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REFERENCES

Abed N, Saïd-Hassane F, Zouhiri F, Mougin J, Nicolas V, Desmaële D *et al* (2015). An efficient system for intracellular delivery of beta-lactam antibiotics to overcome bacterial resistance. *Sci Rep* **5**: 13500.

Abrudan MI, Smakman F, Grimbergen AJ, Westhoff S, Miller EL, van Wezel GP *et al* (2015). Socially mediated induction and suppression of antibiosis during bacterial coexistence. *Proc Natl Acad Sci USA* **112**: 11054-11059.

Achouak W, Heulin T, Pagès J-M (2001). Multiple facets of bacterial porins. *FEMS Microbiol Lett* **199**: 1-7.

Alpha CJ, Campos M, Jacobs-Wagner C, Strobel SA (2015). Mycofumigation by the volatile organic compound-producing fungus *Muscodor albus* induces bacterial cell death through DNA damage. *Appl Environ Microbiol* **81**: 1147-1156.

Andrade-Ochoa S, Nevarez-Moorillon GV, Sanchez-Torres LE, Villanueva-Garcia M, Sanchez-Ramirez BE, Rodriguez-Valdez LM *et al* (2015). Quantitative structure-activity relationship of molecules constituent of different essential oils with antimycobacterial activity against *Mycobacterium tuberculosis* and *Mycobacterium bovis*. *BMC Complement Altern Med* **15**: 332.

Anwar S, Ali B, Sajid I (2016). Screening of rhizospheric actinomycetes for various in-vitro and in-vivo plant growth promoting (PGP) traits and for agroactive compounds. *Front Microbiol* **7**: 1334.

Audrain B, Farag MA, Ryu CM, Ghigo JM (2015). Role of bacterial volatile compounds in bacterial biology. *FEMS Microbiol Rev* **39**: 222-233.

Avalos M, Boetzer M, Pirovano W, Arenas NE, Douthwaite S, van Wezel GP (2018a). Complete genome sequence of *Escherichia coli* AS19, an antibiotic-sensitive variant of *E. coli* Strain B REL606. *Genome Announc* **6**.

Avalos M, van Wezel GP, Raaijmakers JM, Garbeva P (2018b). Healthy scents: microbial volatiles as new frontier in antibiotic research? *Curr Opin Microbiol* **45**: 84-91.

Barbe V, Cruveiller S, Kunst F, Lenoble P, Meurice G, Sekowska A *et al* (2009). From a consortium sequence to a unified sequence: the *Bacillus subtilis* 168 reference genome a decade later. *Microbiology* **155**: 1758-1775.

- Barber CE, Tang JL, Feng JX, Pan MQ, Wilson TJ, Slater H *et al* (1997). A novel regulatory system required for pathogenicity of *Xanthomonas campestris* is mediated by a small diffusible signal molecule. *Mol Microbiol* **24**: 555-566.
- Bárcenas-Moreno G, Rousk J, Bååth E (2011). Fungal and bacterial recolonisation of acid and alkaline forest soils following artificial heat treatments. *Soil Biol Biochem* **43**: 1023-1033.
- Barka EA, Vatsa P, Sanchez L, Gaveau-Vaillant N, Jacquard C, Klenk HP *et al* (2016). Taxonomy, physiology, and natural products of actinobacteria. *Microbiol Mol Biol Rev* **80**: 1-43.
- Beceiro A, Maharjan S, Gaulton T, Doumith M, Soares NC, Dhanji H *et al* (2011). False extended-spectrum β -lactamase phenotype in clinical isolates of *Escherichia coli* associated with increased expression of OXA-1 or TEM-1 penicillinases and loss of porins. *J Antimicrob Chemother* **66**: 2006-2010.
- Bentley R, Meganathan R (1981). Geosmin and methylisoborneol biosynthesis in streptomycetes. Evidence for an isoprenoid pathway and its absence in non-differentiating isolates. *FEBS Lett* **125**: 220-222.
- Bentley SD, Chater KF, Cerdeno-Tarraga AM, Challis GL, Thomson NR, James KD *et al* (2002). Complete genome sequence of the model actinomycete *Streptomyces coelicolor* A3(2). *Nature* **417**: 141-147.
- Berdy J (2012). Thoughts and facts about antibiotics: where we are now and where we are heading. *J Antib (Tokyo)* **65**: 385-395.
- Berg G, Eberl L, Hartmann A (2005). The rhizosphere as a reservoir for opportunistic human pathogenic bacteria. *Environ Microbiol* **7**: 1673-1685.
- Bernier SP, Letoffe S, Delepierre M, Ghigo JM (2011). Biogenic ammonia modifies antibiotic resistance at a distance in physically separated bacteria. *Mol Microbiol* **81**: 705-716.
- Bierman M, Logan R, O'Brien K, Seno ET, Nagaraja Rao R, Schoner BE (1992). Plasmid cloning vectors for the conjugal transfer of DNA from *Escherichia coli* to *Streptomyces spp.* *Gene* **116**: 43-49.

Blondelet-Rouault MH, Weiser J, Lebrihi A, Branny P, Pernodet JL (1997). Antibiotic resistance gene cassettes derived from the omega interposon for use in *E. coli* and *Streptomyces*. *Gene* **190**: 315-317.

Blumer C, Haas D (2000). Mechanism, regulation, and ecological role of bacterial cyanide biosynthesis. *Arch Microbiol* **173**: 170-177.

Boerjesson TS, Stoellman UM, Schnuerer JL (1993). Off-odorous compounds produced by molds on oatmeal agar: identification and relation to other growth characteristics. *J Agric Food Chem* **41**: 2104-2111.

Bos LDJ, Sterk PJ, Schultz MJ (2013). Volatile metabolites of pathogens: a systematic review. *PLoS Pathog* **9**: e1003311.

Cale JA, Collignon RM, Klutsch JG, Kanekar SS, Hussain A, Erbilgin N (2016). Fungal volatiles can act as carbon sources and semiochemicals to mediate interspecific interactions among bark beetle-associated fungal symbionts. *PLoS One* **11**: e0162197.

Carrion VJ, Cordovez V, Tyc O, Etalo DW, de Bruijn I, de Jager VCL *et al* (2018). Involvement of Burkholderiaceae and sulfurous volatiles in disease-suppressive soils. *ISME J* **12**: 2307-2321.

Castric KF, Castric PA (1983). Method for rapid detection of cyanogenic bacteria. *Appl Environ Microbiol* **45**: 701-702.

Čepl JJ PI, Blahůšková A, Cvrčková F, Markoš A. (2010). Patterning of mutually interacting bacterial bodies: close contacts and airborne signals. *BMC Microbiol* **10**.

Chaisson MJ, Tesler G (2012). Mapping single molecule sequencing reads using basic local alignment with successive refinement (BLASR): application and theory. *BMC Bioinformatics* **13**: 238.

Chen X, Köllner TG, Jia Q, Norris A, Santhanam B, Rabe P *et al* (2016). Terpene synthase genes in eukaryotes beyond plants and fungi: occurrence in social amoebae. *Proc Natl Acad Sci USA* **113**: 12132-12137.

- Chin H-W, Lindsay RC (1994). Ascorbate and transition-metal mediation of methanethiol oxidation to dimethyl disulfide and dimethyl trisulfide. *Food Chem* **49**: 387-392.
- Chitarra GS, Abee T, Rombouts FM, Dijksterhuis J (2005). 1-Octen-3-ol inhibits conidia germination of *Penicillium paneum* despite of mild effects on membrane permeability, respiration, intracellular pH, and changes the protein composition. *FEMS Microbiol Ecol* **54**: 67-75.
- Collignon P (2009). Resistant *Escherichia coli*-we are what we eat. *Clin Infect Dis* **49**: 202-204.
- Conroy MJ, Durand A, Lupo D, Li XD, Bullough PA, Winkler FK *et al* (2007). The crystal structure of the *Escherichia coli* AmtB-GlnK complex reveals how GlnK regulates the ammonia channel. *Proc Natl Acad Sci USA* **104**: 1213-1218.
- Cooke HA, Guenther EL, Luo Y, Shen B, Bruner SD (2009). Molecular basis of substrate promiscuity for the SAM-dependent O-methyltransferase NcsB1, involved in the biosynthesis of the enediyne antitumor antibiotic neocarzinostatin. *Biochemistry* **48**: 9590-9598.
- Cooper MA, Shlaes D (2011). Fix the antibiotics pipeline. *Nature* **472**: 32.
- Cordovez V, Carrion VJ, Etalo DW, Mumm R, Zhu H, van Wezel GP *et al* (2015). Diversity and functions of volatile organic compounds produced by *Streptomyces* from a disease-suppressive soil. *Front Microbiol* **6**: 1081.
- Cugini C, Calfee MW, Farrow JM, 3rd, Morales DK, Pesci EC, Hogan DA (2007). Farnesol, a common sesquiterpene, inhibits PQS production in *Pseudomonas aeruginosa*. *Mol Microbiol* **65**: 896-906.
- Daegelen P, Studier FW, Lenski RE, Cure S, Kim JF (2009). Tracing ancestors and relatives of *Escherichia coli* B, and the derivation of B strains REL606 and BL21(DE3). *J Mol Biol* **394**: 634-643.
- Dalilla Carvalho Rezende MBF, Simone Cristiane Brand, Silvia Blumer and Sérgio Florentino Pascholati (2015). Antimicrobial activity of volatile organic compounds and their effect on lipid peroxidation and electrolyte loss in *Colletotrichum gloeosporioides* and *Colletotrichum acutatum* mycelia. *Afr J Microbiol Res* **9**: 1527-1535.

Datsenko KA, Wanner BL (2000). One-step inactivation of chromosomal genes in *Escherichia coli* K-12 using PCR products. *Proc Natl Acad Sci USA* **97**: 6640-6645.

Davies J (1994). Inactivation of antibiotics and the dissemination of resistance genes. *Science* **264**: 375-382.

Davies J (2006). Are antibiotics naturally antibiotics? *J Ind Microbiol and Biotechnol* **33**: 496-499.

De Boer W, Klein Gunnewiek PJA, Lafeber P, Janse JD, Spit BE, Woldendorp JW (1998). Anti-fungal properties of chitinolytic dune soil bacteria. *Soil Biol and Biochem* **30**: 193-203.

Degenhardt J, Kollner TG, Gershenzon J (2009). Monoterpene and sesquiterpene synthases and the origin of terpene skeletal diversity in plants. *Phytochemistry* **70**: 1621-1637.

Deng Y, Lim A, Lee J, Chen S, An S, Dong Y-H *et al* (2014). Diffusible signal factor (DSF) quorum sensing signal and structurally related molecules enhance the antimicrobial efficacy of antibiotics against some bacterial pathogens. *BMC Microbiol* **14**: 51-51.

Dickschat JS, Bode HB, Mahmud T, Müller R, Schulz S (2005). A novel type of geosmin biosynthesis in Myxobacteria. *J Org Chem* **70**: 5174-5182.

Dickschat JS, Nawrath T, Thiel V, Kunze B, Müller R, Schulz S (2007). Biosynthesis of the off-flavor 2-methylisoborneol by the Myxobacterium *Nannocystis exedens*. *Angew Chem Int Ed Engl* **46**: 8287-8290.

Dickschat JS (2011). Isoprenoids in three-dimensional space: the stereochemistry of terpene biosynthesis. *Natl Prod Rep* **28**: 1917-1936.

Dickschat JS (2016). Bacterial terpene cyclases. *Nat Prod Rep* **33**: 87-110.

Dorr T, Vulic M, Lewis K (2010). Ciprofloxacin causes persister formation by inducing the TisB toxin in *Escherichia coli*. *PLoS Biol* **8**: e1000317.

- Drotar A, Burton GA, Jr., Tavernier JE, Fall R (1987). Widespread occurrence of bacterial thiol methyltransferases and the biogenic emission of methylated sulfur gases. *Appl and Environ Microbiol* **53**: 1626-1631.
- Effmert U, Kalderas J, Warnke R, Piechulla B (2012). Volatile mediated interactions between bacteria and fungi in the soil. *J Chem Ecol* **38**: 665-703.
- Fadli M, Chevalier J, Hassani L, Mezrioui NE, Pages JM (2014). Natural extracts stimulate membrane-associated mechanisms of resistance in Gram-negative bacteria. *Lett Appl Microbiol* **58**: 472-477.
- Fedorushyn M, Welle E, Bechthold A, Luzhetskyy A (2008). Functional expression of the Cre recombinase in actinomycetes. *Appl Microbiol Biotechnol* **78**: 1065-1070.
- Fernandez L, Hancock RE (2012). Adaptive and mutational resistance: role of porins and efflux pumps in drug resistance. *Clin Microbiol Rev* **25**: 661-681.
- Fiddaman PJ, Rossall S (1993). The production of antifungal volatiles by *Bacillus subtilis*. *J Appl Bacteriol* **74**: 119-126.
- Fierer N, Jackson RB (2006). The diversity and biogeography of soil bacterial communities. *Proc Natl Acad Sci USA* **103**: 626-631.
- Firn RD, Jones CG (2000). The evolution of secondary metabolism - a unifying model. *Mol Microbiol* **37**: 989-994.
- Fischbach MA, Clardy J (2007). One pathway, many products. *Nat Chem Biol* **3**: 353.
- Fischer G, Schwalbe R, Moller M, Ostrowski R, Dott W (1999). Species-specific production of microbial volatile organic compounds (MVOC) by airborne fungi from a compost facility. *Chemosphere* **39**: 795-810.
- Fleming A (1929). The antibacterial action of a *Penicillium*, with special reference to their use for the isolation of *B. influenzae*. *Brit J Exp Pathol* **10**: 226-236.
- Freeman KS (2010). Harmful algal blooms: musty warnings of toxicity. *Environ Health Perspect* **118**: A473-A473.

Gallucci MN, Oliva M, Casero C, Dambolena J, Luna A, Zygodlo J *et al* (2009). Antimicrobial combined action of terpenes against the food-borne microorganisms *Escherichia coli*, *Staphylococcus aureus* and *Bacillus cereus*. *Flavour Fragr J* **24**: 348-354.

Garbeva P, Hordijk C, Gerards S, de Boer W (2014). Volatile-mediated interactions between phylogenetically different soil bacteria. *Front Microbiol* **5**: 289.

Ge F, Zeng F, Liu S, Guo N, Ye H, Song Y *et al* (2010). In vitro synergistic interactions of oleanolic acid in combination with isoniazid, rifampicin or ethambutol against *Mycobacterium tuberculosis*. *J Med Microbiol* **59**: 567-572.

Geisen S, Weinert J, Kudryavtsev A, Glotova A, Bonkowski M, Smirnov A (2014). Two new species of the genus *Stenamoeba* (Discosea, Longamoebia): Cytoplasmic MTOC is present in one more amoebae lineage. *Eur J Protistol* **50**: 153-165.

Geisen S, Tveit AT, Clark IM, Richter A, Svenning MM, Bonkowski M *et al* (2015). Metatranscriptomic census of active protists in soils. *ISME J* **9**: 2178-2190.

Germain E, Castro-Roa D, Zenkin N, Gerdes K (2013). Molecular mechanism of bacterial persistence by HipA. *Molecular cell* **52**: 248-254.

Gershenzon J, Dudareva N (2007). The function of terpene natural products in the natural world. *Nat Chem Biol* **3**: 408-414.

Gilardi G, Gullino ML, Garibaldi A (2017). Soil disinfestation with dimethyl disulfide for management of *Fusarium* wilt on lettuce in Italy. *J Plant Dis Protect* **124**: 361-370.

Girard G, Traag BA, Sangal V, Mascini N, Hoskisson PA, Goodfellow M *et al* (2013). A novel taxonomic marker that discriminates between morphologically complex actinomycetes. *Open Biol* **3**: 130073.

Gorbach SL (1996). Chapter 95. Microbiology of the gastrointestinal tract. Baron S (eds). *Medical Microbiology*. University of Texas Medical Branch at Galveston

Graff GR, Burns JL (2002). Factors affecting the incidence of *Stenotrophomonas maltophilia* isolation in cystic fibrosis. *Chest* **121**: 1754-1760.

- Groenhagen U, Baumgartner R, Bailly A, Gardiner A, Eberl L, Schulz S *et al* (2013). Production of bioactive volatiles by different *Burkholderia ambifaria* strains. *J Chem Ecol* **39**: 892-906.
- Groenhagen U, Maczka M, Dickschat JS, Schulz S (2014). Streptopyridines, volatile pyridine alkaloids produced by *Streptomyces* sp. FORM5. *Beilstein J Org Chem* **10**: 1421-1432.
- Groenhagen U, Leandrini De Oliveira AL, Fielding E, Moore BS, Schulz S (2016). Coupled biosynthesis of volatiles and salinosporamide A in *Salinispora tropica*. *Chembiochem* **17**: 1978-1985.
- Gu Y-Q, Mo M-H, Zhou J-P, Zou C-S, Zhang K-Q (2007). Evaluation and identification of potential organic nematicidal volatiles from soil bacteria. *Soil Biol Biochem* **39**: 2567-2575.
- Gürtler H, Pedersen R, Anthoni U, Christophersen C, Nielsen PH, Wellington EM *et al* (1994). Albaflavenone, a sesquiterpene ketone with a zizaene skeleton produced by a streptomycete with a new rope morphology. *J Antibiot (Tokyo)* **47**: 434-439.
- Gusarov I, Nudler E (2005). NO-mediated cytoprotection: Instant adaptation to oxidative stress in bacteria. *Proc Natl Acad Sci USA* **102**: 13855-13860.
- Gusarov I, Shatalin K, Starodubtseva M, Nudler E (2009). Endogenous nitric oxide protects bacteria against a wide spectrum of antibiotics. *Science* **325**: 1380-1384.
- Gusarov I, Gautier L, Smolentseva O, Shamovsky I, Eremina S, Mironov A *et al* (2013). Bacterial nitric oxide extends the lifespan of *C. elegans*. *Cell* **152**: 818-830.
- Gust B, Challis GL, Fowler K, Kieser T, Chater KF (2003). PCR-targeted *Streptomyces* gene replacement identifies a protein domain needed for biosynthesis of the sesquiterpene soil odor geosmin. *Proc Natl Acad Sci USA* **100**: 1541-1546.
- Hammes W, Schleifer KH, Kandler O (1973). Mode of action of glycine on the biosynthesis of peptidoglycan. *J Bacteriol* **116**: 1029-1053.

Harris GG, Lombardi PM, Pemberton TA, Matsui T, Weiss TM, Cole KE *et al* (2015). Structural studies of geosmin synthase, a bifunctional sesquiterpene synthase with $\alpha\alpha$ domain architecture that catalyzes a unique cyclization-fragmentation reaction sequence. *Biochemistry* **54**: 7142-7155.

Hemaiswarya S, Doble M (2009). Synergistic interaction of eugenol with antibiotics against Gram negative bacteria. *Phytomedicine* **16**: 997-1005.

Higashi T, Iwasaki Y, Ohnishi Y, Horinouchi S (2007). A-factor and phosphate depletion signals are transmitted to the grixazone biosynthesis genes via the pathway-specific transcriptional activator GriR. *J Bacteriol* **189**: 3515-3524.

Hopwood DA, Kieser T, Wright HM, Bibb MJ (1983). Plasmids, recombination and chromosome mapping in *Streptomyces lividans* 66. *J Gen Microbiol* **129**: 2257-2269.

Hopwood DA (2007). *Streptomyces in nature and medicine. The antibiotic makers*. Oxford University Press Inc: New York, NY.

Huang CJ, Tsay JF, Chang SY, Yang HP, Wu WS, Chen CY (2012). Dimethyl disulfide is an induced systemic resistance elicitor produced by *Bacillus cereus* C1L. *Pest Manag Sci* **68**: 1306-1310.

Hughes R, Magee EA, Bingham S (2000). Protein degradation in the large intestine: relevance to colorectal cancer. *Curr Issues Intest Microbiol* **1**: 51-58.

Iida S, Sekiguchi M (1971). Infection of actinomycin-permeable mutants of *Escherichia coli* with urea-disrupted bacteriophage. *J Virol* **7**: 121-126.

Izaguirre G, Hwang CJ, Krasner SW, McGuire MJ (1982). Geosmin and 2-methylisoborneol from cyanobacteria in three water supply systems. *Appl Environ Microbiol* **43**: 708-714.

Jaffe A, Chabbert YA, Semonin O (1982). Role of porin proteins OmpF and OmpC in the permeation of beta-lactams. *Antimicrob Agents Chemother* **22**: 942-948.

Janssen PH (2006). Identifying the dominant soil bacterial taxa in libraries of 16S rRNA and 16S rRNA genes. *Appl Environ Microbiol* **72**: 1719-1728.

- Jiang J, He X, Cane DE (2007). Biosynthesis of the earthy odorant geosmin by a bifunctional *Streptomyces coelicolor* enzyme. *Nat Chem Biol* **3**: 711-715.
- Jones SE, Ho L, Rees CA, Hill JE, Nodwell JR, Elliot MA (2017). *Streptomyces* exploration is triggered by fungal interactions and volatile signals. *Elife* **6**.
- Jousset A (2012). Ecological and evolutive implications of bacterial defences against predators. *Environ Microbiol* **14**: 1830-1843.
- Junker RR, Tholl D (2013). Volatile organic compound mediated interactions at the plant-microbe interface. *J Chem Ecol* **39**: 810-825.
- Kai M, Haustein M, Molina F, Petri A, Scholz B, Piechulla B (2009). Bacterial volatiles and their action potential. *Appl Microbiol Biotechnol* **81**: 1001-1012.
- Kai M, Crespo E, Cristescu SM, Harren FJ, Francke W, Piechulla B (2010). *Serratia odorifera*: analysis of volatile emission and biological impact of volatile compounds on *Arabidopsis thaliana*. *Appl Microbiol Biotechnol* **88**: 965-976.
- Kai M, Effmert U, Piechulla B (2016). Bacterial-plant-interactions: approaches to unravel the biological function of bacterial volatiles in the rhizosphere. *Front Microbiol* **7**: 108.
- Kanchiswamy CN, Malnoy M, Maffei ME (2015). Chemical diversity of microbial volatiles and their potential for plant growth and productivity. *Front Plant Sci* **6**: 151.
- Kashiwagi K, Miyaji A, Ikeda S, Tobe T, Sasakawa C, Igarashi K (1992). Increase of sensitivity to aminoglycoside antibiotics by polyamine-induced protein (oligopeptide-binding protein) in *Escherichia coli*. *Journ Bacteriol* **174**: 4331-4337.
- Kaspy I, Rotem E, Weiss N, Ronin I, Balaban NQ, Glaser G (2013). HipA-mediated antibiotic persistence via phosphorylation of the glutamyl-tRNA-synthetase. *Nat Comms* **4**: 3001.
- Khodakaramian G, Lissenden S, Gust B, Moir L, Hoskisson PA, Chater KF *et al* (2006). Expression of Cre recombinase during transient phage infection permits efficient marker removal in *Streptomyces*. *Nucleic Acids Res* **34**: e20-e20.

Kieser T, Bibb MJ, Buttner MJ, Chater KF, Hopwood DA (2000). Practical *Streptomyces* Genetics. John Innes Centre.

Kikuchi G, Motokawa Y, Yoshida T, Hiraga K (2008). Glycine cleavage system: reaction mechanism, physiological significance, and hyperglycinemia. *Proc Jpn Acad, Series B* **84**: 246-263.

Kim KS, Lee S, Ryu CM (2013). Interspecific bacterial sensing through airborne signals modulates locomotion and drug resistance. *Nat Comms* **4**: 1809.

Kim Y, Wood TK (2010). Toxins Hha and CspD and small RNA regulator Hfq are involved in persister cell formation through MqsR in *Escherichia coli*. *Biochem Biophys Res Commun* **391**: 209-213.

Kitagawa M, Ara T, Arifuzzaman M, Ioka-Nakamichi T, Inamoto E, Toyonaga H *et al* (2005). Complete set of ORF clones of *Escherichia coli* ASKA library (a complete set of *E. coli* K-12 ORF archive): unique resources for biological research. *DNA Res* **12**: 291-299.

Klapschinski TA, Rabe P, Dickschat JS (2016). Pristinol, a sesquiterpene alcohol with an unusual skeleton from *Streptomyces pristinaespiralis*. *Angew Chem Int Ed Engl* **55**: 10141-10144.

Kolter R, van Wezel GP (2016). Goodbye to brute force in antibiotic discovery? *Nat Microbiol* **1**: 15020.

Komatsu M, Tsuda M, Omura S, Oikawa H, Ikeda H (2008). Identification and functional analysis of genes controlling biosynthesis of 2-methylisoborneol. *Proc Natl Acad Sci USA* **105**: 7422-7427.

Kuzuyama T (2017). Biosynthetic studies on terpenoids produced by *Streptomyces*. *J Antibiot (Tokyo)* **70**: 811-818.

Lee HS, Ohnishi Y, Horinouchi S (2001). A sigmaB-like factor responsible for carotenoid biosynthesis in *Streptomyces griseus*. *J Mol Microbiol Biotechnol* **3**: 95-101.

Lemfack MC, Nickel J, Dunkel M, Preissner R, Piechulla B (2014). mVOC: a database of microbial volatiles. *Nucleic Acids Res* **42**: D744-748.

- Lemfack MC, Ravello SR, Lorenz N, Kai M, Jung K, Schulz S *et al* (2016). Novel volatiles of skin-borne bacteria inhibit the growth of Gram-positive bacteria and affect quorum-sensing controlled phenotypes of Gram-negative bacteria. *Syst Appl Microbiol* **39**: 503-515.
- Lesuffleur F, Paynel F, Bataillé M-P, Le Deunff E, Cliquet J-B (2007). Root amino acid exudation: measurement of high efflux rates of glycine and serine from six different plant species. *Plant and Soil* **294**: 235-246.
- Letoffe S, Audrain B, Bernier SP, Delepierre M, Ghigo JM (2014). Aerial exposure to the bacterial volatile compound trimethylamine modifies antibiotic resistance of physically separated bacteria by raising culture medium pH. *MBio* **5**: e00944-00913.
- Li Q, Ning P, Zheng L, Huang J, Li G, Hsiang T (2010). Fumigant activity of volatiles of *Streptomyces globisporus* JK-1 against *Penicillium italicum* on *Citrus microcarpa*. *Postharvest Bioland Technol* **58**: 157-165.
- Liu C, Yan F, Gao H, He M, Wang Z, Cheng Y *et al* (2015). Features of citrus terpenoid production as revealed by carotenoid, limonoid and aroma profiles of two pummelos (*Citrus maxima*) with different flesh color. *J Sci Food Agric* **95**: 111-119.
- Liu M, Douthwaite S (2002a). Activity of the ketolide telithromycin is refractory to Erm monomethylation of bacterial rRNA. *Antimicrob Agents Chemother* **46**: 1629-1633.
- Liu M, Douthwaite S (2002b). Resistance to the macrolide antibiotic tylosin is conferred by single methylations at 23S rRNA nucleotides G748 and A2058 acting in synergy. *Proc Natl Acad Sci USA* **99**: 14658-14663.
- Liu Z, Shi Y, Zhang Y, Zhou Z, Lu Z, Li W *et al* (2005). Classification of *Streptomyces griseus* (Krainsky 1914) Waksman and Henrici 1948 and related species and the transfer of '*Microstreptospora cinerea*' to the genus *Streptomyces* as *Streptomyces yanii* sp. nov. *Int J Syst Evol Microbiol* **55**: 1605-1610.
- Luhachack L, Nudler E (2014). Bacterial gasotransmitters: an innate defense against antibiotics. *Curr Opin Microbiol* **21**: 13-17.

Martin JL, McMillan FM (2002). SAM (dependent) I AM: the S-adenosylmethionine-dependent methyltransferase fold. *Curr Opin Struct Biol* **12**: 783-793.

Mattheis JP, Roberts RG (1992). Identification of geosmin as a volatile metabolite of *Penicillium expansum*. *Appl Environ Microbiol* **58**: 3170-3172.

Meldau DG, Meldau S, Hoang LH, Underberg S, Wünsche H, Baldwin IT (2013). Dimethyl disulfide produced by the naturally associated bacterium *Bacillus* sp B55 promotes *Nicotiana attenuata* growth by enhancing sulfur nutrition. *The Plant Cell* **25**: 2731-2747.

Mohan C (2006). Buffers. A guide for the preparation and use of buffers in biological systems. EMD Bioscience.

Molina-Santiago C, Daddaoua A, Fillet S, Duque E, Ramos J-L (2014). Interspecies signalling: *Pseudomonas putida* efflux pump TtgGHI is activated by indole to increase antibiotic resistance. *Environ Microbiol* **16**: 1267-1281.

Mortazavi A, Williams BA, McCue K, Schaeffer L, Wold B (2008). Mapping and quantifying mammalian transcriptomes by RNA-Seq. *Nature methods* **5**: 621-628.

Nijland R, Burgess JG (2010). Bacterial olfaction. *Biotechnol J* **5**: 974-977.

Nikaido H (2003). Molecular basis of bacterial outer membrane permeability revisited. *Microbiol Mol Biol Rev* **67**: 593-656.

Ohnishi Y, Furusho Y, Higashi T, Chun HK, Furihata K, Sakuda S *et al* (2004). Structures of grixazone A and B, A-factor-dependent yellow pigments produced under phosphate depletion by *Streptomyces griseus*. *J Antibiot (Tokyo)* **57**: 218-223.

Oldfield E, Lin F-Y (2012). Terpene biosynthesis: modularity rules. *Angew Chem Int Ed Engl* **51**: 1124-1137.

Ossowicki A, Jafra S, Garbeva P (2017). The antimicrobial volatile power of the rhizospheric isolate *Pseudomonas donghuensis* P482. *PLoS One* **12**: e0174362.

Page R, Peti W (2016). Toxin-antitoxin systems in bacterial growth arrest and persistence. *Nat Chem Biol* **12**: 208-214.

- Park YS, Dutta S, Ann M, Raaijmakers JM, Park K (2015). Promotion of plant growth by *Pseudomonas fluorescens* strain SS101 via novel volatile organic compounds. *Biochem Biophys Res Commun* **461**: 361-365.
- Payne DJ, Gwynn MN, Holmes DJ, Pompliano DL (2007). Drugs for bad bugs: confronting the challenges of antibacterial discovery. *Nat Rev Drug Discov* **6**: 29-40.
- Phillips DA, Fox TC, King MD, Bhuvaneshwari TV, Teuber LR (2004). Microbial products trigger amino acid exudation from plant roots. *Plant Physiol* **136**: 2887-2894.
- Pichersky E, Raguso RA (2018). Why do plants produce so many terpenoid compounds? *New Phytol* **220**: 692-702.
- Piechulla B, Lemfack MC, Kai M (2017). Effects of discrete bioactive microbial volatiles on plants and fungi. *Plant Cell Environ* **40**: 2042-2067.
- Pimentel D, Bellotti AC (1976). Parasite-host population systems and genetic stability. *Am Nat* **110**: 877-888.
- Pluskal T, Castillo S, Villar-Briones A, Orešič M (2010). MZmine 2: Modular framework for processing, visualizing, and analyzing mass spectrometry-based molecular profile data. *BMC Bioinformatics* **11**: 395.
- Popova AA, Koksharova OA, Lipasova VA, Zaitseva JV, Katkova-Zhukotskaya OA, Eremina SI *et al* (2014). Inhibitory and toxic effects of volatiles emitted by strains of *Pseudomonas* and *Serratia* on growth and survival of selected microorganisms, *Caenorhabditis elegans*, and *Drosophila melanogaster*. *BioMed Res Int* **2014**: 11.
- Que YA, Hazan R, Strobel B, Maura D, He J, Kesarwani M *et al* (2013). A quorum sensing small volatile molecule promotes antibiotic tolerance in bacteria. *PLoS One* **8**: e80140.
- Riclea R, Aigle B, Leblond P, Schoenian I, Spiteller D, Dickschat JS (2012). Volatile lactones from streptomycetes arise via the antimycin biosynthetic pathway. *Chembiochem* **13**: 1635-1644.

Rodríguez A, Shimada T, Cervera M, Alquézar B, Gadea J, Gómez-Cadenas A *et al* (2014). Terpene down-regulation triggers defense responses in transgenic orange leading to resistance against fungal pathogens. *Plant Physiol* **164**: 321-339.

Rousk J, Brookes PC, Bååth E (2009). Contrasting soil pH effects on fungal and bacterial growth suggest functional redundancy in carbon mineralization. *Appl Environ Microbiol* **75**: 1589-1596.

Ryu C-M, Farag MA, Hu C-H, Reddy MS, Wei H-X, Paré PW *et al* (2003). Bacterial volatiles promote growth in *Arabidopsis*. *Proc Natl Acad Sci USA* **100**: 4927-4932.

Sambrook J, Fritsch, E.F., Maniatis, T. (1989). Molecular cloning: a laboratory manual. Cold Spring Harbor Laboratory Press: Cold Spring Harbor, N.Y.

Schmidt-Dannert C (2015). Biosynthesis of terpenoid natural products in fungi. *Adv Biochem Eng Biotechnol* **148**: 19-61.

Schmidt K, Spiteller D (2017). Ammonia released by *Streptomyces aburaviensis* induces droplet formation in *Streptomyces violaceoruber*. *J Chem Ecol*.

Schmidt R, Cordovez V, de Boer W, Raaijmakers J, Garbeva P (2015a). Volatile affairs in microbial interactions. *ISME J* **9**: 2329-2335.

Schmidt R, Etalo DW, de Jager V, Gerards S, Zweers H, de Boer W *et al* (2015b). Microbial small talk: volatiles in fungal–bacterial interactions. *Front Microbiol* **6**: 1495.

Schmidt R, Jager Vd, Zühlke D, Wolff C, Bernhardt J, Cankar K *et al* (2017). Fungal volatile compounds induce production of the secondary metabolite sodorifen in *Serratia plymuthica* PRI-2C. *Sci Rep* **7**: 862.

Schöller CEG, Gürtler H, Pedersen R, Molin S, Wilkins K (2002). Volatile metabolites from actinomycetes. *J Agric Food Chem* **50**: 2615-2621.

Schulz-Bohm K, Geisen S, Wubs ER, Song C, de Boer W, Garbeva P (2017a). The prey's scent - Volatile organic compound mediated interactions between soil bacteria and their protist predators. *ISME J* **11**: 817-820.

- Schulz-Bohm K, Martín-Sánchez L, Garbeva P (2017b). Microbial volatiles: small molecules with an important role in intra- and inter-kingdom interactions. *Front Microbiol* **8**.
- Schulz S, Dickschat JS (2007). Bacterial volatiles: the smell of small organisms. *Nat Prod Rep* **24**: 814-842.
- Schulz S, Dickschat JS, Kunze B, Wagner-Dobler I, Diestel R, Sasse F (2010). Biological activity of volatiles from marine and terrestrial bacteria. *Mar Drugs* **8**: 2976-2987.
- Schumacher MA, Piro KM, Xu W, Hansen S, Lewis K, Brennan RG (2009). Molecular mechanisms of HipA-mediated multidrug tolerance and its neutralization by HipB. *Science* **323**: 396-401.
- Schumacher MA, Balani P, Min J, Chinnam NB, Hansen S, Vulic M *et al* (2015). HipBA-promoter structures reveal the basis of heritable multidrug tolerance. *Nature* **524**: 59-64.
- Sekiguchi M, Iida S (1967). Mutants of *Escherichia coli* permeable to actinomycin. *Proc Natl Acad Sci USA* **58**: 2315-2320.
- Serrano A, Gallego M (2006). Sorption study of 25 volatile organic compounds in several mediterranean soils using headspace-gas chromatography-mass spectrometry. *J Chromatogr A* **1118**: 261-270.
- Shatalin K, Gusarov I, Avetissova E, Shatalina Y, McQuade LE, Lippard SJ *et al* (2008). *Bacillus anthracis*-derived nitric oxide is essential for pathogen virulence and survival in macrophages. *Proc Natl Acad Sci USA* **105**: 1009-1013.
- Shatalin K, Shatalina E, Mironov A, Nudler E (2011). H₂S: a universal defense against antibiotics in bacteria. *Science* **334**: 986-990.
- Sieniawska E, Swatko-Ossor M, Sawicki R, Skalicka-Woźniak K, Ginalska G (2017). Natural terpenes influence the activity of antibiotics against isolated *Mycobacterium tuberculosis*. *Med Princ Pract* **26**: 108-112.
- Singh N, Yeh PJ (2017). Suppressive drug combinations and their potential to combat antibiotic resistance. *J Antibiot* **70**: 1033.

Song C, Schmidt R, de Jager V, Krzyzanowska D, Jongedijk E, Cankar K *et al* (2015). Exploring the genomic traits of fungus-feeding bacterial genus *Collimonas*. *BMC Genomics* **16**: 1103.

Song JY, Yoo YJ, Lim SK, Cha SH, Kim JE, Roe JH *et al* (2016). Complete genome sequence of *Streptomyces venezuelae* ATCC 15439, a promising cell factory for production of secondary metabolites. *J Biotechnol* **219**: 57-58.

Stensmyr Marcus C, Dweck Hany KM, Farhan A, Ibba I, Strutz A, Mukunda L *et al* (2012). A conserved dedicated olfactory circuit for detecting harmful microbes in drosophila. *Cell* **151**: 1345-1357.

Strobel GA, Dirkse E, Sears J, Markworth C (2001). Volatile antimicrobials from *Muscodor albus*, a novel endophytic fungus. *Microbiol* **147**: 2943-2950.

Suh B, Bae IK, Kim J, Jeong SH, Yong D, Lee K (2010). Outbreak of meropenem-resistant *Serratia marcescens* mediated by chromosomal AmpC β -Lactamase overproduction and outer membrane protein loss. *Antimicrob Agents Chemother* **54**: 5057-5061.

Suzuki H (2011). Improvement of transformation efficiency by strategic circumvention of restriction barriers in *Streptomyces griseus*. *J Microbiol Biotechnol* **21**: 675-678.

Świątek MA, Tenconi E, Rigali S, van Wezel GP (2012). Functional analysis of the N-acetylglucosamine metabolic genes of *Streptomyces coelicolor* and role in control of development and antibiotic production. *J Bacteriol* **194**: 1136-1144.

Tetzlaff CN, You Z, Cane DE, Takamatsu S, Omura S, Ikeda H (2006). A gene cluster for biosynthesis of the sesquiterpenoid antibiotic pentalenolactone in *Streptomyces avermitilis*. *Biochemistry* **45**: 6179-6186.

Tezuka T, Ohnishi Y (2014). Two glycine riboswitches activate the glycine cleavage system essential for glycine detoxification in *Streptomyces griseus*. *J Bacteriol* **196**: 1369-1376.

Trombetta D, Castelli F, Sarpietro MG, Venuti V, Cristani M, Daniele C *et al* (2005). Mechanisms of antibacterial action of three monoterpenes. *Antimicrob Agents Chemother* **49**: 2474-2478.

- Tyc O, de Jager VCL, van den Berg M, Gerards S, Janssens TKS, Zaagman N *et al* (2017a). Exploring bacterial interspecific interactions for discovery of novel antimicrobial compounds. *Microb Biotechnol* **10**: 910-925.
- Tyc O, Song C, Dickschat JS, Vos M, Garbeva P (2017b). The ecological role of volatile and soluble secondary metabolites produced by soil bacteria. *Trends Microbiol* **25**: 280-292.
- van Dissel D, Claessen D, van Wezel GP (2014). Chapter One - Morphogenesis of *Streptomyces* in submerged cultures. In: Sariaslani S, Gadd GM (eds). *Advances in Applied Microbiology*. Academic Press. pp 1-45.
- van Hoek AH, Mevius D, Guerra B, Mullany P, Roberts AP, Aarts HJ (2011). Acquired antibiotic resistance genes: an overview. *Front Microbiol* **2**: 203.
- van Sorge NM, Beasley FC, Gusarov I, Gonzalez DJ, von Kockritz-Blickwede M, Anik S *et al* (2013). Methicillin-resistant *Staphylococcus aureus* bacterial nitric-oxide synthase affects antibiotic sensitivity and skin abscess development. *J Biol Chem* **288**: 6417-6426.
- Vara J, Lewandowska-Skarbek M, Wang YG, Donadio S, Hutchinson CR (1989). Cloning of genes governing the deoxysugar portion of the erythromycin biosynthesis pathway in *Saccharopolyspora erythraea* (*Streptomyces erythreus*). *J Bacteriol* **171**: 5872-5881.
- Vickers CE, Gershenzon J, Lerdau MT, Loreto F (2009). A unified mechanism of action for volatile isoprenoids in plant abiotic stress. *Nat Chem Biol* **5**: 283-291.
- von Reuß SH, Kai M, Piechulla B, Francke W (2010). Octamethylbicyclo[3.2.1]octadienes from the rhizobacterium *Serratia odorifera*. *Angew Chem Int Ed Engl* **49**: 2009-2010.
- Wang C, Wang Z, Qiao X, Li Z, Li F, Chen M *et al* (2013a). Antifungal activity of volatile organic compounds from *Streptomyces alboflavus* TD-1. *FEMS Microbiol Lett* **341**: 45-51.
- Wang CM, Cane DE (2008). Biochemistry and molecular genetics of the biosynthesis of the earthy odorant methylisoborneol in *Streptomyces coelicolor*. *J Am Chem Soc* **130**: 8908-8909.

Wang L-H, He Y, Gao Y, Wu JE, Dong Y-H, He C *et al* (2004). A bacterial cell–cell communication signal with cross-kingdom structural analogues. *Mol Microbiol* **51**: 903-912.

Wang X, Lord DM, Cheng HY, Osbourne DO, Hong SH, Sanchez-Torres V *et al* (2012). A new type V toxin-antitoxin system where mRNA for toxin GhoT is cleaved by antitoxin GhoS. *Nat Chem Biol* **8**: 855-861.

Wang Z, Wang C, Li F, Li Z, Chen M, Wang Y *et al* (2013b). Fumigant activity of volatiles from *Streptomyces alboflavus* TD-1 against *Fusarium moniliforme* Sheldon. *J Microbiol* **51**: 477-483.

Weber T, Blin K, Duddela S, Krug D, Kim HU, Brucoleri R *et al* (2015). antiSMASH 3.0-a comprehensive resource for the genome mining of biosynthetic gene clusters. *Nucleic Acids Res* **43**: W237-243.

Weekers PHH, Vogels GD (1994). Axenic cultivation of the free-living amoebae, *Acanthamoeba castellanii* and *Hartmannella vermiformis* in a chemostat. *J Microbiol Methods* **19**: 13-18.

Weise T, Kai M, Piechulla B (2013). Bacterial ammonia causes significant plant growth inhibition. *PLoS ONE* **8**: e63538.

Weisskopf L (2013). The potential of bacterial volatiles for crop protection against phytopathogenic fungi vol. 2. Formatex Research Center: Bajadoz, Spain.

Wirén Nv, Merrick M (2004). Regulation and function of ammonium carriers in bacteria, fungi, and plants. *Molecular Mechanisms Controlling Transmembrane Transport*. Springer Berlin Heidelberg: Berlin, Heidelberg. pp 95-120.

Woodford N, Ellington MJ (2007). The emergence of antibiotic resistance by mutation. *Clin Microbiol and Infect* **13**: 5-18.

Wright GD (2011). Molecular mechanisms of antibiotic resistance. *Chem Commun* **47**: 4055-4061.

Wright GD (2015). Solving the Antibiotic Crisis. *ACS Infect Dis*.

- Xia J, Mandal R, Sineelnikov IV, Broadhurst D, Wishart DS (2012). MetaboAnalyst 2.0--a comprehensive server for metabolomic data analysis. *Nucleic Acids Res* **40**: W127-133.
- Xia J, Sineelnikov IV, Han B, Wishart DS (2015). MetaboAnalyst 3.0--making metabolomics more meaningful. *Nucleic Acids Res* **43**: W251-257.
- Yamada Y, Kuzuyama T, Komatsu M, Shin-ya K, Omura S, Cane DE *et al* (2015). Terpene synthases are widely distributed in bacteria. *Proc Natl Acad Sci USA* **112**: 857-862.
- Yang L, Wang K, Li H, Denstedt JD, Cadieux PA (2014). The influence of urinary pH on antibiotic efficacy against bacterial uropathogens. *Urology* **84**: 731.e731-731.e737.
- Yung PY, Grasso LL, Mohidin AF, Acerbi E, Hinks J, Seviour T *et al* (2016). Global transcriptomic responses of *Escherichia coli* K-12 to volatile organic compounds. *Sci Rep* **6**: 19899.
- Zetola NM, Modongo C, Matsiri O, Tamuhla T, Mbongwe B, Matlhagela K *et al* (2017). Diagnosis of pulmonary tuberculosis and assessment of treatment response through analyses of volatile compound patterns in exhaled breath samples. *J Infect* **74**: 367-376.
- Zgurskaya HI, Lopez CA, Gnanakaran S (2015). Permeability barrier of Gram-Negative cell envelopes and approaches to bypass it. *ACS Infect Dis* **1**: 512-522.
- Zhang L (2015). Identification and characterization of developmental genes in *Streptomyces*. PhD thesis, Leiden University, Leiden.
- Zhou F, Xu L, Wang S, Wang B, Lou Q, Lu M *et al* (2017). Bacterial volatile ammonia regulates the consumption sequence of d-pinitol and d-glucose in a fungus associated with an invasive bark beetle. *ISME J* **11**: 2809.
- Zhu H, Swierstra J, Wu C, Girard G, Choi YH, van Wamel W *et al* (2014). Eliciting antibiotics active against the ESKAPE pathogens in a collection of actinomycetes isolated from mountain soils. *Microbiol* **160**: 1714-1725.

CURRICULUM VITAE
&
LIST OF PUBLICATIONS

CURRICULUM VITAE

Mariana Avalos Garcia was born in Cuautla, Morelos, Mexico in May 26th, 1986. She graduated from the College of Sciences and Humanities (Colegio de Ciencias y Humanidades) in Mexico City in 2004. From 2005-2009 she performed her undergraduate studies at the Faculty of Chemistry from the National Autonomous University of Mexico (UNAM) and in 2010 she obtained her Bachelor diploma in Pharmaceutical and Biological Chemistry. From 2010-2012 she carried out her MSc project “Characterization of secondary metabolites with antibiotic activity from *Streptomyces*” under the supervision of Prof. Dr. Sergio Sánchez Esquivel at the Biomedical Research Institute in Mexico City. In January 2013 she obtained her MSc degree with specialization in Biochemistry from the National Autonomous University of Mexico (UNAM). In 2013 she obtained a personal grant from the National Council of Science and Technology (CONACyT) to perform her PhD at Leiden University in The Netherlands under the supervision of Prof. Dr. Gilles van Wezel. The work done as a PhD student is presented in this thesis. Mariana is currently working as a postdoc researcher with Prof. Dr. Jos Raaijmakers studying the role of Oxalotrophic bacteria in disease suppressive soils at the Microbial Ecology department from the Netherlands Institute of Ecology (NIOO-KNAW).

PUBLICATIONS

Sánchez S, Chávez A, Forero A, García-Huante Y, Romero A, Sánchez M, Rocha D, Sánchez B, **Avalos M**, Guzmán-Trampe S, Rodríguez-Sanoja R, Langley E, Ruiz B. (2010). Carbon source regulation of antibiotic production. *J Antibiot* (Tokyo). **63**:442-59

Sánchez S M. Guzmán Trampe S, **Avalos M**, Ruiz B, Rodríguez-Sanoja R, Jiménez-Estrada, M. (2012). Microbial Natural Products: Chemical Diversity. In *Wiley Encyclopedia of Chemical Biology*, T. P. Begley (Ed.).

Avalos M, van Wezel GP, Raaijmakers JM, Garbeva P (2018). Healthy scents: microbial volatiles as new frontier in antibiotic research? *Curr Opin Microbiol* **45**: 84-91.

Avalos M, Boetzer M, Pirovano W, Arenas NE, Douthwaite S, van Wezel GP (2018). Complete genome sequence of *Escherichia coli* AS19, an antibiotic-sensitive variant of *E. coli* Strain B REL606. *Genome Announc* **6**.

Martín-Sánchez L, Singh KS, **Avalos M**, Wezel GP, Dickschat J, Garbeva P. (2019). Phylogenomic analyses and distribution of terpene synthases among *Streptomyces*. *Beilstein Journal of Organic Chemistry*. **15**: 1181-1193

Avalos M, Garbeva P, Raaijmakers JM, Wezel GP. (2019). Production of glycine-derived ammonia as a low-cost and long-distance antibiotic strategy by *Streptomyces* species. (*submitted*)

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