horticulturae

MDPI

Editorial

Special Issue "Sustainable Control Strategies of Plant Pathogens in Horticulture"

Hillary Righini [1,*], Roberta Roberti [1,*] and Stefania Galletti [2]

[1] Department of Agriculture and Food Sciences, Alma Mater Studiorum, University of Bologna, 40127 Bologna, Italy
[2] Research Centre for Agriculture and Environment, Council for Agricultural Research and Economics, 40128 Bologna, Italy; stefania.galletti@crea.gov.it
* Correspondence: hillary.righini2@unibo.it (H.R.); roberta.roberti@unibo.it (R.R.)

1. Introduction

European Regulation No. 1107/2009 [1] recommends the adoption of alternatives to synthetic products among plant protection products, thereby repealing Council Directives 79/117/EEC [2] and 91/414/EEC [3]. This recommendation is driven by the potential adverse effects of synthetic products on the environment, as well as on human and animal health [4,5]. Furthermore, the European "Green Deal" has introduced various initiatives that aim to facilitate a green transition to counteract climate change and safeguard the environment.

One of the key objectives outlined in the "Green Deal" is to substantially reduce the use of chemical pesticides in agriculture by 2030 [6,7], to reduce the associated risks and to address potential challenges in the management of plant pathogens. This strategy also outlines a set of measures to be achieved by 2030, including the promotion of 25% of organic agriculture. This ambitious target highlights the need for innovative research to identify alternative solutions to chemical pesticides. Over the past ten years, most of the research has focused on the use of beneficial microorganisms such as fungi and bacteria [8–10], natural substances [11,12], resistant varieties [13,14], RNAi gene silencing that targets specific pathogens [15,16] and organic cultivation systems [17].

2. Special Issue Contents

The Special Issue on "Sustainable Control Strategies of Plant Pathogens in Horticulture" features research articles and two reviews. These contributions present potential alternatives to synthetic pesticides, showing innovative results related to the use of natural substances, beneficial microorganisms and resistant varieties in the management of several pathogens affecting plants.

The majority of the articles deal with the antifungal activity of natural substances derived from plants (Table 1), such as essential oils from thyme, common juniper and hyssop (1); giant reed extract (*Arundo donax*) (2) against *Alternaria* spp. and *Phytium ultimum*; and extracts from Argentinian plant species against *Penicillium* spp. and *Geotrichum citri-aurantii* (3). On the same topic, two articles demonstrate the in vitro antifungal activity of saponins from *Medicago* species; oat grains and homogenates from sprouts of Brassica species against *Verticillium dahliae* (4); and the *in planta* disease reduction of *Rhizoctonia solani*, *P. ultimum* and *Fusarium oxysporum* following tomato seed treatment with water-soluble polysaccharides from *Jania adhaerens* (5). Three more articles focus on the potential of by-products and bio-composts to reduce disease symptoms and increase plant resistance to pathogens. An alkaline residue from *Gelidium sesquipedale* agar production elicits resistance in tomato and reduces *Plasmopara viticola* symptoms in the vineyard (6), and the guava wood vinegar by-product of charcoal production effectively reduces potato black dot disease by *Colletotrichum coccodes* (7). Several bio-composts from aromatic plant residues controlled damping-off by *R. solani* and *Sclerotinia sclerotiorum* on garden cress (8).

Citation: Righini, H.; Roberti, R.; Galletti, S. Special Issue "Sustainable Control Strategies of Plant Pathogens in Horticulture". *Horticulturae* **2024**, *10*, 146. https://doi.org/10.3390/horticulturae10020146

Received: 4 January 2024
Revised: 29 January 2024
Accepted: 1 February 2024
Published: 4 February 2024

Table 1. Main results obtained with natural substances in this Special Issue.

Natural Substances	Plant/Pathogen/Method	Activity	Ctrb.
Essential oils of thyme, common juniper, hyssop	Carrot (C), tomato (T) and onion (O) seeds naturally infected by *Alternaria* spp. Agar plate assay amended with essential oils.	Thyme and common juniper: 40–100% long-lasting antifungal activity for C, T and O. Hyssop: no activity for C; 20–60% long-lasting antifungal activity for T and O.	1
Giant reed extract	Zucchini. Plant growth substrate inoculated with *Pythium ultimum* and treated with the extract.	Disease reduction up to 73% and pathogen growth (colony forming units) in the substrate by 90%.	2
Forty extracts from 20 Argentinian plant species	*Penicillium digitatum*, *P. italicum* and *Geotrichum citri-aurantii.* Agar plate diffusion assay.	Inhibition of *G. citri-aurantii* growth of more than 50% by most of the extracts. Inhibition of *P. digitatum* and *P. talicum* by some extracts.	3
Saponins from *Medicago* species and oat grains and homogenates from sprouts of *Brassica* species	*Verticillium dahliae*. Agar plate assay amended with saponins and homogenates. Maize and tomato seeds treated and sown on filter paper.	Reduction in mycelium growth and conidium formation. No phytotoxic effect on seed germination.	4
Water-soluble polysaccharides from *Jania adhaerens*	Tomato. Seeds treated with polysaccharides. Plant growth substrate inoculated with *Rhizoctonia solani* and *P. ultimum* before seeding or with *Fusarium oxysporum* before transplant.	Disease reduction of *R. solani*, *P. ultimum* and *F. oxysporum* up to 58%, 53% and 29%, respectively. Increase in seedling emergence and plant development. Up-regulation of HQT, HCT, PR1 PAL and PR2 genes. Increase in β-1,3-glucanase activity.	5
Gelidium sesquipedale by-product (alkaline residue)	Tomato. Greenhouse experiments. Grapevine. *Plasmopara viticola* in field trials.	Increase in peroxidase and PAL activities and up-regulation of PR9 genes in tomato plants. Reduction in downy mildew symptoms in grapewine.	6
Guava wood vinegar by-product of charcoal production	Potato. *Colletotrichum coccodes.* Agar plate assay amended with the by-product. Pot experiments—stem/soil inoculation with the pathogen.	Inhibition of pathogen mycelial growth. Black dot disease reduction by an average of 23% (stem colonization), 20% (roots covered with sclerotia) and 30% (wilted plants) in the two seasons of experiments.	7
Bio-composts from aromatic plant residues	Garden cress. *R. solani*, *Sclerotinia sclerotiorum*.	Reduction in *S. sclerotiorum* damping-off by all of the raw composts. Reduction in *R. solani* damping-off by 7 composts. Overall, 2 composts showed suppression levels up to 60%.	8

Three articles deal with beneficial microorganisms to control fungal and viral diseases (Table 2). Among these, *Bacillus amyloliquefaciens* as a soil amendment and *B. subltilis* culture filtrate that was sprayed on leaves were effective in reducing apple replant disease (9) and TMV accumulation in tomato (10). One contribution showed the mycoparasitic activity of *Trichoderma* species against *Fusarium solani*, the compatibility of *T. asperellum* with captan and mancozeb and the incompatibility of all *Trichoderma* species with chlorothalonil in vitro (11).

Table 2. Main results obtained with beneficial microorganisms and resistant varieties in this Special Issue.

	Plant/Pathogen/Method	Activity	Ctrb.
Microorganisms			
Bacillus amyloliquefaciens QSB-6	Apple replant disease. Soil amendment. Field conditions.	Increase in plant growth parameters (i.e., plant height), soil bacteria population (i.e., *Actinomycetes*) and soil enzymatic activity. Reduction in soil phenolic acid content and *Fusarium* spp. population.	9
Bacillus subtilis HA1 culture filtrate	Tomato. TMV. Foliar treatment. Pot experiments.	Increase in plant growth (root and shoot parameters). Increase in total phenolic and flavonoid content up to 27 and 50%, respectively, and in the activity of ROS-scavenging enzymes. Reduction in TMV accumulation up to 91%. Up-regulation of PR1, PAL, CHS and HQT genes.	10
Trichoderma asperellum *T. hamatum* *T. harzianum* *T. koningiopsis*	*Fusarium solani.* Dual plate assay on agar medium not amended or amended with the fungicides captan, chlorothalonil and mancozeb.	*Trichoderma* species inhibited *F. solani* up to 67%. High compatibility of *T. asperellum* with captan and mancozeb. No compatibility of *Trichoderma* species with chlorothalonil.	11
Resistant varieties			
Fourteen Tunisian melon landraces	*Podosphaera xanthii*, 3 races (2, 3.5 and 5). Artificial infection in a growth chamber. Natural infection in a greenhouse.	Susceptibility of all landraces to the 3.5 and 5 races and resistance of several landraces to race 2, in the growth chamber. The resistance of three landraces to *P. xanthii* race 2 was confirmed under natural conditions.	12

Table 2 also reports an article on the possibility of using melon landraces to counteract powdery mildew caused by three races of *Podosphaera xanthii* (2, 3.5 and 5) under both artificial and natural infection, showing that the resistance of the three melon landraces to race 2 of the pathogen was confirmed under natural conditions (12).

The topic of this Special issue is complemented by two reviews (13, 14). One review (13) focuses on sustainable options for the management of diseases in horticulture, such as the use of biocontrol agents, natural products, forecasting models, precision farming, nanotechnology, endotherapy, systemic resistance inducers and gene silencing. The second review (14) deals with the use of basic substances against several seed-borne pathogens, fungi, oomycetes, phytoplasma, bacteria and viruses. The basic substances are active, non-toxic substances which fulfil the criteria of a "foodstuff" as defined in Article 2 of Regulation (EC) No 178/2002 [18]. For their use as plant protection products, basic substances are regulated in the EU according to criteria presented in Article 23 of Regulation (EC) No 1107/2009 [1]. The basic substances examined in this review (14) are those already approved in Europe and some of those that are still under evaluation.

3. Conclusions

This Special Issue comprises articles that aimed to identify alternative, sustainable and effective strategies for the management of important plant diseases. The extensive use of synthetic fungicides in managing plant diseases has led to the development of resistance in fungi and oomycetes. Additionally, in recent years, there has been growing consumer demand for food devoid of residues and produced in an environmentally friendly manner. Following this trend, the potential strategies outlined in this Special Issue offer viable alternatives for adoption in large-scale trials.

All the articles contribute valuable insights that enhance understanding in these research fields and have the potential to facilitate future sustainable practical solutions for plant disease management.

The Guest Editors express their gratitude to all authors for delivering interesting research findings in this Special Issue and for sharing their expertise. Furthermore, they extend appreciation to the Journal "*Horticulturae*" for its helpful support, enabling the realization of this Special Issue.

Author Contributions: Writing—Original Draft Preparation, Writing—Review and Editing, Visualization, Supervision, H.R., R.R. and S.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflicts of interest.

List of Contributions

1. Chrapačienė, S.; Rasiukevičiūtė, N.; Valiuškaitė, A. Control of Seed-Borne Fungi by Selected Essential Oils. *Horticulturae* **2022**, *8*, 220. https://doi.org/10.3390/horticulturae8030220.
2. Galletti, S.; Cianchetta, S.; Righini, H.; Roberti, R. A Lignin-Rich Extract of Giant Reed (*Arundo donax* L.) as a Possible Tool to Manage Soilborne Pathogens in Horticulture: A Preliminary Study on a Model Pathosystem. *Horticulturae* **2022**, *8*, 589. https://doi.org/10.3390/horticulturae8070589.
3. Alvarez, N.H.; Stegmayer, M.I.; Seimandi, G.M.; Pensiero, J.F.; Zabala, J.M.; Favaro, M.A.; Derita, M.G. Natural Products Obtained from Argentinean Native Plants Are Fungicidal against Citrus Postharvest Diseases. *Horticulturae* **2023**, *9*, 562. https://doi.org/10.3390/horticulturae9050562.
4. Morcia, C.; Piazza, I.; Ghizzoni, R.; Delbono, S.; Felici, B.; Baima, S.; Scossa, F.; Biazzi, E.; Tava, A.; Terzi, V.; Finocchiaro, F. In Search of Antifungals from the Plant World: The Potential of Saponins and *Brassica* Species against *Verticillium dahliae* Kleb. *Horticulturae* **2022**, *8*, 729. https://doi.org/10.3390/horticulturae8080729.
5. Righini, H.; Roberti, R.; Cetrullo, S.; Flamigni, F.; Quintana, A.M.; Francioso, O.; Panichi, V.; Cianchetta, S.; Galletti, S. *Jania adhaerens* Primes Tomato Seed against Soil-Borne Pathogens. *Horticulturae* **2022**, *8*, 746. https://doi.org/10.3390/horticulturae8080746.
6. Koçi, R.; Dupuy, F.; Lebbar, S.; Gloaguen, V.; Faugeron Girard, C. A New Promising Plant Defense Stimulator Derived from a By-Product of Agar Extraction from *Gelidium sesquipedale*. *Horticulturae* **2022**, *8*, 958. https://doi.org/10.3390/horticulturae8100958.
7. El-Fawy, M.M.; Abo-Elyousr, K.A.M.; Sallam, N.M.A.; El-Sharkawy, R.M.I.; Ibrahim, Y.E. Fungicidal Effect of Guava Wood Vinegar against *Colletotrichum coccodes* Causing Black Dot Disease of Potatoes. *Horticulturae* **2023**, *9*, 710. https://doi.org/10.3390/horticulturae9060710.
8. Pane, C.; Spaccini, R.; Caputo, M.; De Falco, E.; Zaccardelli, M. Multi-Parameter Characterization of Disease-Suppressive Bio-composts from Aromatic Plant Residues Evaluated for Garden Cress (*Lepidium sativum* L.) Cultivation. *Horticulturae* **2022**, *8*, 632. https://doi.org/10.3390/horticulturae8070632.
9. Duan, Y.; Zhou, Y.; Li, Z.; Chen, X.; Yin, C.; Mao, Z. Effects of *Bacillus amyloliquefaciens* QSB-6 on the Growth of Replanted Apple Trees and the Soil Microbial Environment. *Horticulturae* **2022**, *8*, 83. https://doi.org/10.3390/horticulturae8010083.
10. El-Gendi, H.; Al-Askar, A.A.; Király, L.; Samy, M.A.; Moawad, H.; Abdelkhalek, A. Foliar Applications of *Bacillus subtilis* HA1 Culture Filtrate Enhance Tomato Growth and Induce Systemic Resistance against *Tobacco mosaic virus* Infection. *Horticulturae* **2022**, *8*, 301. https://doi.org/10.3390/horticulturae8040301.
11. Parraguirre Lezama, C.; Romero-Arenas, O.; Valencia de Ita, M.D.L.A.; Rivera, A.; Sangerman Jarquín, D.M.; Huerta-Lara, M. In Vitro Study of the Compatibility of Four Species of *Trichoderma* with Three Fungicides and Their Antagonistic Activity against *Fusarium solani*. *Horticulturae* **2023**, *9*, 905. https://doi.org/10.3390/horticulturae9080905.
12. Chikh-Rouhou, H.; Garcés-Claver, A.; Kienbaum, L.; Ben Belgacem, A.; Gómez-Guillamón, M.L. Resistance of Tunisian Melon Landraces to *Podosphaera xanthii*. *Horticulturae* **2022**, *8*, 1172. https://doi.org/10.3390/horticulturae8121172
13. Scortichini, M. Sustainable Management of Diseases in Horticulture: Conventional and New Options. *Horticulturae* **2022**, *8*, 517. https://doi.org/10.3390/horticulturae8060517.
14. Orzali, L.; Allagui, M.B.; Chaves-Lopez, C.; Molina-Hernandez, J.B.; Moumni, M.; Mezzalama, M.; Romanazzi, G. Basic Substances and Potential Basic Substances: Key Compounds for a Sustainable Management of Seedborne Pathogens. *Horticulturae* **2023**, *9*, 1220. https://doi.org/10.3390/horticulturae9111220.

References

1. Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 Concerning the Placing of Plant Protection Products on the Market and Repealing Council Directives 79/117/EEC and 91/414/EEC. Available online: https://eur-lex.europa.eu/eli/reg/2009/1107/oj (accessed on 1 January 2024).
2. Council Directive 79/117/EEC of 21 December 1978 Prohibiting the Placing on the Market and Use of Plant Protection Products Containing Certain Active Substances. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31979L0117 (accessed on 1 January 2024).
3. Council Directive 91/414/EEC of 15 July 1991 Concerning the Placing of Plant Protection Products on the Market. Available online: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:31991L0414 (accessed on 1 January 2024).
4. Geiger, F.; Bengtsson, J.; Berendse, F.; Weisser, W.W.; Emmerson, M.; Morales, M.B.; Ceryngier, P.; Liira, J.; Tscharntke, T.; Winqvist, C.; et al. Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic Appl. Ecol.* **2010**, *11*, 97–105. [CrossRef]
5. Pathak, V.M.; Verma, V.K.; Rawat, B.S.; Kaur, B.; Babu, N.; Sharma, A.; Dewali, S.; Yadav, M.; Kumari, R.; Singh, S.; et al. Current status of pesticide effects on environment, human health and it's eco-friendly management as bioremediation: A comprehensive review. *Front. Microbiol.* **2022**, *17*, 962619. [CrossRef] [PubMed]
6. Guyomard, H.; Soler, L.G.; Détang-Dessendre, C.; Réquillart, V. The European Green Deal improves the sustainability of food systems but has uneven economic impacts on consumers and farmers. *Commun. Earth Environ.* **2023**, *4*, 358. [CrossRef]
7. Montanarella, L.; Panagos, P. The relevance of sustainable soil management within the European Green Deal. *Land Use Policy* **2021**, *100*, 104950. [CrossRef]
8. Vieira, M.E.O.; Nunes, V.V.; Calazans, C.C.; Silva-Mann, R. Unlocking plant defenses: Harnessing the power of beneficial microorganisms for induced systemic resistance in vegetables—A systematic review. *Biol. Control* **2023**, *188*, 105428.
9. Pastor, N.; Palacios, S.; Torres, A.M. Microbial consortia containing fungal biocontrol agents, with emphasis on *Trichoderma* spp.: Current applications for plant protection and effects on soil microbial communities. *Eur. J. Plant Pathol.* **2023**, *167*, 593–620. [CrossRef]
10. Ünlü, E.; Çalış, Ö.; Say, A.; Karim, A.A.; Yetişir, H.; Yılmaz, S. Investigation of the effects of *Bacillus subtilis* and *Bacillus thuringiensis* as bio-agents against powdery mildew (*Podosphaera xanthii*) disease in zucchini (*Cucurbita pepo* L.). *Microb. Pathog.* **2023**, *185*, 106430. [CrossRef] [PubMed]
11. Righini, H.; Somma, A.; Cetrullo, S.; D'Adamo, S.; Flamigni, F.; Quintana, A.M.; Roberti, R. Inhibitory activity of aqueous extracts from *Anabaena minutissima*, *Ecklonia maxima* and *Jania adhaerens* on the cucumber powdery mildew pathogen in vitro and in vivo. *J. Appl. Phycol.* **2020**, *32*, 3363–3375. [CrossRef]
12. Davari, M.; Ezazi, R. Mycelial inhibitory effects of antagonistic fungi, plant essential oils and propolis against five phytopathogenic *Fusarium* species. *Arch. Microbiol.* **2022**, *204*, 480. [CrossRef] [PubMed]
13. Zhang, Y.; Wang, J.; Xiao, Y.; Jiang, C.; Cheng, L.; Guo, S.; Luo, C.; Wang, Y.; Jia, H. Proteomics analysis of a tobacco variety resistant to brown spot disease and functional characterization of NbMLP423 in *Nicotiana benthamiana*. *Mol. Biol. Rep.* **2023**, *50*, 4395–4409. [CrossRef] [PubMed]
14. Mbinda, W.; Masaki, H. Breeding strategies and challenges in the improvement of blast disease resistance in finger millet. A current review. *Front. Plant Sci.* **2021**, *11*, 602882. [CrossRef] [PubMed]
15. Biedenkopf, D.; Will, T.; Knauer, T.; Jelonek, L.; Furch, A.C.U.; Busche, T.; Koch, A. Systemic spreading of exogenous applied RNA biopesticides in the crop plant *Hordeum vulgare*. *ExRNA* **2020**, *2*, 12. [CrossRef]
16. Haile, Z.M.; Gebremichael, D.E.; Capriotti, L.; Molesini, B.; Negrini, F.; Collina, M.; Sabbadini, S.; Mezzetti, B.; Baraldi, E. Double-stranded RNA targeting dicer-like genes compromises the pathogenicity of *Plasmopara viticola* on grapevine. *Front. Plant Sci.* **2021**, *12*, 667539. [CrossRef] [PubMed]
17. Van Bruggen, A.H.C.; Finckh, M.R. Plant diseases and management approaches in organic farming systems. *Annu. Rev. Phytopathol.* **2016**, *54*, 25–54. [CrossRef] [PubMed]
18. Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 Laying Down the General Principles and Requirements of Food Law, Establishing the European Food Safety Authority and Laying Down Procedures in Matters of Food Safety. Available online: https://www.legislation.gov.uk/eur/2002/178/contents (accessed on 1 January 2024).