

Zhejiang Province, supporting a cultivar-by-region matching strategy rather than a uniform national model (Jiang et al., 2019). Field evidence also shows that cultivation models must be adjusted to local edaphic conditions, because the major coastal production regions are characterized by relatively high soil salinity, while understory systems face poor fertility constraints that require different soil-improvement strategies (Liu et al., 2025; Liu et al., 2026). More broadly, *Fritillaria* domestication research supports region-specific artificial cultivation, careful survey of growth environments, and integration of bulb and tissue-culture propagation with seed systems where appropriate (Figure 2) (Qu et al., 2022).



Figure 2 Artificial and imitating wild cultivation of *F. thunbergii* (Adopted from Qu et al., 2022)

Image caption: (A): The large-scale artificial cultivation of *F. thunbergii* in Zhangshui town of Ningbo in Zhejiang Province of China; (B): The imitating wild cultivation of *F. thunbergii* in Siming Mountain in Zhejiang Province of China; (C): The *F. thunbergii* Flos; (D): The bulb of *F. thunbergii* by artificial cultivation, Bar: 1 cm; (E): The bulb of *F. thunbergii* by the imitating wild cultivation; Bar: 1 cm (Adopted from Qu et al., 2022)

Within these regional models, production conditions should be optimized for the local balance between yield and medicinal quality rather than yield alone. In Pan'an, Zhejiang, organic fertilizer produced the best combined outcome, with peimine and peiminine contents of 0.060 3% and 0.050 2% and a yield of 2.70 kg/m², indicating that fertilization schemes can be regionally standardized around local soil conditions (Huang et al., 2024). Potassium management is another core regional variable, because field studies across two cultivars showed that potassium fertilization increased bulb yield, bulb quality, and net income, with 120 kg K₂O/hm² emerging as the best overall rate when economic and environmental benefits were considered (Sui et al., 2021). In areas using ecological or understory cultivation, biochar plus organic fertilizer appears especially suitable, because it improved yield, total alkaloids, soil nutrient status, and rhizosphere microbial structure under forest conditions (Liu et al., 2026). In contrast, where light is excessive or medicinal quality is prioritized, regional ecological regulation by shading combined with potassium can increase active ingredients while partly offsetting the biomass penalty of shading alone, which supports differentiated production models for medicinal bulbs versus propagation bulbs (Liu et al., 2025).

5.2 Integration of bulb propagation, storage, and scalable production technologies

Large-scale production depends on linking rapid propagation with reliable storage and transplant establishment. Conventional bulb reproduction remains the main domestication method in *Fritillaria*, but its multiplication cycle ranges from about 100 days to 3 years, so industrial systems increasingly need to combine field bulb propagation with in vitro multiplication to supply enough healthy seed bulbs (Qu et al., 2022). In *F. thunbergii*, bulb-scale culture already provides a workable expansion route, producing an optimum of 13.7 bulblets per explant on solid MS medium, with leaf and root formation within 12 weeks. More generally across *Fritillaria*, bulb scales are among the most effective explants for large-scale morphogenesis, and tissue culture can provide many homogeneous plants year-round from small amounts of starting material (Marković et al., 2023). This propagation module can be paired with regional field nurseries, where elite bulbs are further enlarged under standardized fertilizer and spacing regimes before entering commercial production (Liu et al., 2025).