

2 Biological Characteristics and Foundation of Bulb Propagation in *Fritillaria thunbergii*

2.1 Growth and development characteristics and bulb formation patterns of *Fritillaria thunbergii*

Fritillaria thunbergii is a perennial bulbous medicinal plant whose commercial organ is the dried bulb, and artificial cultivation has long relied on the biology of bulb growth and renewal rather than on rapid seed-based turnover (He et al., 2021; Qu et al., 2022). In cultivated production, its growth cycle is distinctly seasonal: one field study reported planting in mid-September with sprouting the following season, while another experiment recorded October planting and emergence in February, indicating a clear autumn planting-winter dormancy-spring emergence rhythm (Liu et al., 2025). Variety traits modify this rhythm, as the cultivar “Zhebei 3” emerged early, senesced later, and showed an average growth period of about 100 days, longer than the comparison cultivars (Jiang et al., 2019). Bulb enlargement is concentrated in a relatively short developmental window, with rapid filling beginning 32 days after sprouting and full bulb growth requiring about 72 days, which helps explain why cultivation management during the expansion stage has disproportionate effects on final bulb size and propagation value.

Bulb formation in *F. thunbergii* follows the general geophyte pattern in which daughter bulbs arise from the mother bulb and then pass through dormancy before sprouting in the next cycle. Temperature is central to this pattern: high temperatures induce dormancy, whereas winter chilling breaks dormancy and promotes spring sprouting, and fritillary bulbs regenerated in vitro likewise fail to resume normal growth unless they receive low-temperature treatment (Marković et al., 2021). Evidence from *F. thunbergii* tissue culture matches this developmental requirement, because regenerated bulblets were cold-treated at 5°C for 5 weeks, and bulblets larger than 10 mm then achieved 100% sprouting after transplantation. At the molecular level, bulb development also appears to be linked to hormonal regulation, as ABA-related signaling was associated with bulb yield and the gene *FtGGPS* was implicated in coordinating GA and ABA levels during bulb development, providing a mechanistic basis for differences in bulb expansion and propagation coefficient among cultivars (Huang et al., 2024; Xu et al., 2026).

2.2 Propagation methods and bulb development processes of *Fritillaria thunbergii*

The propagation of *F. thunbergii* mainly includes vegetative bulb reproduction, seed reproduction, and in vitro rapid propagation, with bulb reproduction historically serving as the principal domestication method. Across *Fritillaria*, bulb reproduction generally requires about 100 days to 3 years, whereas seed reproduction usually takes more than five years, which is why bulbs are commonly used as planting material in production systems seeking faster turnover (Qu et al., 2022). Even so, seed-based pathways still matter for breeding and propagation diversification, and an early study showed that total alkaloid content in *F. thunbergii* seedling bulbs already met the Pharmacopoeia standard, supporting the practical value of sexual propagation for future production. Conventional vegetative propagation remains biologically constrained because only a few daughter bulbs can be produced from each mother bulb each year, and repeated use of mother bulbs can also transmit viral and fungal infections to progeny bulbs (Marković et al., 2021).

For these reasons, tissue culture has become a key supplementary route for large-scale propagation of *F. thunbergii* (Qu et al., 2022). In vitro morphogenesis in fritillaries can be induced from bulbs, bulb scales, inflorescence parts, and embryos, and whole plants can be regenerated through bulblet formation or somatic embryogenesis. For *F. thunbergii* specifically, bulb-scale sections cultured on MS medium with 1.62 µM NAA and 4.65 µmol/L KN produced an optimum of 13.7 bulblets per explant, and these bulblets formed leaves and roots within 12 weeks under a 16 h light/8 h dark regime at 25°C. Other culture work found that combinations of 2,4-D and kinetin were more effective than NAA and BA for bulblet induction, that most bulbs formed from axillary buds of nodal explants, and that light culture outperformed dark culture for bulb formation, shoot growth, callusing, and rooting. Taken together, the developmental process of propagated bulbs in *F. thunbergii* can be summarized as explant induction, bulblet differentiation, root and shoot formation, dormancy establishment, low-temperature dormancy release, and transplant establishment, after which field bulb expansion determines whether the propagated material becomes productive seed bulbs or commercial medicinal bulbs (Marković et al., 2021).