

Biogenic Volatile Organic Compounds

Subjects: **Biochemistry & Molecular Biology**

Contributor: Giulia Castorina , Flaminia Grassi , Gabriella Consonni , Sara Vitalini , Roberto Oberti , Aldo Calcante , Enrico Ferrari , Monica Bononi , Marcello Iriti

Upon pathogen attack, plants very quickly undergo rather complex physico-chemical changes, such as the production of new chemicals or alterations in membrane and cell wall properties, to reduce disease damages. An underestimated threat is represented by root parasitic nematodes. In *Vitis vinifera* L., the nematode *Xiphinema index* is the unique vector of *Grapevine fanleaf virus*, responsible for fanleaf degeneration, one of the most widespread and economically damaging diseases worldwide. The aim of this study was to investigate changes in the emission of biogenic volatile organic compounds (BVOCs) in grapevines attacked by *X. index*. BVOCs play a role in plant defensive mechanisms and are synthetized in response to biotic damages. In our study, the BVOC profile was altered by the nematode feeding process. We found a decrease in β -ocimene and limonene monoterpene emissions, as well as an increase in α -farnesene and α -bergamotene sesquiterpene emissions in nematode-treated plants. Moreover, we evaluated the PR1 gene expression. The transcript level of *PR1* gene was higher in the nematode-wounded roots, while in the leaf tissues it showed a lower expression compared to control grapevines.

BVOCs

dagger nematodes

GC-MS

grapevine

monoterpenes

PR1 gene

sesquiterpenes

SPME

Xiphinema index

The European Union is the world's main wine producer, with a share of about 60% [1]. Given the economic relevance of *Vitis vinifera* L., grapevine pests are of rising interest to agrochemical companies and plant researchers. Among root parasites, nematodes can go undetected for years, especially in perennial crops, but eventually, they strongly decrease crop productivity.

The phylum Nematoda is largely widespread around the world and occupies a huge range of ecological niches [2]. In soil, nematodes play an important role in the decomposition of organic matter and the recycling of nutrients, determining the health of the soil itself. However, several taxa are harmful to many crops of economic importance [3], such as grapevine.

Annual crop losses caused by plant-parasitic nematodes are estimated at 8.8–14.6% of total crop production and 80 billion USD worldwide [4][5]. At least 2000 species of plant-parasitic nematodes are characterized by the presence of a stylet used for root tissue penetration. Some species are endoparasitic, others ectoparasitic [6]. Worldwide, several grapevine-parasitic nematodes can be mentioned, but root-knot nematodes *Meloidogyne* spp. and dagger nematode *Xiphinema index* are the most diffused. They are representative of the two root-feeding models, endoparasitic and ectoparasitic, respectively. *X. index* is a soil-borne nematode that lives in proximity to the rhizosphere [7] and feeds on cell content thanks to its strong stylet [8]. *X. index* is per se a harmful pathogen for

viticulture because it causes root necrosis and deformation which considerably reduce productivity [9]. Besides, it specifically transmits the *Grapevine fanleaf virus* (GFLV) [10][11][12], whose symptoms are belatedly visible at the leaf level. Nevertheless, GFLV disease can lead to severe economic losses with a yield decrease up to 80% [13] due to the reduction in fruit quality and the shortening of plant longevity [14].

Preventive application of nematicides, due to their limited efficacy in pest control and negative impact on the environment, is no longer used routinely by farmers [15]. For this reason, it is of fundamental importance to find a way to detect nematode attacks early and prevent their damage.

Plants defend themselves from parasite attacks in different ways, in continuous coevolution with pathogens [16]. Their stationary status makes them vulnerable but plants limit damage using a variety of defense mechanisms [17], so disease is an exceptional condition rather than normality. Defense mechanisms can be both constitutive and inducible, but while the first is pre-established and energetically irrelevant, the second requires a high amount of energy and is stimulated by pathogen attacks. Inducible defenses act at the time of pathogen recognition and rapidly limit possible damages. A typical feature of resistance is the induction of cell death at the site of attempted attack such as the hypersensitive response (HR) [18], a mechanism which highly limits pathogen proliferation in the host organism. Subsequently, a large set of defense-related genes are expressed as resistance develops [19]. HR settlement involves the induction of many defense mechanisms such as the strengthening of cell walls, salicylic acid (SA) pathway, synthesis of phytoalexins organic molecules and HR-related molecules (H_2O_2) which are among the main molecules secreted and produced during the plant/pathogen interaction [20]. Among proteins involved in defense mechanisms, the so-called pathogenesis-related proteins (PRs) certainly have deep importance in plant protection.

Besides accumulating locally in the infected tissues, PRs are also induced systemically, associated with the development of systemic acquired resistance (SAR) against other infections [21]. For example, in *Arabidopsis thaliana* there are 17 evolutionarily conserved families of PRs [22] with 22 *PR1*-type genes [23], but only one of them is activated by pathogens whereas other *PR1*-type genes are constitutively expressed [24].

Nematode attack can affect PR gene expression through the injection of substances produced in salivary glands, which can inhibit host response. Root-knot nematodes secrete molecules called “effectors” to facilitate the invasion of the host roots, avoid plant defense responses and reprogram root cells to form specialized feeding cells [25]. Various PRs have been identified as direct targets of nematode effectors, but nevertheless, their precise mode of action remains largely unknown and only a few of their direct targets in plants have been identified [25].

Plants can either act directly on pathogen feeding and reproduction, for example through trichomes or thorns or indirectly, through the emission of phytochemicals. In particular, the production of secondary metabolites is a defense strategy to cope with several pests [26]. Among secondary metabolites, plants produce root-specific volatile organic compounds (VOCs) [27], which can influence the rhizosphere and plant-pathogen interaction [28][29][30][31].

There is growing evidence that both the quantity and type of volatiles produced by roots are dramatically altered by the presence of different biotic and abiotic stresses [32][33]. It was also reported that VOC changes in response to pathogens or symbionts are species-specific [34]. For example, it has been demonstrated that plants produce chemical signals to ward off herbivorous insects by attracting their natural enemies [35]. Biogenic VOCs (BVOCs) are the major secondary metabolites in plants involved in communications between plants and the external environment, in a mechanism known as “talking plants” [36].

The term BVOCs defines organic atmospheric gases different from carbon dioxide and monoxide [37]. BVOCs include a wide range of different compounds, among which isoprene and monoterpenes are the most prominent [37]. BVOC emission can be stimulated in response to insect feeding [38] and it is largely demonstrated that plants vary the emission of organic compounds in different plant-parasite interactions [16][38][39][40][41]. Moreover, BVOC emission seems to be stimulated by the presence of elicitors present in parasite oral secretions [39].

References

1. Wine Market Observatory. European Commission, Wine Production 2015. Available online: https://ec.europa.eu/agriculture/wine/statistics_it (accessed on 22 April 2020).
2. Parkinson, J.; Mitreva, M.; Whitton, C.; Thomson, M.; Daub, J.; Martin, J.; Schmid, R.; Hall, N.; Barrell, B.; Waterston, R.H.; et al. A transcriptomic analysis of the phylum Nematoda. *Nat. Genet.* 2004, 36, 1259. [Google Scholar] [CrossRef]
3. Pastorelli, R.; Irdani, T. Metagenomica Nella Rizosfera: Il Ruolo dei Nematodi; Accademia dei Georgofili: Florence, Italy, 2010. [Google Scholar]
4. Davies, L.J.; Elling, A.A. Resistance genes against plant-parasitic nematodes: A durable control strategy? *Nematology* 2015, 17, 249–263. [Google Scholar] [CrossRef]
5. Singh, S.K.; Hodda, M.; Ash, G.J. Plant-parasitic nematodes of potential phytosanitary importance, their main hosts and reported yield losses. *Bull. OEPP* 2013, 43, 334–374. [Google Scholar] [CrossRef]
6. Nicol, J.M.; Stirling, G.R.; Rose, B.J.; May, P.; Van Heeswijck, R. Impact of nematodes on grapevine growth and productivity: Current knowledge and future directions, with special reference to Australian viticulture. *Aust. J. Grape Wine Res.* 1999, 5, 109–127. [Google Scholar] [CrossRef]
7. Andret-Link, P.; Marmonier, A.; Belval, L.; Hleibieh, K.; Ritzenthaler, C.; Demangeat, G. Ectoparasitic nematode vectors of grapevine viruses. In *Grapevine Viruses: Molecular Biology, Diagnostics and Management*; Meng, B., Martelli, G.P., Golino, D.A., Fuchs, M., Eds.; Springer: Cham, Switzerland, 2017; pp. 505–529. [Google Scholar]

8. Bonkowski, M.; Villenave, C.; Griffiths, B. Rhizosphere fauna: The functional and structural diversity of intimate interactions of soil fauna with plant roots. *Plant Soil* 2009, 321, 213–233. [Google Scholar] [CrossRef]
9. Nguyen, V.C.; Villate, L.; Gutierrez-Gutierrez, C.; Castillo, P.; Van Ghelder, C.; Plantard, O.; Esmenjaud, D. Phylogeography of the soil-borne vector nematode *Xiphinema* index highly suggests Eastern origin and dissemination with domesticated grapevine. *Sci. Rep.* 2019, 9, 7313. [Google Scholar] [CrossRef] [PubMed]
10. Andret-Link, P.; Laporte, C.; Valat, L.; Ritzenthaler, C.; Demangeat, G.; Vigne, E.; Laval, V.; Pfeiffer, P.; Stussi-Garaud, C.; Fuchs, M. Grapevine fanleaf virus: Still a major threat to the grapevine industry. *J. Plant Pathol.* 2004, 86, 183–195. [Google Scholar]
11. Groen, S.C.; Wamonje, F.O.; Murphy, A.M.; Carr, J.P. Engineering resistance to virus transmission. *Curr. Opin. Virol.* 2017, 26, 20–27. [Google Scholar] [CrossRef] [PubMed]
12. Taylor, C.E.; Raski, D.J. On the transmission of grape fanleaf by *Xiphinema* index. *Nematologica* 1964, 10, 489–495. [Google Scholar] [CrossRef]
13. Oliver, J.E.; Fuchs, M.F. Fanleaf Degeneration/Decline Disease of Grapevines. Integrated Pest Management; New York State IPM Program: New York, NY, USA, 2011; pp. 1–3. [Google Scholar]
14. Bovey, R.; Gärtel, W.; Hewitt, W.B.; Martelli, G.P.; Vuittenez, A. Soil-borne viruses transmitted by nematodes. In Virus and Virus-Like Diseases of Grapevines; Bovey, R., Gartel, W., Hewitt, W.B., Martelli, G.P., Vuittenez, A., Eds.; Payot: Lausanne, Switzerland, 1980; pp. 46–50. [Google Scholar]
15. Andret-Link, P.; Schmitt-Keichinger, C.; Demangeat, G.; Komar, V.; Fuchs, M. The specific transmission of Grapevine fanleaf virus by its nematode vector *Xiphinema* index is solely determined by the viral coat protein. *Virology* 2004, 320, 12–22. [Google Scholar] [CrossRef]
16. Coppola, M.; Cascone, P.; Madonna, V.; Di Lelio, I.; Esposito, F.; Avitabile, C.; Romanelli, A.; Guerrieri, E.; Vitiello, A.; Pennacchio, F.; et al. Plant-to-plant communication triggered by systemin primes anti-herbivore resistance in tomato. *Sci. Rep.* 2017, 7, 15522. [Google Scholar] [CrossRef] [PubMed]
17. Bennett, A.E.; Bever, J.D.; Bowers, M.D. Arbuscular mycorrhizal fungal species suppress inducible plant responses and alter defensive strategies following herbivory. *Oecologia* 2009, 160, 771–779. [Google Scholar] [CrossRef] [PubMed]
18. Pontier, D.; Balagué, C.; Roby, D. The hypersensitive response. A programmed cell death associated with plant resistance. *Comptes Rendus Acad. Sci. III Sci. Vie* 1998, 321, 721–734. [Google Scholar] [CrossRef]
19. Morel, J.B.; Dangl, J.L. The hypersensitive response and the induction of cell death in plants. *Cell Death Differ.* 1997, 4, 671–683. [Google Scholar] [CrossRef]

20. Mittler, R.; Shulaev, V.; Seskar, M.; Lam, E. Inhibition of programmed cell death in tobacco plants during a pathogen-induced hypersensitive response at low oxygen pressure. *Plant Cell* 1996, 8, 1991–2001. [Google Scholar] [CrossRef]

21. Van Loon, L.C.; Van Strien, E.A. The families of pathogenesis-related proteins, their activities, and comparative analysis of PR-1 type proteins. *Physiol. Mol. Plant Pathol.* 1999, 55, 85–97. [Google Scholar] [CrossRef]

22. Pečenková, T.; Pleskot, R.; Žárský, V. Subcellular localization of *Arabidopsis* pathogenesis-related 1 (PR1) protein. *Int. J. Mol. Sci.* 2017, 18, 825. [Google Scholar] [CrossRef]

23. Mitsuhashi, I.; Iwai, T.; Seo, S.; Yanagawa, Y.; Kawahigasi, H.; Hirose, S.; Ohkawa, Y.; Ohashi, Y. Characteristic expression of twelve rice PR1 family genes in response to pathogen infection, wounding, and defense-related signal compounds (121/180). *Mol. Genet. Genom.* 2008, 279, 415–427. [Google Scholar] [CrossRef]

24. Van Loon, L.C.; Rep, M.; Pieterse, C.M. Significance of inducible defense-related proteins in infected plants. *Annu. Rev. Phytopathol.* 2006, 44, 135–162. [Google Scholar] [CrossRef]

25. Mejias, J.; Truong, N.M.; Abad, P.; Favery, B.; Quentin, M. Plant proteins and processes targeted by parasitic nematode effectors. *Front. Plant Sci.* 2019, 10. [Google Scholar] [CrossRef]

26. Lin, J.; Wang, D.; Chen, X.; Köllner, T.G.; Mazarei, M.; Guo, H.; Pantalone, V.R.; Arelli, P.; Stewart, C.N., Jr.; Wang, N.; et al. An (E,E)- α -farnesene synthase gene of soybean has a role in defence against nematodes and is involved in synthesizing insect-induced volatiles. *Plant Biotechnol. J.* 2017, 15, 510–519. [Google Scholar] [CrossRef] [PubMed]

27. Chen, F.; Ro, D.K.; Petri, J.; Gershenzon, J.; Bohlmann, J.; Pichersky, E.; Tholl, D. Characterization of a root-specific *Arabidopsis* terpene synthase responsible for the formation of the volatile monoterpenes 1,8-cineole. *Plant Physiol.* 2004, 135, 1956–1966. [Google Scholar] [CrossRef]

28. Rostás, M.; Cripps, M.G.; Silcock, P. Aboveground endophyte affects root volatile emission and host plant selection of a belowground insect. *Oecologia* 2015, 177, 487–497. [Google Scholar] [CrossRef] [PubMed]

29. Unsicker, S.B.; Kunert, G.; Gershenzon, J. Protective perfumes: The role of vegetative volatiles in plant defense against herbivores. *Curr. Opin. Plant Biol.* 2009, 12, 479–485. [Google Scholar] [CrossRef] [PubMed]

30. Lin, C.; Owen, S.M.; Peñuelas, J. Volatile organic compounds in the roots and rhizosphere of *Pinus* spp. *Soil Biol. Biochem.* 2007, 39, 951–960. [Google Scholar] [CrossRef]

31. Lazník, Ž.; Trdán, S. An investigation on the chemotactic responses of different entomopathogenic nematode strains to mechanically damaged maize root volatile compounds. *Exp. Parasitol.* 2013, 134, 349–355. [Google Scholar] [CrossRef] [PubMed]

32. Degenhardt, J.; Hiltpold, I.; Köllner, T.G.; Frey, M.; Gierl, A.; Gershenzon, J.; Hibbard, B.E.; Ellersieck, M.R.; Turlings, T.C. Restoring a maize root signal that attracts insect-killing nematodes to control a major pest. *Proc. Natl. Acad. Sci. USA* 2009, 106, 13213–13218. [Google Scholar] [CrossRef]

33. Rasmann, S.; Köllner, T.G.; Degenhardt, J.; Hiltpold, I.; Toepfer, S.; Kuhlmann, U.; Gershenzon, J.; Turlings, T.C. Recruitment of entomopathogenic nematodes by insect-damaged maize roots. *Nature* 2005, 434, 732. [Google Scholar] [CrossRef] [PubMed]

34. Sun, X.G.; Tang, M. Effect of arbuscular mycorrhizal fungi inoculation on root traits and root volatile organic compound emissions of *Sorghum bicolor*. *S. Afr. J. Bot.* 2013, 88, 373–379. [Google Scholar] [CrossRef]

35. Zitzelsberger, C.; Buchbauer, G. Essential oils as “a cry for help”. A review. *Nat. Prod. Commun.* 2015, 10, 1127–1138. [Google Scholar] [CrossRef]

36. Šimpraga, M.; Takabayashi, J.; Holopainen, J.K. Language of plants: Where is the word? *J. Integr. Plant Biol.* 2016, 58, 343–349. [Google Scholar] [CrossRef]

37. Kesselmeier, J.; Staudt, M. Biogenic volatile organic compounds (VOC): An overview on emission, physiology and ecology. *J. Atmos. Chem.* 1999, 33, 23–88. [Google Scholar] [CrossRef]

38. Paré, P.W.; Tumlinson, J.H. De novo biosynthesis of volatiles induced by insect herbivory in cotton plants. *Plant Physiol.* 1997, 114, 1161–1167. [Google Scholar] [CrossRef] [PubMed]

39. Imbiscuso, G.; Trotta, A.; Maffei, M.; Bossi, S. Herbivory induces a ROS burst and the release of volatile organic compounds in the fern *Pteris vittata* L. *J. Plant Interact.* 2009, 4, 15–22. [Google Scholar] [CrossRef]

40. Trowbridge, A.M.; Stoy, P.C. BVOC-mediated plant-herbivore interactions. In *Biology, Controls and Models of Tree Volatile Organic Compound Emissions*; Niinemets, Ü., Monson Russell, K., Eds.; Springer: Dordrecht, The Netherlands, 2013; pp. 21–46. [Google Scholar]

41. Cheng, A.X.; Lou, Y.G.; Mao, Y.B.; Lu, S.; Wang, L.J.; Chen, X.Y. Plant terpenoids: Biosynthesis and ecological functions. *J. Integr. Plant Biol.* 2007, 49, 179–186.

Retrieved from <https://encyclopedia.pub/entry/history/show/2819>