divergence. Complementary evidence from subtropical mountain forests in nearby Fujian showed clear elevational replacement of medicinal plant communities and stronger environmental effects on shrub and herb β-diversity than on tree-layer diversity, indicating that medicinal plant habitat adaptation in southeastern China is strongly stratified across elevation and vegetation layers.

2. 2 Growth phenology and developmental characteristics

The growth dynamics of Zhejiang medicinal plants are inherently seasonal, and their developmental trajectories are best interpreted through standardized phenological frameworks. Broad phenological theory shows that plants time leafing, flowering, fruiting, and dormancy in ways that reflect adaptation to local environments, while long-term phenology linked with molecular and climate data can improve prediction of future shifts.For medicinal plant research, this matters because the timing and duration of developmental stages determine not only biomass accumulation but also the windows during which organs with pharmacological value are formed, mature, and harvested.

Standardized BBCH-based studies provide practical models for describing these developmental sequences in medicinal species. In *Astragalus membranaceus* var. *mongholicus*, phenological development was organized into distinct vegetative, reproductive, and senescence stages, and the chronology of these stages was linked to accumulated thermal time through growing degree days. Mechanistic developmental evidence from first-year *Panax ginseng* further showed that storage-root thickening follows a stage-specific program in which early growth is associated with auxin, gibberellin, and nitrate signaling, middle growth with cell division and wall biogenesis, and late growth with jasmonic-acid-associated preparation for dormancy.

2.3 Environmental regulation of growth performance

Environmental regulation of medicinal plant growth in Zhejiang is likely to be multidimensional, because temperature, light, water, soil conditions, and nutrient supply act together on both growth and phytochemical traits.Reviews across medicinal species show that environmental optimization can substantially improve plant growth and metabolite synthesis, while ecologically limiting factors such as temperature, lighting, soil water, salinity, and fertility alter both physiological performance and secondary metabolism (Pant et al., 2021). For Zhejiang production systems, this means that growth performance cannot be evaluated independently of environmental management, especially where high humidity, seasonal rainfall, and mountainous microclimates create sharp local differences in resource availability and stress exposure.

More recent cultivation studies indicate that environmental effects are not only strong but also highly context dependent. Controlled-environment systems can improve the consistency, concentration, and yield of bioactive phytochemicals by precisely regulating light, carbon dioxide, temperature, humidity, nutrients, and airflow, whereas climate-related stresses can reshape plant morphology, physiology, and secondary metabolite production in less predictable ways under field conditions. Experimental evidence also shows that microclimate manipulation can shift growth-quality tradeoffs: in medicinal crops grown under dynamic agrivoltaics, heavy shade reduced biomass in most species but increased essential oil yield and sharply lowered evapotranspiration, highlighting the need for computational models that optimize both growth performance and active compound accumulation rather than maximizing yield alone.

3 Computational Frameworks for Growth Trait Analysis in Medicinal Plants

3.1 Data acquisition and multi-source dataset integration

Computational analysis of growth traits in Zhejiang medicinal plants depends first on building datasets that combine field observations with remote sensing and chemical measurements.In medicinal plants, growth and quality vary strongly with environment and across medicinal parts, so single-source measurements often fail to capture the biological basis of active-compound accumulation. Reviews of medicinal-plant monitoring therefore emphasize integrated satellite-, UAV-, and ground-based sensing as the main route toward dynamic growth retrieval, stress monitoring, and non-destructive quality evaluation.At the operational level, multi-source acquisition increasingly joins spectral imagery with synchronous phenotypic sampling.In *Glycyrrhiza uralensis*, UAV multispectral images were collected together with plant height, tiller number, SPAD, and nitrogen content,