5 Advanced Computational Technologies for Zhejiang Medicinal Plant Research

5.1 Remote sensing and digital phenotyping technologies

Remote sensing and digital phenotyping are becoming core technologies for medicinal plant research because they replace labor-intensive, subjective field inspection with scalable and dynamic observation.Reviews of medicinal plant cultivation show that remote sensing addresses major limits of conventional methods, while broader assessments indicate that integrated satellite-, UAV-, and ground-based sensing can already support distribution mapping, growth retrieval, stress monitoring, and non-destructive quality evaluation across many medicinal species. For Zhejiang medicinal plants, this is especially valuable because cultivation systems require repeated measurements of canopy condition, habitat variation, and developmental stage over large and heterogeneous production areas. At the field scale, UAV-based phenotyping has shown that medicinal plant growth can be monitored with high precision when spectral indices are combined with direct phenotypic measurements.In *Glycyrrhiza uralensis*, high-resolution full-phenology UAV data supported BP, SVM, and RF models for yield forecasting, and combining multiple indicators improved accuracy beyond single-parameter prediction (Zhang et al., 2025). Similar progress appears in wild-resource surveys, where UAV imagery plus Mask R-CNN enabled automated identification, counting, yield prediction, and spatial mapping of individual *Lamiophlomis rotata* plants in complex high-altitude environments (Ding et al., 2023).

Digital phenotyping is also advancing from simple imaging toward environmentally informed monitoring. Remote sensing can characterize growth-regulating variables such as soil moisture and soil-available silicon, and long-term time-series observation can track medicinal-plant phenology together with climate responses. This matters because medicinal plant phenotypes emerge from genotype-environment interaction, so Zhejiang-focused digital phenotyping platforms should link plant traits with water, nutrient, soil, and weather data rather than treating canopy images as isolated inputs. A further technological shift is the move toward chemical-sensitive phenotyping rather than morphology alone. Hyperspectral imaging captures continuous spectral information related to chemical composition and has supported both traditional machine learning and deep learning for component inversion, including simultaneous prediction of multiple ginsenosides through attention-based temporal convolutional models. Because medicinal plant quality depends on the joint distribution of multiple active constituents, these methods are likely to be especially important for Zhejiang geo-authentic herbs where growth monitoring and quality monitoring must be integrated within the same sensing framework.

5.2 Network biology and systems-level modeling

Network biology provides the systems framework needed to connect growth characteristics with active compound accumulation.Plant metabolic network modeling has emerged as a major tool for integrating and predicting the spatial and temporal distribution of metabolic flows, and recent reviews emphasize that mathematical models are essential for investigating growth, development, metabolic regulation, and secondary metabolism across plant stages (Rao and Liu, 2025). For Zhejiang medicinal plants, this means that systems-level models can serve as bridges between observable traits in the field and less visible pathway-level changes that determine compound accumulation.These models are particularly valuable because medicinal plant metabolism is not a single-pathway process but a coordinated network with competing fluxes, feedback regulation, and environmental sensitivity.Network modeling is now used to quantify pathway fluxes and guide strategies for directing metabolism in plant natural product systems, while broader systems-biology perspectives argue that advances in bioinformatics are shifting medicinal plant research away from reductionist explanation toward network-based interpretation (Noor et al., 2022; Rao and Liu, 2025). This transition is important for Zhejiang studies seeking to explain why the same species shows different growth quality or active-compound profiles under different ecological and agronomic settings.

Another key application is linking chemical constituents to targets, pathways, and biological functions through network pharmacology.This approach typically starts by identifying active compounds and predicting associated genes or targets from chemical representations, providing a structured route from phytochemical data to multi-target functional hypotheses (Noor et al., 2022). In traditional Chinese medicine research more broadly, network pharmacology is used to build multilayer relationships among compounds, targets, and pathways, and it