Underground alarms: volatile-mediated recruitment of beneficial soil bacteria by plants under biotic stress

Rizaludin, M.S.

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Curriculum Vitae

Muhammad Syamsu Rizaludin was born on 20 September 1992 in Blitar, East Java, Indonesia. His early interest in life sciences, particularly biology, led him to pursue a Bachelor's degree in Microbiology at the School of Life Sciences and Technology, Bandung Institute of Technology (Institut Teknologi Bandung, Indonesia), from which he graduated in 2015. After graduation, he worked as a research assistant at a national agricultural company in collaboration with his alma mater, focusing on soil health and plant growth–promoting rhizobacteria.

His growing interest in agriculture and soil ecology encouraged him to continue his studies abroad. In 2017, he began his Master's program at Wageningen University and Research, the Netherlands, majoring in Organic Agriculture (currently *Resilient Farming and Food Systems*) with a specialization in Agroecology. During his Master's studies, he conducted his thesis research at the Department of Microbial Ecology (NIOO-KNAW) under Prof. dr. Wietse de Boer and Dr. Anna Chlochiatti, focusing on stimulating indigenous saprophytic fungal communities using organic amendments, particularly sawdust from different tree species. His research combined *in vitro* and *in planta* experiments to examine their effects on soil-borne fungal pathogens. He later joined the PROMISE project under Prof. dr. Jos M. Raaijmakers and Dr. Desalegn Etalo as part of his Master's internship, investigating the role of endophytic fungi and their volatile organic compounds (VOCs) in regulating *Striga* seed germination. Motivated by his interest in microbial interactions and volatile-mediated communication, Muhammad joined the Gravitation-funded MiCRop project as a PhD candidate under Prof. dr. Jos M. Raaijmakers and Prof. dr. Paolina Garbeva. His PhD research focused on the role of root-emitted VOCs in the recruitment of beneficial soil bacteria and the influence of stress-induced volatiles on this process. Within the MiCRop consortium, he contributed his expertise in microbial and plant VOC research and actively participated in collaborative projects and meetings. As his interest in academia continues, Muhammad now works as a postdoctoral researcher within the MiCrop Phase II team, focusing on microbial molecular perception of plant stress–associated volatile signals.

Beyond academia, he is a co-founder and active member of the Rotasi Institute, a non-profit organization in Indonesia promoting sustainable agriculture, particularly emphasizing the importance of the microbiome in maintaining soil health. Through this initiative, he engages with smallholder

farmers in rural areas to share knowledge and practices that bridge scientific understanding with real-world agricultural sustainability.

List of Publications

1. **Rizaludin MS**, Stopnisek N, Raaijmakers JM, Garbeva P. The chemistry of stress: understanding the 'cry for help'of plant roots. *Metabolites* 11(6):357 (Chapter 2 of this thesis)

2. Clocchiatti A, Hannula SE, **Rizaludin MS**, Hundscheid MP, Klein Gunnewiek PJ, Schilder MT, Postma J, de Boer W. Impact of cellulose-rich organic soil amendments on growth dynamics and pathogenicity of rhizoctonia solani. *Microorganisms* 9(6):1285.

3. Lee Díaz AS, **Rizaludin MS**, Zweers H, Raaijmakers JM, Garbeva P. Exploring the volatiles released from roots of wild and domesticated tomato plants under insect attack. *Molecules* 27(5):1612. (Chapter 4 of this thesis)

4. **Rizaludin MS**, Garbeva P, Zwart M, Hu J. Microbial volatiles mediate bacterial evolutionary dynamics. *The ISME Journal* 12:2144-6.

5. **Rizaludin MS**, Díaz AS, Zweers H, Raaijmakers JM, Garbeva P. Foliar infections by Botrytis cinerea modulate the tomato root volatilome and microbiome. *FEMS Microbiology Ecology* 101:5 (Chapter 3 of this thesis)

Acknowledgements

This thesis represents the result of several years of research, learning, and collaboration. Although it bears my name, it would not have been possible without the support and contributions of many people to whom I am deeply grateful.

First and foremost, I would like to express my sincere gratitude to my supervisors, **Jos** and **Paolina**, for their invaluable guidance and support throughout my PhD journey.
To **Jos**, thank you for the opportunity to join your group and for the trust you placed in me, even when I lacked confidence in myself. Your advice on experimental work and presentation skills has helped me a lot as a researcher, and I appreciated the patience and freedom you gave me to explore my ideas.
To **Paolina**, thank you for your constant support, encouragement, and care. You have an exceptional ability to elevate my confidence and help me see the positive sides of myself. Thank you for creating room for ideas and guiding me to stay focused. Your mentorship has contributed greatly to both my professional and personal growth.

I am also thankful to my **paranymphs, Jiayi** and **Joséphine**.
To **Jiayi**, thank you for the many thoughtful conversations about parenthood. It has been comforting and inspiring to exchange our parenting experiences while balancing the demands of our PhDs.
To **Joséphine**, although you only recently started your PhD, you have already brought great enthusiasm and positive energy. I hope we will have the opportunity to work together in the future, and I wish you the very best in your PhD journey.

My sincere thanks go to my NIOO MiCrop Phase I team **Stalin, Nejc, Jie, Dario,** and **Deborah** for all the scientific discussions, mutual help, shared travels, and continuous support. Working and learning together has been both productive and enjoyable. I am also grateful to the **MiCrop consortium members (PhDs, postdocs and PIs)** for the fruitful discussions and inspiring collaborations.

I would like to thank my students **Sama, Isabel, Cristina, Clara,** and **Maria** whose enthusiasm and hard work enriched this project. It has been a pleasure to supervise and learn alongside you.

To my research collaborators **Yan, Zulema, Hinako, Ivan, Sasiwimon,** and **Ying** thank you for the fruitful research collaborations. Working together with you has expanded my scientific perspectives.

To my colleagues in the Microbial Ecology (ME) department **Christina, Mahdere, Desalegn, Ana, Dominika, Azkia, Anna, Adam, Ben, Alex, Khoiri, Mingxue, Lino, Xinya, Han, Lena, Linda, Luisa, Lhais, Xue, Hinako, Ellen, Charishma, Omar, Gabriel, Akari, Marcio, Ruchen, Germán, Changji, Jing, Benedikt, Erik, Ate, Kang, Brandon, Luzia, Eline, Einar, Samin, Ohana, Sewunet, Getahun, Raul, Cristina, Dieke, Marcelle, Stijn, Makrina, Luc, Sascha, Mark, Viviane, Wietse, Eiko, Paul, Mattias, Tom**, **Very** and many others, thank you for creating such a pleasant and stimulating environment. I am grateful for the discussions and countless moments of laughter and support we shared.

I would also like to acknowledge the invaluable technical and laboratory support that made my experiments possible. Thank you to **Hans** for his expertise with volatile measurements, and to **Saskia, Maria, Marion, Paulien, Agata, Tanja, Ciska, Iris** and **Roos** for their excellent microbial, chemical and molecular laboratory supports. I also thank **Gregor Disveld** for technical assistance in the greenhouse.

Beyond the university, I owe heartfelt thanks to my friends **Iqbal** and **Putri, Dana** and **Diana, Margi** and **Nindya, Zagi** and **Ana, Putri** and **Ahmi, Mayang, Reni**, and your wonderful children, as well as **Obi** and **Zidnie**, who have accompanied me and my family during our time in the Netherlands. Your companionship and understanding provided the balance I needed beyond research life.

I would also like to express my deepest gratitude to my **mom** and **dad, grandma, aunt,** and **uncle** for their unwavering support and belief in me throughout this long journey. Your encouragement and faith carried me through the most challenging moments and made it possible for me to pursue this PhD with confidence and perseverance.

Finally, and most importantly, I would like to thank my **wife, Isnawati,** and **my daughter, Sofia**. You have been my greatest source of motivation and happiness.
Isna, thank you for listening to all my complaints and still doing your best to offer thoughtful solutions, even while being busy as both a mother and a PhD student yourself. Your strength and understanding have been truly inspiring.
To my daughter **Sofia**, no word can explain how happy I am watching you grow so fast into such a happy little girl. You bring endless joy and light into my life. This work is dedicated to both of you.

Lastly, I would like to thank everyone who has accompanied me throughout both my scientific and personal journeys. Each of you has left a lasting impact on this work and on me as a person.

Education Statement of the Graduate School

Experimental Plant Sciences

Issued to:	**Muhammad Syamsu Rizaludin**
Date:	**21 January 2026**
Group:	**Microbial Ecology**
University:	**Leiden University & Netherlands Institute of Ecology (NIOO-KNAW)**

1) Start-up phase	**date**	**credits**
▶ First presentation of your project		
Volatile-mediated bacterial recruitment in rhizosphere of plants under biotic stresses	22 February 2021	1,5
▶ Writing or rewriting a project proposal		
PhD proposal writing for EPS and Leiden University registration	24 July 2020	6,0
▶ MSc courses		
Subtotal start-up phase		7,5

2) Scientific exposure	**date**	**credits**
▶ **EPS PhD days**		
EPS Student Day “Get2Gether” , Online	1-2 February 2021	0,4
EPS Student Day “Get2Gether” , Soest (NL)	3-4 May 2022	0,6
▶ **EPS theme symposia**		
EPS theme 3 symposium ‘’Metabolism and Adaptation’, Online	30 October 2020	0,2
EPS theme 4 symposium ‘Genome biology’, Online	11 December 2020	0,2
EPS theme 2 symposium ‘Interactions between plants and biotic agents’, Online	9 February 2021	0,2

EPS theme 2 symposium “Interactions between plants and biotic agents”, Amsterdam	19 January 2023	0,3
▶ **Lunteren days and other national platforms**		
Annual Meeting ‘Experimental Plant Sciences’, Lunteren (NL)	11-12 April 2022	0,6
Annual Meeting ‘Experimental Plant Sciences’, Lunteren (NL)	17-18 April 2023	0,6
▶ **Seminars (series), workshops and symposia**		
Workshop on Good academic practice by NIOO Integrity Advisory Board	1 September 2020	0,1
NIOO-wide seminar at NIOO-KNAW	25 October 2021	0,1
Untargeted metabolomic using LC-MS at NIOO-KNAW	20 October 2022	0,1
WEES seminar on potential for microbial volatiles to enhance biological control of insect pests, WUR	22 September 2022	0,1
Workshop on working with bioinformatic servers, NIOO-KNAW	17 October 2022	0,2
Workshop on the Tidyverse and Rmarkdown, NIOO-KNAW	20 December 2022	0,1
Workshop on “Agilent Masshunter software for LC/GC-QTOF-MS” at NIOO-KNAW	22 February & 3 March 2023	0,6
Computational Metabolomics Seminar-Hidden features in MZmine, GNPS, and fastMASST, WUR	17 March 2023	0,1
Untargeted Volatilomics Analysis workshop at NIOO-KNAW	27 January 2023	0,1
Molecular network analysis workshop for rapid and visual exploration of MS-based datasets, NIOO-KNAW	28 March 2025	0,1

▶ **Seminar plus**

▶ **International symposia and congresses**

NWO-JAPAN(JSPS) online seminar: Microbial chemical communication “from basic to application”	3 March 2022	0,2
Microbe-assisted crop production (miCROPe); opportunities, challenges, & needs, Vienna, Austria	11-14 July 2022	1,2
4th Plant Microbiome Symposium, Quito, Ecuador	1-4 August 2023	1,2
5th Plant Microbiome Symposium, Amsterdam, The Netherlands	17-21 June 2024	1,2
1st International Symposium for Volatile Interactions in Ecosystems	21-23 May 2025	0,8

▶ **Presentations**

Oral presentation at NIOO-KNAW-wide seminar series	17 May 2021	1,0
Oral presentation at NWO-JAPAN(JSPS) online seminar : Microbial chemical communication	3 March 2022	1,0
Oral presentation at online seminar by Netherlands Metabolomic Center (NMC)	24 February 2022	1,0
Oral presentation at MiCROp annual meeting (consortium meeting), Amsterdam	23 June 2022	1,0
Poster presentation at miCROPe conference, Vienna, Austria	12 July 2022	1,0
Poster presentation at applied Meta-omics summer school, ETH Zurich, Switzerland	12 June 2023	1,0
Oral presentation at MiCROp annual meeting (consortium meeting) with partner industry, Amsterdam	21 June 2023	1,0
Oral presentation at 4th Plant Microbiome Symposium, Quito, Ecuador	1 August 2023	1,0

Poster presentation at 5th Plant Microbiome Symposium, Amsterdam, The Netherlands	18 June 2024	1,0
Oral presentation at 1st International Symposium for Volatile Interactions in Ecosystems	23 May 2025	1,0
▶ **Interviews**		
Annual meeting with mentor year 2	1 December 2022	0,1
Annual meeting with mentor year 3	1 March 2023	0,1
3rd year interview with theme coordinator	15 August 2023	0,7
▶ **Excursions**		
MiCRop (consortium) PhDs and Postdocs company visit to Koppert	26 October 2023	0,2
Subtotal scientific exposure		20,4

3) In-depth scientific training	**date**	**credits**
▶ **Advanced scientific courses & workshops**		
Workshop on “Mass spectrometry data processing and molecular networking”, IOCB Prague	19-20 July 2021	0,6
Workshop on “An introduction to metabolomics”, STARGATE, WUR	6-8 December 2021	0,9
Workshop on “ EPS CRISPR/Cas”, EPS Graduate school	13-14 September 2021	0,6
Introduction to R and R studio, PE&RC & WIMEK	1,3,8,10 February 2022	0,9
Genome Assembly, EPS	20-21 April 2023	0,6
Applied meta-omics (transcriptomic, metabolomic and metagenomic) summer school, ETH Zurich	12-16 June 2023	1,5
Meta-analysis, PE&RC &WIMEK	6-7 July 2023	0,6
Biogenic Volatile Organic Compounds (BVOCs) and Isotope Techniques, Copenhagen University	19-23 May 2025	3,0
Subtotal in-depth studies		8,7

4) Personal development	date	credits
EPS Introduction Course, Online	20 April 2021	0,3
Training on “Unconscious bias” by Franklin Covey, held by MiCRop-Gravitation consortium	30 November 2022	0,3
Workshop on Active Bystander, NIOO-KNAW	1 December 2022	0,1
Project ME: Taking control of your academic career by taking control of yourself, Leiden University	27 March-22 May 2023	0,6
Scientific conduct for PhDs (Science), Leiden University	11 May 2023	0,2
Online workshop on “Irresistible Resume”, KNAW	3 July 2024	0,2
Online workshop on “Motivation Letter”, KNAW	17 July 2024	0,2
Online workshop on “LinkedIn”, KNAW	31 July 2024	0,2
Online workshop on “How to ace your job interview”, KNAW	14 August 2024	0,2
Subtotal professional & career development		2,3

5) Academic services, governance & outreach activities	date	credits
Subtotal academic services, governance & outreach activities		0,0

6) Teaching & Supervision Duties	date	credits
▶ **Courses**		
▶ **Supervision of BSc/MSc projects**		3,0
HBO student “The role of root volatiles on bacterial growth and motility”	September 2021-February 2022	
MSc student “The role of stressed-induced root volatile dimethyl disulfide on soil bacterial growth, motility and biofilm formation”	February-July 2022	

MSc student “Investigating the role of root-associated bacteria in protecting tomato (*S. Lycopersicum L.*) against *Spodoptera exigua* and *Botrytis cinerea*“	April-July 2023	
MSc Student “ Bacterial recruitment induces changes in biomass production of herbivore-stressed plants”	September-December 2023	
MSc student “The impact of synthetic root volatile organic compounds on *Pseudomonas* spp.”	January-July 2024	
Subtotal Teaching & Supervision Duties		3,0
TOTAL NUMBER OF CREDITS*		**41,9**

Herewith the Graduate School declares that the PhD candidate has complied with the educational requirements set by the Educational Committee of EPS with a minimum total of 30 ECTS credits.

* A credit represents a normative study load of 28 hours of study.