2 Growth Characteristics and Cultivation Basis of Perennial *Paeonia lactiflora*

2.1 Growth and development patterns and stage characteristics of perennial *Paeonia lactiflora*

Paeonia lactiflora is a perennial geophyte with a clear annual cycle built around overwintering bud dormancy, spring sprouting, vegetative and reproductive growth, summer senescence, and renewed underground persistence. Long-running observations in low-latitude introductions show that annual growth cycle traits, dormancy duration, and resistance performance differ substantially among cultivars, which makes stage-based cultivar evaluation essential for perennial production planning (Wang et al., 2022). In the low-chilling cultivar 'Meiju', sprouting can exceed 50% in March, leaves unfold 1~2 weeks later, and aboveground parts usually wither by early August, illustrating a compressed aboveground season followed by underground dormancy. Reproductively, mature clumps can support annual cut-flower harvest after establishment, and healthy plants may remain productive for about 10 years under suitable management (Li et al., 2023).

The earliest developmental bottleneck occurs at seed germination because *P. lactiflora* seeds exhibit double dormancy of the hypocotyl and epicotyl. Dormancy release requires warm stratification first to promote radicle growth, followed by cold stratification to trigger epicotyl elongation and seedling emergence, and this prolonged sequence lengthens the propagation cycle and lowers field emergence. Physiological evidence indicates that the warm phase mainly drives root growth, whereas the cold phase intensifies reserve degradation, hydrolytic enzyme activity, and hormonal rebalancing needed for shoot emergence; in transcriptome-metabolome profiling, the 28-day warm-stratification stage was the key transition period (Mu et al., 2026). Because conventional propagation from rhizomes or seeds is slow, in vitro embryo culture and rooted shoot systems now provide a practical basis for compressing early developmental stages and stabilizing seedling supply (Xin et al., 2025; Zhu et al., 2026).

2.2 Root development and formation characteristics of medicinal quality in *Paeonia lactiflora*

As a perennial root medicinal crop, the underground organ of *P. lactiflora* is both the main harvested product and the principal site of bioactive compound accumulation, so root development directly determines yield and medicinal quality (Guo et al., 2026). Reviews of its phytochemistry show that more than 200 compounds have been identified, including terpenoids, flavonoids, polyphenols, and organic acids, with paeoniflorin recognized as the major indicator compound and a major focus of quality evaluation. Root secondary metabolism is not autonomous: metabolomic and microbiome studies show that root metabolite accumulation is closely linked to rhizosphere microbial communities, and varietal comparisons further indicate that differences in paeoniflorin, total phenols, flavonoids, and antioxidant capacity track biological variation among germplasms (Wu et al., 2025). Environmental-response analysis similarly found that root secondary metabolites are jointly shaped by soil water content, mean annual precipitation, pH, and specific biotic factors such as *Alternaria*, indicating that medicinal quality is an outcome of genotype-environment-microbiome interaction rather than age alone (Sun et al., 2022).

Root medicinal quality also changes markedly with plant age, harvest season, and post-harvest processing (Guo et al., 2026). Across cultivation studies, active components tend to reach comparatively high levels in 4-year-old roots, while further extension to older ages yields limited chemical gain and greater structural or pathological risk; 5-year-old plants often show more disease, and 6-year-old roots can become hollow and lignified, which lowers medicinal quality. In the Tongliao study, comprehensive evaluation ranked late September of the fourth growing year as the optimal harvest period, and paeoniflorin content was positively correlated with root dry weight. Wild-like cultivation work further showed that root traits and paeoniflorin content increased year by year under simulated natural conditions, suggesting that ecological cultivation patterns can improve medicinal attributes when matched to developmental timing

2.3 Ecological requirements and cultivation conditions for optimal growth of *Paeonia lactiflora*

The optimal growth of *P. lactiflora* depends on a temperate ecological niche characterized by cool winters, moderate thermal seasonality, adequate summer moisture, and sufficient light, which explains why the species is concentrated in temperate regions and is difficult to maintain in hot, humid low latitudes (Cai et al., 2026). Distribution modeling identified precipitation of the warmest quarter, mean temperature of the coldest quarter,