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Editorial: The Use of Plant Extracts and Essential Oils as Biopesticides

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Editorial on the Research Topic

The Use of Plant Extracts and Essential Oils as Biopesticides

Essential oils (EOs) and plant extracts contain valuable natural products, many of which can be used in pest and disease control safely due to their ability to degrade in nature (Ni et al., 2021; El Khetabi et al., 2022). Despite their qualities, biopesticides represent only 5% of the overall pesticide market (Balog et al., 2017; Kumar et al., 2021; Rakshit et al., 2021). Nevertheless, biopesticides are experiencing rapid growth in recent years with an average annual growth rate of 9–20%, predicted to outpace that of chemical pesticides (Balog et al., 2017; Marrone, 2019; Kumar et al., 2021; Rakshit et al., 2021). Common management practices focus on the application of EOs and plant extract-based biopesticides without deeply understanding their mode of action (Álvarez-Martínez et al., 2021). Recent research focusing on pest management using EOs and plant extracts revealed several mechanisms involved in the insecticidal effects of EOs on targeted organisms (Ni et al., 2021). Moreover, several reports suggest specific strategies that could help in optimizing application of EOs and plant extracts as part of integrated pest management programs (de Oliveira, 2021). Apart from their role in plant development and growth, plant secondary compounds are also essential in plant resistance to biotic and abiotic stressors, and can be involved in metabolic processes that control plant tolerance (Yang et al., 2018; Karimi and Meiners, 2021; Ni et al., 2021). However, EOs and plant extracts are biologically unstable as they are easily destroyed by environmental pH, oxygen, light, and moderate temperatures. EOs exhibit poor aqueous solubility and high volatility in general. Efforts are being made to overcome these challenges. The present Research Topic gathers together studies that focus on the use of plant extracts and essential oils as biopesticides while aiming at the same time to shed light on their mode of action on different targeted key agricultural pest and plant diseases including insects, mites, nematodes, and oomycetes.

Several bioassays of different EOs and plant extracts have been used to demonstrate potential control of different key insect and mite populations. In one study, the strong ixodicidal and antifeedant agents included EOs of *Thymus zygis*, *T. vulgaris*, and *Mentha suaveolens*, which were suggested to be developed as biopesticides to effectively control ticks and insect pests (Valcárcel et al.). Interestingly, synergistic effects were also observed between these EOs (Valcárcel et al.). In a large-scale field trial, the application of aqueous extracts of *Murraya paniculata*, *Cassia tora*, *Amphineuron opulentum*, *Tithonia diversifolia*, and *C. alata* equally reduced the population of the red spider mite, a major tea pest, with a lower impact on natural enemies and increased the yield of tea plants without lethal consequence for the tea plants or consumers (Deka et al.).

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Furthermore, the larvicidal activity of EOs from five piper species including *Piper aduncum*, *P. marginatum*, *P. gaudichaudianum*, *P. crassinervium*, and *P. arboreum* against the yellow fever mosquito *Aedes aegypti* showed up to a 90% lethality at a screening concentration of 100 ppm, making these EOs potential alternatives for control of *A. aegypti* mosquito larvae (Pereira Filho et al.). Despite these effects, EO-based products are often chemically variable, requiring rigorous control of the cultivation process and an understanding of the regulatory aspects of the biosynthesis of these phenylpropanoids (Pereira Filho et al.), especially in developing countries such as sub-Saharan Africa (SSA) (Uyi et al.). The latter review summarized the existing insecticidal activity of invasive plants in SSA including Asteraceae, Solanaceae, Fabaceae, and Euphorbiaceae amongst others. These plants caused 50–100% mortality against various insect pests (Uyi et al.). However, using extracts from these invasive plants as biopesticides in African countries, especially among resource-poor smallholder farmers and locals, remains challenging (Stevenson et al., 2017; Uyi et al.).

Unlike studies on insects and mites, very few bioactivity evaluation bioassays with different EOs and plant extracts have been carried out on controlling different nematode populations. Recently the nematicidal potential of *Citrus sinensis*, *Cymbopogon nardus*, and *Melaleuca alternifolia* has been reported against the cotton root-knot nematode *Meloidogyne incognita* (Kundu et al.). On the other hand, potential botanical products against plant diseases have been extensively studied. For example, volatile organic compounds (VOCs) from soybean plants have been tested against harmful oomycetes, represented by *Phytophthora* (Ge et al.). The VOCs, mainly containing 4-ethylphenol, were simultaneously inoculated with the causal agent of soybean root rot, *P. sojae* and the black shank, *P. nicotiana*. VOCs inhibited the growth of the pathogens by destroying their cell membrane (Ge et al.). These VOCs have potent antifungal activity against other soil-borne phytopathogenic fungi including *Rhizoctonia solani*, *Fusarium graminearum*, and *Gaeumannomyces graminis* var *tritici*, and four forma specialis of *Fusarium oxysporum* (Ge et al.), making it ideal for simultaneously controlling major soilborne diseases.

The identification of active compounds of EOs and plant extracts is crucial to study their mode of action and thus develop effective biopesticide products. Nanotechnology using active biomolecules represents a potential solution to control the release of the active ingredient with less product waste. Biochemical and molecular modes of action of plant extracts and EOs have been recently investigated. *Thymus proximus* EO contains carvacrol, *p*-cymene, and γ-terpinene, representing 85.9% of the total oil, and these major constituents are responsible for both the plant suppressive effect and the insecticidal activity of the EOs (Zhou et al.). Furthermore, Azadirachtin, a tetranortriterpenoid derived from the neem seed of the Indian neem tree, have been reviewed many, many times in the past going back to the early 1980s for its insecticidal activity (Schmutterer, 2002). In this Research Topic, the literature review of Kilani-Morakchi et al. summarized the state of the art on key azadirachtin insecticidal activities and risk assessment. The effect of *T. zygis*, *T. vulgaris*, and *M. suaveolens* was mainly due to the presence of active compounds including piperitenone oxide, carvacrol, piperitenone, and thymol (Valcárcel et al.). The major compounds of the EOs from *Piper* species were identified and included β-asarone, (E)-anethole, (E)-β-caryophyllene, γ-terpinene, *p*-cymene, limonene, α-pinene, and β-pinene and showed larvicidal activity with mortality between 90 and 100% (Pereira Filho et al.). Phytochemical analyses of EOs of *Origanum compactum* tested against *Callosobruchus maculatus* showed that the main components were carvacrol and thymol (38 and 31.5%, respectively) (Aimad et al.). A comprehensive chemoprofiling of nematicidal action of EOs was performed to understand their possible interactions with the target sites of *M. incognita*, suggesting the most prominent monoterpene was l-limonene, with a range of 32–98%. In particular, industrially important *Commiphora myrrha*, *Cymbopogon nardus*, *Artemisia absinthium*, and *Pogostemon cablin* contained a higher amount of furanoeudesm 1,3 diene, geraniol, myrcene, camphor, and patchoulol, respectively. *In silico* analysis suggested a higher binding capacity of geraniol, β-terpineol, citronellal, l-limonene, and γ-terpinene, to the selected target proteins (Kundu et al.). Terpenoids which are present in most essential oils have been reported responsible for their bioactivity (Kundu et al.). Interestingly, several studies pointed out that synergistic interactions among terpenoids in EOs can be important (Tak and Isman, 2015, 2017). Therefore, these biochemical analyses of EOs and plant extracts will open a new door to specifically devise efficient and eco-friendly biopesticides and will help in effectively targeting the plant system (Werrie et al.).

The present Research Topic provides important updates on the roles of EOs and plant extracts in pest and disease management and highlights the chemical compositions responsible for their mode of action. This Research Topic contributes to define potential EO and plant extract candidates, which can be implemented in eco-friendly and sustainable management strategies. Moreover, plants are an important source of biomolecules, which are essential for fighting against economically devastating pests and diseases, and are also listed in this Research Topic. As such, it contributes to advancing the development of sustainable strategies for pest and disease management of food crops. However, there is a big disconnect between academic studies on insecticidal activity of plant metabolites and production of commercial bioinsecticides. Many such compounds are touted as potential biopesticides, but very few meet all the necessary criteria to be produced at scale for commercial use (Isman, 2017, 2020). Finally, besides providing an update on the state of the art of biopesticide research, the current Research Topic offers a perspective on future research needs and priorities. Emerging areas of research related to biopesticides include investigating (i) biopesticides' roles and function in plant metabolism and (ii) novel biopesticide management strategies to address biopesticide waste such as that of nanotechnology. Biopesticides and related products should be evaluated in a more biological and ecological context to further enhance the penetration of biopesticides into plant tissues, thus decreasing the waste and degradation of biopesticides and contributing to more sustainable integrated pest management systems.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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