temperature seasonality, and November solar radiation as the dominant environmental drivers, highlighting that active-season water supply and an appropriate winter cold period are both indispensable. Low-latitude cultivation is constrained because hot-humid spring weather can induce stem bending, bud abortion, and severe disease, extreme summer heat can hasten withering, and warm autumn-winter conditions can leave chilling requirements unmet (Wang et al., 2022). This pattern is consistent across observational, physiological, and modeling studies showing that winter warmth is a major barrier to southward expansion (Wang et al., 2020).

Cultivation practice therefore needs to align site selection, cultivar choice, chilling management, and soil regulation with the species' perennial biology. Chilling studies show that lower temperatures and longer durations improve sprouting and flowering, with 0℃ for 6 weeks or 5℃ for 9 weeks sufficient to break dormancy in Korean cultivars, while low-CR cultivars such as 'Hang Baishao' and 'Meiju' are better suited to warm-winter regions (Rhie et al., 2012). Practical regulation can also be effective: chilling at 0~4℃ for four weeks plus humic-acid irrigation improved forcing performance in 'Hang Baishao', and high-tunnel cultivation advanced harvest by 21~34 days, although excessive heating and humidity reduced quality and increased pest and disease pressure (Zhang et al., 2019b). Belowground management is equally important because long-term replanting lowers pH, nutrients, enzyme activities, and microbial diversity while increasing harmful taxa, whereas rhizosphere studies indicate that cation exchange capacity, soil water, and cooperative microbial networks are closely tied to growth and metabolite accumulation (Sun et al., 2022; Li et al., 2023).

3 Cultivation Models and Application Characteristics of Perennial *Paeonia lactiflora*

3.1 Traditional open-field perennial cultivation model and production characteristics

The traditional open-field perennial cultivation model remains the basic production form for medicinal and ornamental *P. lactiflora* because the crop is widely grown in temperate regions and performs as a cool-season, field-based perennial with strong dependence on local seasonal temperature patterns (Qi et al., 2020). In this model, establishment is slow: medicinal production generally requires more than three years from rhizomes and more than six years from seed, and conventional seed propagation also suffers from long cycles, season-dependent germination, and delayed flowering after 4~5 years (Yamamoto et al., 2025). Seed-based open-field expansion is further constrained by double dormancy, because radicle growth requires warm stratification and shoot emergence then requires cold stratification, which prolongs winter propagation and lowers emergence (Mu et al., 2026). Even so, open-field cultivation remains attractive because it is simple, broadly adaptable in temperate zones, and can support multiple product types including medicinal roots, cut flowers, and even seed oil production, although fertility traits vary markedly among genotypes (Sun et al., 2022).

Its production characteristics are defined by strong environmental exposure and by tradeoffs among yield, flower timing, and medicinal quality. In field production of 'Coral Charm', natural field systems yielded about 16.1~20.8 stems/m², and combining field with protected production extended harvest duration up to 38 days, showing the value of open-field plots for staggered supply. Open-field cultivation can also outperform forcing systems in yield: in 'Taebaek', greenhouse forcing shortened time from sprouting to flowering by about 26 days, but yield was lower than under open-field cultivation and early forcing increased susceptibility to powdery mildew and gray mold (Bae et al., 2008). For medicinal roots, open-field management strongly affects both biomass and chemistry: late September of the fourth year produced the best combined yield-quality score in Inner Mongolia, and root dry weight declined with later harvest dates (Guo et al., 2026). Field weed and tillage regimes also matter, because inter-tillage substantially reduced weed biomass, while grass management tended to increase paeoniflorin content and sometimes yield, indicating that conventional open-field systems involve a real balance between cleaner fields and stress-linked quality formation (Seki et al., 2021).

3.2 Large-scale standardized cultivation model and technical advantages

Large-scale standardized cultivation models are designed to overcome the main bottlenecks of perennial *P. lactiflora* production: slow multiplication, unstable seedling supply, and inconsistent field performance (Yamamoto et al., 2025). The strongest technical basis for this model is tissue culture. Mature embryo systems achieved germination rates up to 91.11%, direct seedling formation up to 67.78%, multiple-shoot induction of