5.3 Promotion of precision cultivation management through digital agricultural technologies

Digital agricultural technologies can convert perennial peony management from calendar-based practice to data-driven precision cultivation. More broadly, digital agriculture integrates sensors, drones, satellites, and analytics to collect crop, soil, weather, and phytosanitary data and use them for more precise decisions on irrigation, fertilization, and pest control. Remote sensing and UAVs are particularly useful for non-destructive, near real-time monitoring of growth and field heterogeneity, while AI and big-data tools improve pattern detection and operational decision-making (Fuentes-Peñailillo et al., 2024). For perennial *P. lactiflora*, this framework is well matched to key control points that already show strong environmental sensitivity, including chilling fulfillment, dormancy release, stem emergence, flowering timing, soil moisture, and disease pressure (Wang et al., 2020).

In practice, precision management should prioritize cultivar-specific models that combine climatic suitability, stage regulation, and harvest optimization. Protected-cultivation experiments already show that high tunnels advance initial harvest by 21~34 days, low tunnels with soil heating can further advance harvest, and excessive heat-humidity lowers stem quality and increases disease pressure. Those results are directly translatable into digital control rules, where real-time sensing could regulate tunnel temperature and humidity against cultivar-specific thresholds rather than relying on fixed schedules. Precision systems should also integrate biochemical quality targets, because 4-year roots already match 5-year roots in major active constituents and antidepressant-related bioactivity, making prolonged cultivation unnecessary when monitored quality indices are achieved (Jin et al., 2026). The main limitation is implementation: scalable AI-IoT systems still need better dataset integration, user-friendly interfaces, and adaptation to diverse farm conditions, so digitalization in peony should advance in parallel with standardized field data collection and model validation.

6 Current Research Problems and Future Development Directions

6.1 Insufficient research on perennial cultivation cycles and optimal harvesting strategies

Research on perennial cultivation cycles and optimal harvesting strategies for *P. lactiflora* is still insufficient because most available studies identify useful local harvest windows but do not yet establish a broadly validated, multi-region production calendar. Recent work in Tongliao compared 3-, 4-, and 5-year-old plants on the same plot and found that 4-year-old plants gave the best combined yield-quality score, with late September outperforming earlier and later harvest dates, but the authors explicitly noted that these results are region-specific rather than universal (Guo et al., 2026). Independent chemical-bioactivity integration reached a similar conclusion that 4-year roots were comparable to 5-year roots in key active constituents and antidepressant-related effects, supporting a shorter production cycle, yet this line of evidence is still based on limited cultivation-year contrasts rather than long-term multilocation validation (Jin et al., 2026). At the same time, the long juvenile period and double seed dormancy of *P. lactiflora* continue to slow cycle optimization research itself, because warm-cold stratification, prolonged establishment, and difficult rooting make full-cycle experiments expensive and slow to repeat across environments (Mu et al., 2026).

Future work should therefore move from single-point harvest screening to a full life-cycle optimization framework integrating cultivar, site, developmental stage, and end-use quality. Existing studies already show that flowering, sprouting, and dormancy release are highly climate-sensitive, especially in low-latitude regions where winter warmth disrupts chilling fulfillment and spring-summer heat damages growth. Long-running observation and multi-criteria evaluation have proven useful for comparing cultivar performance across years, and low-chilling materials such as ‘Hang Baishao’, ‘Meiju’, and ‘Qihua Lushuang’ offer a practical basis for region-specific cycle design. Future studies should combine multilocation age-by-harvest experiments with metabolomics, bioactivity assessment, and controlled environment trials so that cultivation years, harvest dates, and post-harvest methods can be optimized for both medicinal roots and ornamental stems rather than inferred from isolated local trials (Sun et al., 2022).

6.2 Incomplete understanding of continuous cropping obstacle mechanisms and green control technologies

The mechanism of continuous-cropping obstacles in *P. lactiflora* remains incomplete because current evidence clearly identifies soil deterioration and microbial imbalance, but does not yet resolve how autotoxins, root