods14101700

Attia, M. S., Abdelaziz, A. M., Al-Askar, A. A., & Arishi, A. A. (2022). Plant growth-promoting fungi as biocontrol tool against fusarium wilt disease of tomato plant.

Journal of Fungi, 8(8), 775. https://doi.org/10.3390/jof8080775

Amaresan, N., Jayakumar, V., Kumar, K., & Ramasamy, S. (2019). Biocontrol and plant growth-promoting ability of plant-associated bacteria from tomato (Lycopersicum esculentum) under field condition. Microbial Pathogenesis, 132, 97–107. https://doi.org/10.1016/j.micpath.2019.05.017

Shahid, M., Singh, U. B., Ilyas, T., & Malviya, D. (2022). Bacterial inoculants for control of fungal diseases in Solanum lycopersicum L. (Tomatoes): A comprehensive overview. In Stress Management (pp. 247–268). Springer. https://doi.org/10.1007/978-981-19-5872-4_15

Fayyadh, M. A., & Yousif, E. Q. (2019). Biological control of tomato leaf spot disease caused by Alternaria alternata using Chaetomium globosum and some other saprophytic fungi. IOP Conference Series: Earth and Environmental Science, 388(1), 012017. https://doi.org/10.1088/1755-1315/388/1/012017

Awan, Z. A., Shoaib, A., Iftikhar, M. S., & Jan, B. L. (2022). Combining biocontrol agent with plant nutrients for integrated control of tomato early blight through the modulation of physio-chemical attributes and key antioxidants. Frontiers in Microbiology, 13, 807699. https://doi.org/10.3389/fmicb.2022.807699

Ampatzidis, Y., Kakarla, S. C., & Roberts, P. (2020). Detection of target spot and bacterial spot diseases in tomato using UAV-based and benchtop-based hyperspectral imaging techniques. Precision Agriculture, 21, 1604–1620. https://doi.org/10.1007/s11119-019-09703-4

Chien, Y. C., & Huang, C. H. (2020). Biocontrol of bacterial spot on tomato by foliar spray and growth medium application of Bacillus amyloliquefaciens and Trichoderma asperellum. European Journal of Plant Pathology, 156, 1095–1109. https://doi.org/10.1007/s10658-020-01947-5

Sarkar, M. K. I., Roy, C. K., & Akter, N. (2019). Control of early blight of tomato caused by Alternaria solani and screening of tomato varieties against the pathogen. The Open Microbiology Journal, 13, 41–51. https://doi.org/10.2174/1874285801913010041

MubarakAli, D., Vignesh, M., & Shankar, S. R. M. (2022). A novel rhizospheric bacterium: Bacillus velezensis NKMV-3 as a biocontrol agent against Alternaria leaf blight in tomato. Applied Biochemistry and Biotechnology, 194, 463–480. https://doi.org/10.1007/s12010-021-03684-9

Ferreira, F. V., & Musumeci, M. A. (2021). Trichoderma as biological control agent: Scope and prospects to improve efficacy. World Journal of Microbiology and Biotechnology, 37(10), 174. https://doi.org/10.1007/s11274-021-03058-7

Komhorm, A., Thongmee, S., & Thammakun, T. (2021). In vivo testing of antagonistic fungi against Alternaria brassicicola causing Chinese kale black spot disease. Journal of Plant Diseases and Protection, 128(4), 567–575. https://doi.org/10.1007/s41348-020-00382-2

Wang, X., Li, M., Wang, D., Wang, F., Shen, H., Sun, G., & Feng, C. (2021). Biocontrol efficacy of Bacillus siamensis LZ88 against brown spot disease of tobacco caused by Alternaria alternata. Biological Control, 157, 104576. https://doi.org/10.1016/j.biocontrol.2021.1

04576

Kaushik, N., Sharma, A., Sharma, A., & Bajaj, A. (2021). Screening of tomato seed bacterial endophytes for antifungal activity reveals lipopeptide producing Bacillus siamensis strain NKIT9 as a potential bio-control agent. Frontiers in Microbiology, 12, 609482. https://doi.org/10.3389/fmicb.2021.609482

Roy, C. K., Akter, N., & Sarkar, M. K. I. (2019). Antifungal activity of some chemical and botanical extracts against early blight of tomato caused by Alternaria solani. The Open Microbiology Journal, 13, 34–40. https://doi.org/10.2174/1874285801913010034

Sunpapao, A., Chairin, T., & Ito, S. (2018). The biocontrol by Streptomyces and Trichoderma of leaf spot disease caused by Curvularia oryzae in oil palm seedlings. Biological Control, 121, 15–23. https://doi.org/10.1016/j.biocontrol.2018.04.002

Fayyadh, M. A., & Yousif, E. Q. (2019). Biocontrol of tomato leaf spot disease caused by Alternaria alternata using Chaetomium globosum and some other saprophytic fungi. IOP Conference Series: Earth and Environmental Science, 388, 012017. https://doi.org/10.1088/1755-1315/388/1/012017

Xie, Z., Li, M., Wang, D., Wang, F., Shen, H., Sun, G., & Feng, C. (2021). Biocontrol efficacy of Bacillus siamensis LZ88 against brown spot disease of tobacco caused by Alternaria alternata. Biological Control, 157, 104576. https://doi.org/10.1016/j.biocontrol.2021.104576

Awan, Z. A., Shoaib, A., Iftikhar, M. S., & Jan, B. L. (2022). Combining biocontrol agent with plant nutrients for integrated control of tomato early blight through modulation of physio-chemical attributes and key antioxidants. Frontiers in Microbiology, 13, 807699. https://doi.org/10.3389/fmicb.2022.807699

Ampatzidis, Y., Kakarla, S. C., & Roberts, P. (2020). Detection of target spot and bacterial spot diseases in tomato using UAV-based and benchtop-based hyperspectral imaging techniques. Precision Agriculture, 21, 1604–1620. https://doi.org/10.1007/s11119-019-09703-4.