Special issue: Botanical pesticides for crop protection

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Crop production forms the foundation of global food security by providing essential nutrients to billions of people and supporting economies worldwide. According to the United Nations,[1] the global population in 2024 is projected to reach 8.2 billion, with expectations to grow to approximately 10.3 billion by the mid-2080s. This population increase places immense pressure on the resources needed for quality crop production. Additionally, climate change has led to global warming, affecting temperature and rainfall patterns, which in turn impacts crop production and plant pest management. This complicates efforts to secure sufficient, safe, and nutritious food to maintain healthy populations.

Currently, plant production faces numerous challenges caused by both abiotic and biotic factors. Among the latter, plant pathogens—including fungi, bacteria, nematodes, and viruses—not only cause significant yield losses but also have broader implications for food prices, biodiversity, and ecological balance. Moreover, intensive, repeated cultivation of economic crops on the same land has increased pathogen aggressiveness and virulence, leading to severe plant diseases, poor growth, and yield losses. These pathogens are easily spread by wind, rain, or contaminated seeds, exacerbating problems in seed germination and plant development.

Effective crop protection is thus crucial for ensuring food security, economic stability, and high-quality produce. While synthetic chemicals are effective and form an integral part of pest control, their use is increasingly unsustainable due to environmental and health concerns. Chemical fungicides can contaminate ecosystems, harm non-target organisms, and lead to pest resistance, reducing their long-term efficacy. They pose health risks to humans and animals and degrade soil health, diminishing its fertility and productivity.

Sustainable alternatives like integrated pest management (IPM) and organic farming offer more balanced approaches by promoting ecological health and reducing reliance on harmful chemicals. Botanical pesticides, derived from plants and minerals with natural defensive properties, are a promising alternative. They have gained traction globally for several reasons: their pesticidal potential, varied modes of action, biodegradability, perceived low toxicity, and availability.

Plants contain a myriad of antimicrobial compounds—such as terpenes, acids, esters, aldehydes, alkaloids, and ketones—that are effective against plant, animal, and human pathogens. Crude extracts and metabolites have been reported to act against pathogens through various mechanisms, including interference with the structural integrity of pathogens,

inhibiting pathogen enzyme activity, impairing protein synthesis, inducing plant defence mechanisms, and exhibiting antioxidative and antimicrobial properties. With so many compounds available, the possibilities for novel mechanisms of action are extensive! These compounds are obtained from various plant parts, including roots, rhizomes, stems, bark, leaves, flowers, cloves, fruits, and seeds, either as essential oils or extracts. Their antimicrobial activities are typically tested in laboratory, greenhouse, and field trials.

However, most research is restricted to *in vitro* experiments. Further investigation is required to assess the transition from research to practical application. This prompts several critical and applied questions: Are these applications feasible? Are they genuinely safe? What are the mechanisms of action of these extracts?

The commercial development of botanical pesticides has been slower compared to biological control agents and synthetic fungicides due to challenges such as sourcing raw materials, variability in active compounds, and difficulties in achieving consistent extraction quality. Additionally, there are hurdles related to botanical pesticide registration that are similar to those required for synthetic products.

Research on botanical pesticides is crucial for identifying new bioactive compounds, optimizing extraction and application methods, and evaluating efficacy and safety. Moreover, research should address issues like variable efficacy, limited shelf life, and inconsistent quality to help unlock the full potential of botanical pesticides as part of IPM strategies.

This special issue commences with an in-depth review article that establishes the foundation for exploring plant-based alternatives to chemical crop protection. It addresses current trends and future perspectives in sustainable agriculture. The issue features a range of studies on innovative plant extracts and essential oils for tackling agricultural issues. Research highlights include the use of neem leaf extract for controlling onion purple blotch through advanced metabolite fingerprinting, and the combined effects of citrus essential oils against *Streptomyces scabiei*. It also examines the suppression of peach fruit rot with microencapsulated clove essential oil sachets and the antifungal potential of volatile compounds from *Trichoderma* species in olive rhizosphere soil. Additional studies cover endotherapeutic treatments with pomegranate peel extract for olive quick decline syndrome, and the integration of thermotherapy with alternative products for melon rot management. Other featured research includes the efficacy of phenolic-rich plant extracts against Fusarium wilt in tomatoes, *Cinnamomum* species extracts for mango anthracnose, and various plant extracts' effects on *Sclerotium rolfsii*. The issue also includes broad-spectrum bioactivity analyses of essential oils, gum Arabic coatings for extending plum shelf life, and the use of *Citrus reticulata* fruits as botanical fungicides for rice foot rot. Further topics explore the impact of *Crotalaria spectabilis* extracts on soybean nematodes, bioprospecting of wild botanicals for radish Alternaria leaf blight, and the antibacterial properties of *Rhus coriaria* fruit extract. Additionally, it examines how plant extracts and cultural practices affect cucumber mosaic virus in *Capsicum*, providing practical guidance for enhancing crop yield and health. In conclusion, this issue offers a comprehensive overview of how plant-based methods can deliver sustainable and effective solutions to modern agricultural challenges.

Notes

1. United Nations Department of Economic and Social Affairs, Population Division (2024). World Population Prospects 2024: Summary of Results (UN DESA/POP/2024/TR/NO. 9).