Digitization in Life Sciences: Smart Phenotyping for Sustainable Viticulture

Youry Pii [1], Guido Orzes [2,3], Fabrizio Mazzetto [1,3,*], Paolo Sambo [4] and Stefano Cesco [1]

[1]Faculty of Agricultural, Environmental and Food Sciences, Free University of Bolzano, Bolzano, Italy,
[2]Faculty of Engineering, Free University of Bolzano, Bolzano, Italy,
[3]Competence Center for Plant Health, Free University of Bolzano, Bolzano, Italy,
[4]Department of Agronomy, Food, Natural Resources, Animals and Environment, University of Padova, Legnaro, Italy

*Corresponding author: fabrizio.mazzetto@unibz.it

Keywords: viticulture, Cu toxicity, smart phenotyping, data fusion, artificial intelligence

The production processes in viticulture are undergoing a transformative shift driven by digitization, particularly through the adoption of smart phenotyping. Modern viticulture faces mounting challenges, including climate change, rising incidences of crop diseases, and the accumulation of harmful substances like copper in vineyard soils. These pressures necessitate innovative solutions to ensure sustainability, reduce reliance on fungicides, and preserve soil health. Smart phenotyping, leveraging advanced technologies, emerges as a crucial tool for addressing these complexities.

A key aspect of sustainable viticulture is the selection of resilient grapevine varieties capable of thriving under environmental stresses, such as copper toxicity. Copper, widely used in fungicides, can accumulate to supra-optimal levels in vineyard soils, impairing nutrient acquisition and triggering ambiguous stress symptoms in plants. Traditional methods of evaluating these stress responses often rely on visual assessments, which are subjective and prone to error, particularly when plants exhibit overlapping symptoms from multiple stressors. Here, smart phenotyping offers a data-driven alternative by integrating non-destructive remote sensing technologies with physiological measurements to identify subtle biophysical and biochemical traits.

Remote sensing technologies, such as hyperspectral imaging, thermal sensors, and LiDAR, are central to smart phenotyping. These tools capture high-resolution data about a plant's physiological and nutritional state, surpassing the detail achievable through conventional methods. This comprehensive profiling enables precise characterization of traits linked to resilience, such as tolerance to altered soil fertility or pathogen resistance. For instance, in the context of copper toxicity, smart phenotyping can detect early stress indicators before visible symptoms appear, providing critical insights for breeding and management decisions.

However, the transition to smart phenotyping is not without challenges. The integration of complex datasets from diverse sources, coupled with the need for accurate symptom interpretation, underscores the necessity of advanced analytical tools like artificial intelligence (AI). AI-driven models can analyze vast datasets, identify patterns, and support decision-making by correlating phenotypic traits with underlying genetic and environmental factors. These capabilities enhance the efficiency of breeding programs aimed at developing robust grapevine varieties.

Despite the promise of AI, human expertise remains indispensable. Trained professionals play a vital role in validating AI outputs, particularly when dealing with uncertainties in symptom interpretation. This collaborative approach—combining AI's computational power with expert oversight—ensures that decisions are both accurate and contextually informed.

Smart phenotyping thus represents a pivotal step in the digitization of life science production processes, enabling sustainable solutions for modern viticulture. By fostering resilience to environmental stressors and optimizing resource use, these technologies align with broader goals of reducing agricultural inputs and enhancing long-term vineyard sustainability. As the wine industry grapples with evolving challenges, the integration of smart phenotyping stands as a beacon of innovation, paving the way for a more resilient and sustainable future.

Reference.

Pii Y, Orzes G, Mazzetto F, Sambo P and Cesco S, 2024. Advances in viticulture via smart phenotyping: current progress and future directions in tackling soil copper accumulation. Front. Plant Sci. 15:1459670. doi: 10.3389/fpls.2024.1459670