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From waste to weapon: the potential of medicinal plant waste extracts for eco-friendly crop disease management

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The increasing challenge of managing crop diseases requires innovative and sustainable approaches. The current reliance on synthetic pesticides raises environmental concerns and contributes to the development of pesticide resistance. Therefore, exploration of alternative, eco-friendly biocontrol agents is crucial. In this article, we examine the underutilized potential of medicinal plant wastes (MPWs) as renewable and eco-friendly resources for the control of crop diseases. MPWs contain a significant portion of bioactive compounds with biopesticidal potential and represent a readily available and cost-effective source. Here, we review the recent findings on the efficacy of MPW extracts, discuss their mechanisms of action, and highlight their applications in crop protection. The contents presented herein emphasize the importance of MPW extracts as sustainable alternatives or complements to conventional synthetic pesticides and offer new possibilities for environmentally conscious strategies in crop disease management.

KEYWORDS

medicinal plant waste extracts, crop diseases, biopesticides, synthetic pesticides, sustainable agriculture, field experiments

1 Introduction

The global agricultural sector is undergoing a profound shift, driven by the increasing demand for organic products and sustainable farming methods. This transformation reflects evolving consumer preferences and a crucial need to reduce the environmental impact of conventional agriculture, particularly the reliance on synthetic pesticides. These pesticides pose significant risks to human health and the environment, threatening long-term agriculture sustainability (Marcelino et al., 2023a; Greff et al., 2023b; Sergeeva, 2015). In response to this challenge, the exploration of medicinal plant waste (MPW) extracts as biopesticides offers a promising avenue for sustainable crop disease management. Repurposing MPW extracts not only reduce reliance on synthetic pesticides but also provide a cost-effective, readily available, and environmentally friendly alternative (Greff et al., 2023b). This perspective article explores the potential of MPW extracts to complement or replace synthetic fungicides in crop disease control, thereby encouraging the development and broader implementation of these eco-friendly solutions for a more sustainable agricultural future.

2 Booming market for medicinal plants

Medicinal plants are a rich and valuable source of bioactive compounds and herbal products, with more than 50,000 plant species used for medicinal purposes worldwide (Greff et al., 2023a). The World Health Organization estimates that 75–80% of the world's population relies on herbal medicines for their primary healthcare needs, and over 25% of prescribed drugs in developed countries are derived from wild plant species (Marcelino et al., 2023b; Chen et al., 2016). The herbal medicine market, valued at $216 billion in 2023, is projected to grow at a compound annual growth rate of 8.17% to $437 billion by 2032 (Fortune-Business-Insights., 2023). Therefore, global trade in medicinal plant resources is experiencing a remarkable annual growth rate of 10–12% annually (Marcelino et al., 2023a). This growth has been attributed to the increasing popularity of herbal medicines and natural ingredients derived from medicinal plants in various sectors, including the pharmaceutical, food, cosmetics, and agrochemical industries (Chen et al., 2016).

3 Looming threat of medicinal plant waste

However, the growing demand for medicinal plants makes them expensive. As only specific organs or tissues are used in herbal medicines, the processing of medicinal plants generates significant amounts of waste in the form of leaves, stems, roots, and other residual materials. These residues are the byproducts of the extraction or decoction of botanical medicines and contain many unused components. In China alone, the national production of Chinese patent medicines in 2021 was ∼2.5 million tons, resulting in 60–70 million tons of Chinese herbal waste annually (Luo et al., 2023). Globally, the medicinal herb industry produces ∼20 million tons of dry mass waste annually (Yarin et al., 2022). Although it is estimated that only a small portion of the plant is used as the final product, the remaining biomass is often disposed of through unsustainable practices, such as landfilling, stacking, incineration, or open burning (Marcelino et al., 2023a). These practices cause a significant waste of valuable resources and contribute to environmental pollution through air, water, and soil contamination (Marcelino et al., 2023a; Luo et al., 2023). In addition, improper waste management poses public health risks, particularly to communities living near dumping sites, because of spontaneous fires and toxic gas emissions (Marcelino et al., 2023a; Luo et al., 2023). Therefore, it is crucial to implement sustainable practices throughout the value chain of medicinal plants.

4 Limitations of synthetic pesticides and the need for alternative strategies

The Food and Agriculture Organization of the United Nations FAO., 2024 estimates that plant diseases and pests cause annual global crop losses of up to 40%, costing over $220 billion globally. Savary et al. (2019) noted that wheat, rice, maize, potato, and soybean losses amount to 10–28, 25–41, 20–41, 8–21, and 11–32%, respectively. These facts highlight the significant impact of plant diseases on agricultural productivity and economic wellbeing. In addition, climate change and trade globalization may act as the drivers of the emergence and spread of new pathogens to previously unaffected areas (Singh et al., 2023), posing additional threats to global crop production.

Crop disease management relies heavily on synthetic pesticides (Nishimoto, 2019; Fones et al., 2020). There could be a significant increase in crop damage without pesticide use because of pathogen infestation, potentially ranging from 20 to 50% (Oerke, 2006). However, the extensive and long-term use of traditional synthetic pesticides raises public health and environmental concerns and creates selection pressure on pathogen populations, leading to the frequent emergence of pesticide-resistant races (Fones et al., 2020; Fisher et al., 2018). For example, the fungicides kasugamycin, phosphorothiolates and melanin biosynthesis inhibitors were developed to control the rice blast fungus *Magnaporthe oryzae*; however, *M. oryzae* strains resistant to these fungicides emerged within six, seven and 2 years of their introduction to the market, respectively (Lucas et al., 2015; Brent and Hollomon, 1995). Alarmingly, the emergence of pesticide resistance is outpacing pesticide discovery (Fisher et al., 2018), threatening future crop protection. The number of new agrochemicals developed has decreased since the 2000s, and the cost and time of development have increased from $152 million and 8.3 years in 1995 to $286 million and 11.3 years in 2010–2014 (Fones et al., 2020; Nishimoto, 2019). Therefore, it is imperative to develop new, eco-friendly, and sustainable strategies that provide viable alternatives to or complement traditional practices for crop disease management.

5 Potential of MPW extracts as biopesticides to control crop diseases in fields

There is a growing interest in innovative methods for repurposing MPWs, which present a range of benefits beyond environmental sustainability. These methods open new economic opportunities and contribute to a more circular bioeconomy by transforming MPW into valuable bioproducts.

Medicinal plant extracts are rich sources of secondary metabolites such as terpenes, phenolic compounds, alkaloids, flavonoids and coumarins, many of which have demonstrated potent inhibitory activity against various plant pathogenic fungi, bacteria, and viruses, effectively reducing the incidence and severity of diseases in various crops (Marcelino et al., 2023b; Greff et al., 2023a; Rahimi et al., 2025). The inherent diversity of bioactive compounds in medicinal plants, each with a unique mode of action, can mitigate the emergence of resistance in pathogen populations, which is a significant drawback of synthetic pesticides. Notably, medicinal plant residues (MPRs) generated during extraction process have been shown to retain 30–50% of essential bioactive compounds (Marcelino et al., 2023a; Luo et al., 2023).

In addition to their pesticidal properties, extracts of some medicinal plants have been shown to activate innate defense mechanisms in plants. In a recent study, Tan et al. (2023)

reported that ethanolic extracts of *Paris polyphylla* pericarps (a tissue generally discarded after rhizome harvesting) exhibit potent antifungal activity against rice blast pathogen *M. oryzae*, with over 70% growth inhibition. Foliar spraying with this extract significantly enhances blast resistance in rice seedlings and the expression of *WRKY45*, a key regulator of immunity, and pathogenesis-related genes *OsPR1b* and *PBZ1*, indicating that this extract protects rice by conferring antifungal activity and stimulating plant defense system. However, whether these effects stem from the same or different bioactive compounds remains unclear. Similarly, Satya et al. (2007) reported that the foliar application of an aqueous extract of zimmu (*Allium sativum* L. × *Allium cepa* L.) leaves to cotton plants induced significant systemic resistance to *Xanthomonas campestris* pv. *malvacearum*, reducing disease lesions by up to 73% compared with that in mock controls. These studies highlight the potential of MPWs as dual-function resources, offering both direct antimicrobial action and the ability to boost crop immunity.

Although numerous medicinal plant extracts have demonstrated antipathogenic activity in *in vitro* experiments and their disease control effects in greenhouse studies, only a few studies have confirmed their efficacy under field conditions. Table 1 provides a summary of MPW extracts that have been shown to reduce the incidence of crop diseases by at least 50% in field trials. These findings highlight the potential of MPW extracts as renewable and eco-friendly biopesticides for sustainable crop protection. As shown in Table 1, most studies have focused on disease management of rice (*Oryza sativa* L.), including sheath blight (*Rhizoctonia solani*), leaf blight (*Xanthomonas oryzae* pv. *oryzae*), and bakanae (*Fusarium fujikuroi*). Given that rice is a staple crop feeding over half of the world's population, these

TABLE 1 Field-validated medicinal plant waste extracts shown to reduce crop disease incidence by ≥ 50%.

Crop species	Disease (causal pathogen)	Plant sources and their main medicinal tissues	Plant tissues and extraction	Concentration, application method	Disease reduction (%)	Mode of action	References
Rice (*Oryza sativa* L.)	Sheath blight (*Rhizoctonia solani*)	Cassumunar ginger (*Zingiber cassumunar* Roxb.), rhizome	Shoot, plant powder	25 g L^{-1} (DW/V), foliar application	Max. 58	Antifungal activity	Dethoup et al. (2022)
		Turmeric (*Curcuma longa* L.), rhizome	Shoot, plant powder	25 g L^{-1} (DW/V), foliar application	Max. 52	Antifungal activity	Dethoup et al. (2022)
		Tree turmeric [*Coscinium fenestratum* (Goetgh.) Colebr.], stem bark, roots	Shoot, plant powder	25 g L^{-1} (DW/V), foliar application	Max. 54	Unknown	Dethoup et al. (2022)
		Thick leaf thyme (*Plectranthus amboinicus*), leaves	Shoot, water	15% filtrate of 1:1 DW/V crude extract, foliar application	77 (trial-1), 77 (trial-2)	Antifungal activity	Persaud et al. (2019)
		Marigold (*Tagetes patula*), flowers	Shoot, water	15% filtrate of 1:1 DW/V crude extract, foliar application	52 (trial-1), 45 (trial-2)	Antifungal activity	Persaud et al. (2019)
	Leaf blight (*Xanthomonas oryzae* pv. *oryzae*)	Neem (*Azadirachta indica*), leaves, seeds and roots	Fruits, water	50% filtrate of 1:10 DW/V crude extract, foliar application	79–82 (varied by CV)	Antibacterial activity	Naqvi et al. (2018)
	Bakanae (*Fusarium fujikuroi*)	Toothpick weed (*Ammi visnaga*), seeds	Shoot, ethanol	Raw extract filtrate, 750 ppm, seed treatment	96 (2,017), 98 (2,018)	Antifungal activity	Kalboush and Hassan (2019)
		Blue gum (*Eucalyptus globulus*), leaves	Shoot, ethanol	Raw extract filtrate, 1,000 ppm, seed treatment	95 (2,017), 96 (2,018)	Antifungal activity	Kalboush and Hassan (2019)
Tomato (*Solanum lycopersicum* L.)	Wilt disease (*Fusarium oxysporum* f.sp. *lycopersici*)	Camphor (*Cinnamomum camphora*), wood	Leaves, ethanol	5% filtrate of 1:4 DW/V crude extract, soil drench	70	Antifungal activity	El-Shennawy and Abo-Kora (2016)
		African marigold (*Tagetes marigold*), flowers	Leaves, ethanol	3% filtrate of 1:4 DW/V crude extract, soil drench	70	Unknown	El-Shennawy and Abo-Kora (2016)
Black currant (*Ribes nigrum*)	Leaf spot and fruit rot {[*Alternaria alternata* (Fr.) Keissl.]}	Valerian (*Valeriana officinalis*), roots	Shoot, hydroalcoholic solution	10% filtrate of 1:10 FW/V crude extract	94	Antifungal activity	Sesan et al. (2016)

FW/V and DW/V represent the ratio of fresh and dry weight of plant material to extraction solvent volume, respectively.

studies hold significant agricultural importance. In field trials, extracts from at least five medicinal plant species have shown efficacy against rice sheath blight (Table 1), an encouraging result given the limited genetic sources of resistance and heavy reliance on synthetic fungicides for disease control (Senapati et al., 2022; Chen et al., 2023). Furthermore, extracts from three medicinal plant species have been shown to be effective in disease control in tomato (*Solanum lycopersicum* L.) and blackcurrant (*Ribes nigrum*), presenting safer plant-based alternatives to synthetic pesticides for vegetable and fruit production. However, the active constituents and precise metabolic pathways of these extracts remain unknown, requiring further investigation to optimize their use.

Additionally, several medicinal plant extracts, although not derived from MPW, have also been shown to be effective in reducing disease incidence in crops such as rice, tomato, and sugar beet by more than 50% in field trials (Supplementary Table S1).

To fully realize the potential of MPWs, future studies should identify and quantify their bioactive compounds and evaluate their efficacy against various pathogens in diverse crops through field trials. Detailed mechanistic studies should investigate whether these compounds are responsible for direct antimicrobial activity, the elicitation of plant defense responses, or both. It is also important to optimize application methods for different crops and environments, and assess any potential environmental impact.

Technically, developing standardized extraction methods and optimizing processes to maximize the retention of effective compounds during extraction will be crucial. Furthermore, integrating MPW-based biopesticides into Integrated Pest Management (IPM) system and advancing formulation technologies can enhance their efficacy and persistence.

6 Conclusion

The processing of medicinal plants generates large amounts of MPW biomass in the form of unused organs or tissues and extraction residues, which are often discarded (Figure 1). Utilizing these materials for biopesticide development offers the dual benefit of advancing both environmental sustainability and the medicinal plant industry (Figure 1). Valorizing these MPW can significantly reduce environmental impacts by replacing synthetic chemical pesticides while also supporting a circular bioeconomy (Khanna et al., 2024). Furthermore, the development and commercialization of MPW-based biopesticides could generate new revenue streams within the sustainable agricultural sector, thereby supporting economic growth.

Collaboration across sectors is essential to facilitate the widespread adoption of MPW-based biopesticides in the field. Government incentives and supportive policies can encourage innovation and funding for MPW research. Research institutions

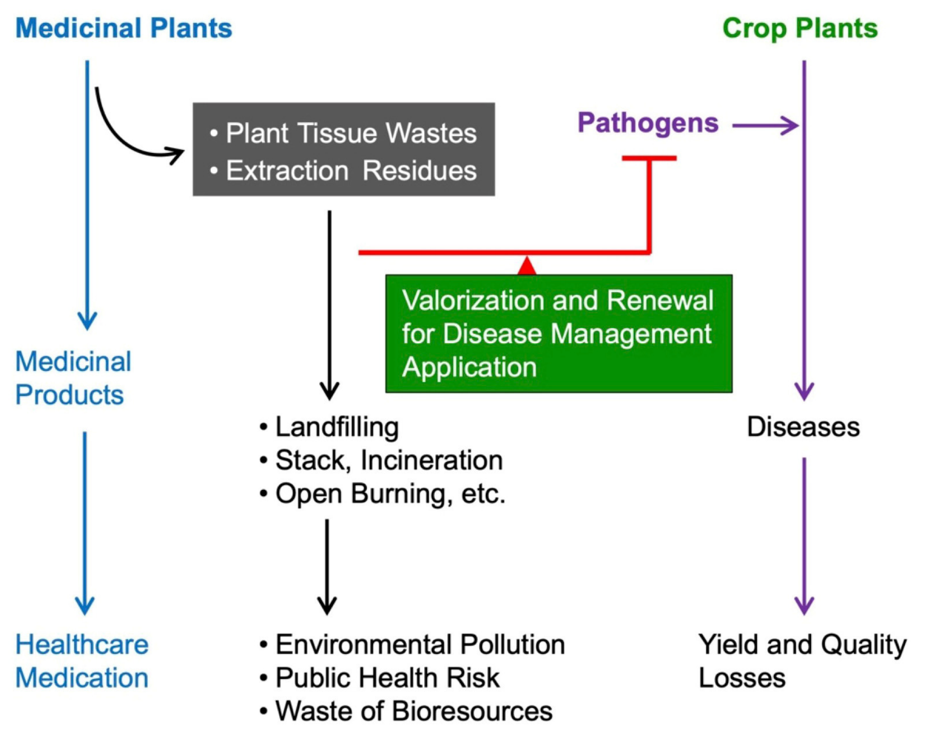

FIGURE 1
Valorization of medicinal plant residues for crop disease management. Medicinal plants are processed to produce healthcare and medicinal products for human use (depicted by light blue arrows). This process generates by-products in the form of plant tissue waste and extraction residues. These by-products are often disposed of through landfilling, stacking, or incineration, leading to environmental pollution and public health risks (black arrows). Repurposing these materials for disease management in crops offers an eco-friendly, sustainable approach to agriculture (red lines). Arrows and lines with a bar at the end indicate positive and negative regulation, respectively.

are well-positioned to analyze the active compounds in MPWs, optimize application methods, and ensure reliable efficacy across diverse agricultural environments. Field trials with farmers and agribusinesses are essential for gathering practical insights into the effectiveness and feasibility of MPWs in real-world settings. A coordinated multi-sector approach is critical for advancing MPW-based solutions and promoting the sustainability of modern agricultural practices.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

C-JJ: Conceptualization, Funding acquisition, Writing – original draft. YS: Data curation, Funding acquisition, Visualization, Writing – review & editing. SX: Data curation, Visualization, Writing – review & editing. XL: Conceptualization, Writing – review & editing. XX: Conceptualization, Writing – review & editing, Funding acquisition.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2025.1556604/full#supplementary-material

References

Brent, K. J., and Hollomon, D. W. (1995). *Fungicide resistance in crop pathogens: How can it be managed?* FRAC Monograph No. 1. Brussels: Fungicide Resistance Action Committee (FRAC).

Chen, J., Xuan, Y., Yi, J., Xiao, G., Yuan, D. P., and Li, D. (2023). Progress in rice sheath blight resistance research. *Front. Plant Sci.* 14:1141697. doi: 10.3389/fpls.2023.1141697

Chen, S.-L., Yu, H., Luo, H.-M., Wu, Q., Li, C.-F., and Steinmetz, A. (2016). Conservation and sustainable use of medicinal plants: problems, progress, and prospects. *Chinese Med.* 11, 1–10. doi: 10.1186/s13020-016-0108-7

Dethoup, T., Auamcharoen, W., Jantasorn, A., and Niphon, K. (2022). The efficacy of dry medicinal plant powders against rice diseases. *Eur. J. Plant Pathol.* 164, 241–252. doi: 10.1007/s10658-022-02554-2

El-Shennawy, M., and Abo-Kora, M. (2016). Management of wilt disease complex caused by *Meloidogyne javanica* and *Fusarium oxysporum* f. sp. lycopersici on tomato using some plant extracts. *J. Plant Protect. Pathol.* 7, 797–802. doi: 10.21608/jppp.2016.52433

FAO. (2024). *Plant Production and Protection. The Food and Agriculture Organization of the United Nations.* Available online at: https://www.fao.org/plant-production-protection/about/en (accessed November 20, 2024).

Fisher, M. C., Hawkins, N. J., Sanglard, D., and Gurr, S. J. (2018). Worldwide emergence of resistance to antifungal drugs challenges human health and food security. *Science* 360, 739–742. doi: 10.1126/science.aap7999

Fones, H. N., Bebber, D. P., Chaloner, T. M., Kay, W. T., Steinberg, G., and Gurr, S. J. (2020). Threats to global food security from emerging fungal and oomycete crop pathogens. *Nature Food* 1, 332–342. doi: 10.1038/s43016-020-0075-0

Fortune-Business-Insights. (2023). Herbal Medicine Market Size, Share and COVID-19 Impact Analysis, By Product (Tablets and Capsules, Powders, Extracts), By Application (Western Herbalism, Traditional Chinese Medicine, Others), By Distribution Channel (Hospital and Retail Pharmacies, E-commerce, Others), and Regional Forecast, 2023–2032. Available online at: https://www.fortunebusinessinsights.com/herbal-medicine-market-106320 (accessed November 20, 2024).

Greff, B., Nagy, Á., Posgay, M., Sáhó, A., and Lakatos, E. (2023a). "Composting of medicinal and aromatic plant waste: challenges and opportunities," in *Recent Trends in Solid Waste Management*, eds B. Ravindran, S. K. Gupta, S. A. Bhat, P. S. Chauhan, and N. Tyagi (Elsevier), 115–136.

Greff, B., Sáhó, A., Lakatos, E., and Varga, L. (2023b). Biocontrol activity of aromatic and medicinal plants and their bioactive components against soil-borne pathogens. *Plants* 12:706. doi: 10.3390/plants12040706

Kalboush, Z. A., and Hassan, A. (2019). Antifungal potential and characterization of plant extracts against *Fusarium fujikuroi* on rice. *J. Plant Protect. and Pathol.* 10, 369–376. doi: 10.21608/jppp.2019.53671

Khanna, M., Zilberman, D., Hochman, G., and Basso, B. (2024). An economic perspective of the circular bioeconomy in the food and agricultural sector. *Commun. Earth Environ.* 5:507. doi: 10.1038/s43247-024-01663-6

Lucas, J. A., Hawkins, N. J., and Fraaije, B. A. (2015). The evolution of fungicide resistance. *Adv. appl. Microbiol.* 90, 29–92. doi: 10.1016/bs.aambs.2014.09.001

Luo, J., Yang, R., Ma, F., Jiang, W., and Han, C. (2023). Recycling utilization of Chinese medicine herbal residues resources: systematic evaluation on industrializable treatment modes. *Environ. Sci. Pollut. Res.* 30, 32153–32167. doi: 10.1007/s11356-023-25614-4

Marcelino, S., Gaspar, P. D., and Paço, A. (2023a). Sustainable waste management in the production of medicinal and aromatic plants—a systematic review. *Sustain.* 15:13333. doi: 10.3390/su151813333

Marcelino, S., Hamdane, S., Gaspar, P. D., and Paço, A. (2023b). Sustainable agricultural practices for the production of medicinal and aromatic plants: evidence and recommendations. *Sustain.* 15:14095. doi: 10.3390/su151914095

Naqvi, S., a,. H., Umar, U., Hasnain, A., Rehman, A., and Perveen, R. (2018). Effect of botanical extracts: a potential biocontrol agent for *Xanthomonas oryzae* pv. oryzae, causing bacterial leaf blight disease of rice. *Pak. J. Agric. Res.* 32, 59–72. doi: 10.17582/journal.pjar/2019/32.1.59.72

Nishimoto, R. (2019). Global trends in the crop protection industry. *J. Pestic. Sci.* 44, 141–147. doi: 10.1584/jpestics.D19-101

Oerke, E-C. (2006). Crop losses to pests. *J. Agric. Sci.* 144, 31–43. doi: 10.1017/S0021859605005708

Persaud, R., Khan, A., Isaac, W-A., Ganpat, W., and Saravanakumar, D. (2019). Plant extracts, bioagents and new generation fungicides in the control of rice sheath blight in Guyana. *Crop Protect.* 119, 30–37. doi: 10.1016/j.cropro.2019.01.008

Rahimi, A., Karimipour Fard, H., and Mohamadzadeh, H. (2025). A review of secondary metabolites and inhibitory effect of medicinal plants on some plant pathogens. *J. Med. Plants By-Prod.* 14, 1–8.

Satya, V., Gayathiri, S., Bhaskaran, R., Paranidharan, V., and Velazhahan, R. (2007). Induction of systemic resistance to bacterial blight caused by *Xanthomonas campestris* pv. malvacearum in cotton by leaf extract from a medicinal plant zimmu (*Allium sativum* L.× *Allium cepa* L.). *Arch. Phytopathol. Pflanzenschutz.* 40, 309–322. doi: 10.1080/03235400600586781

Savary, S., Willocquet, L., Pethybridge, S. J., Esker, P., Mcroberts, N., and Nelson, A. (2019). The global burden of pathogens and pests on major food crops. *Nat. Ecol. Evol.* 3, 430–439. doi: 10.1038/s41559-018-0793-y

Senapati, M., Tiwari, A., Sharma, N., Chandra, P., Bashyal, B. M., Ellur, R. K., et al. (2022). *Rhizoctonia solani* Kühn pathophysiology: status and prospects of sheath blight disease management in rice. *Front. Plant Sci.* 13:881116. doi: 10.3389/fpls.2022.881116

Sergeeva, V. (2015). "Medicinal plants to control diseases and pests," in *Medicinal and Aromatic Plants of the World: Scientific, Production, Commercial and Utilization Aspects*, 257–271. doi: 10.1007/978-94-017-9810-5_13

Sesan, T. E., Enache, E., Iacomi, B. M., Oprea, M., Oancea, F., and Iacomi, C. (2016). Antifungal activity of some plant extracts against *Alternaria alternata* (Fr.) Keissl in the black currant crop (*Ribes nigrum* L.). *Acta Sci. Pol-Hortoru.* 15, 57–68.

Singh, B. K., Delgado-Baquerizo, M., Egidi, E., Guirado, E., Leach, J. E., Liu, H., et al. (2023). Climate change impacts on plant pathogens, food security and paths forward. *Nat. Rev. Microbiol.* 21, 640–656. doi: 10.1038/s41579-023-00900-7

Tan, Y., Deng, S., Qin, Y., Xu, X., Yu, Y., Cui, L., et al. (2023). Evaluation of medicinal plant extracts for rice blast disease control. *Rice Sci.* 30:6. doi: 10.1016/j.rsci.2022.03.003

Yarin, T., Dutta, B., Murmu, D. K., Medda, P., and Das, S. (2022). Valorization of medicinal and aromatic plants waste. *J. Pharm. Innov.* 11, 532–537.