Metabolic profiling of tomato fruits along the plant axis: effects of fertilization and irrigation strategies

Flaminia Cesare Marincola[1,2], Natalia Zuddas[1], Patrizia Pagani[3*], Giulia Siclari[1], Flavia Tasso[3], Daniela Medas[1], Elisabetta Dore[1], Pier Andrea Marras[1], Chiara Alisi[3], Giovanni De Giudici[1]

[1] Department of Chemical and Geological Sciences, Cittadella Universitaria di Monserrato, University of Cagliari, 09042 Monserrato (CA), Italy Email: flaminia@unica.it
[2] Center for Colloid and Surface Science (CSGI), 50019 Sesto Fiorentino (FI), Italy
[3] Department of Sustainability (SSPT), ENEA, Via Anguillarese 301, 00123 Rome, Italy

Tomato fruit metabolism results from the interaction between developmental processes along the plant axis and agronomic inputs, including nutrient availability and water supply. Metabolomics provides a powerful systems-level approach to investigate these interactions by simultaneously profiling a broad range of metabolites involved in central carbon and nitrogen metabolism. Although this approach has been successfully applied to characterize the effects of cultivation practices on tomato fruit composition [1-3], the combined influence of fertilization strategy, irrigation level, and fruit position along the plant axis remains poorly understood under realistic production conditions.

In this study, an untargeted ^{1}H NMR metabolomics approach was used to investigate the effects of fertilization strategy (chemical vs. microbial-based), irrigation level (100% vs. 50%), and fruit position along the plant axis (first vs. third truss) in greenhouse-grown tomato (*Solanum lycopersicum* L.). Fruits harvested at comparable ripening stages were analyzed by ^{1}H NMR spectroscopy. Multivariate analysis (Figure 1) and linear mixed-effects models identified fruit position as the major source of metabolic variation, significantly affecting sugars, amino acids, organic acids, and secondary metabolites. Fertilization exerted broader metabolic effects than irrigation, while significant interactions with truss position highlighted the importance of developmental context in shaping agronomic responses. Correlation-based network analysis revealed treatment-specific differences in metabolic coordination, with microbial-based fertilization associated with more interconnected metabolic networks than chemical fertilization. Notably, these differences occurred without major effects on plant productivity, suggesting that microbial fertilization influences not only metabolite abundance but also the organization of metabolic pathways.

Overall, the results identify metabolic coordination as an additional dimension through which sustainable fertilization strategies can modulate tomato fruit metabolism under greenhouse cultivation and highlight the potential of NMR-based metabolomics to reveal biological responses that are not apparent from conventional agronomic measurements alone.

REFERENCES

[1] Ramírez-Cariño, H. F.; Ochoa-Velasco, C. E.; Guerrero-Analco, J. A.; Monribot-Villanueva, J. L.; Calderón-García, C.; González-Terreros, E.; Escamirosa-Tinoco, C.; Morales, I.; Valadez-Blanco, R. (2023) "Combined Effect of the Potassium Dose and Plant Biofertilization by Acinetobacter Calcoaceticus on the Growth, Mineral Content, Nutritional Quality, Antioxidant Activity, and Metabolomic Features of Tomatillo Fruits (*Physalis Ixocarpa Brot.*)" *Plants*, 12, 466. https://doi.org/10.3390/plants12030466.

[2] Li, W.; Lu, X.; Li, J. (2022) "The Effect of Organic Nutrient Solution on Flavor in Ripe Cherry Tomato Fruit—Transcriptome and Metabolomic Analyses" *Environ. Exp. Bot.* 194, 104721 https://doi.org/10.1016/j.envexpbot.2021.104721.

[3] Xizong, S.; Zonghao, L.; Ruru, Q.; XiLatu, D. (2025) "The Combination of Quantitative and Qualitative Analysis with Targeted Metabolomics Reveals the Differing Impacts of Organic Fertilizer and Biochar Application on the Intrinsic Quality of Tomatoes" *Sci. Hortic.* 345, 114137. https://doi.org/10.1016/j.scienta.2025.114137.