

useful for maintaining elite field materials and supplying initial propagules, while large-scale industrial multiplication increasingly requires combination with scale propagation and tissue culture (Bhardwaj et al., 2025).

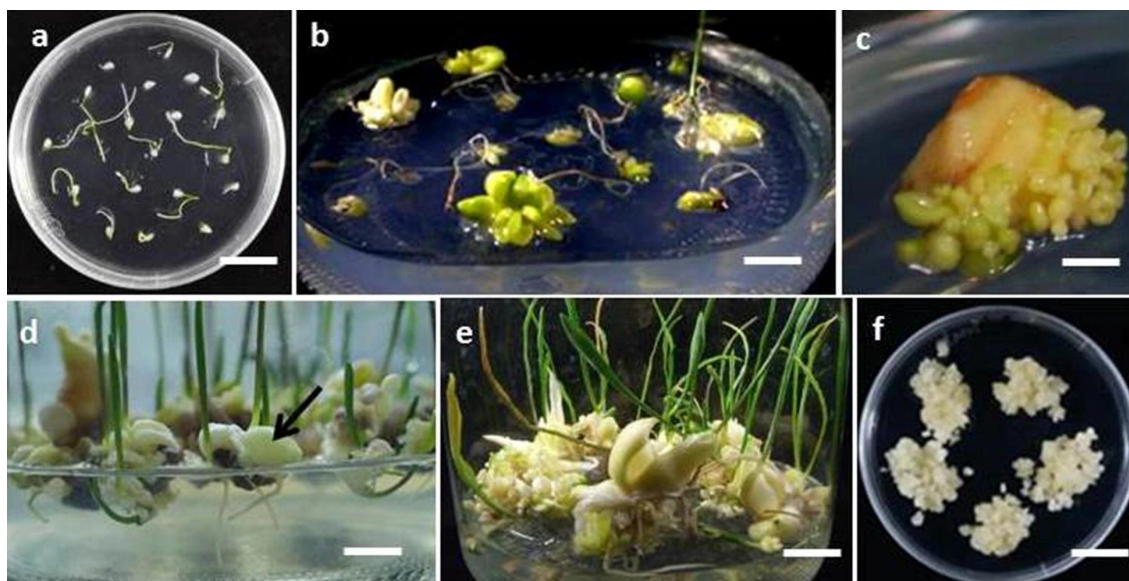


Figure 1 *F. cirrhosa* (Adopted from Chang et al., 2020)

Image caption: a: *In vitro* seed germination on MS basal medium supplemented with BA (1.0 mg/L), NAA (0.4 mg/L) after incubation for 20 days (bar=1.8 cm). b: Bulblet and callus formation in 4 month old seedlings growing on 1/2X MS basal medium supplemented with sucrose (2.5%), GPP (0.4%) (bar=1.24 cm). c, d, e: Bulblet regeneration from bulb sections after 2 months of culture (c, bar=0.25 cm); at the end of subculture 2 (6 months) (d, bar=0.9 cm, arrow showing a bulblet); and at the end of subculture 5 (12 months) (e, bar=1.5 cm); f: Callus growth under darkness (bar=1.8 cm) (Adopted from Chang et al., 2020)

3.2 Scale propagation and rapid multiplication technology using bulb scales and bulblets

Scale propagation uses bulb scales or scale sections as explants to induce direct bulblet formation, and it is one of the most important rapid multiplication routes developed for *F. thunbergii* (Chang et al., 2020). In a classic *F. thunbergii* study, bulb-scale sections cultured on MS medium produced a high frequency of bulblets, with an optimum of 13.7 bulblets per scale section on medium containing 1.62 μ M NAA and 4.65 μ mol/L KN (Marković et al., 2023). Light and temperature are key to this process, because a 16 h light/8 h dark regime at 25°C produced better bulblet formation than continuous darkness (Pasternak and Steinmacher, 2024). Earlier culture-method work in *F. thunbergii* also showed that solid MS medium with 1.0 mg/L kinetin and 0.3 mg/L NAA outperformed liquid and suspension culture for bulblet formation and propagation rate, while activated charcoal and 1~2% mannitol further promoted bulbing and subsequent bulblet growth.

The application value of scale propagation lies in its ability to raise multiplication efficiency while using limited source material, and in fritillaries generally bulb scales are among the most effective explants for morphogenesis and rapid regeneration. This route also reduces pressure on whole mother bulbs, and in vitro-derived bulbs or bulb parts can lower contamination and reduce destructive harvesting of source populations (Chang et al., 2020). However, scale propagation remains sensitive to plant growth regulator combinations and explant source, because different auxin-cytokinin balances can shift cultures toward bulblet formation, shoot proliferation, or somatic embryogenesis rather than a single uniform response (Marković et al., 2023). As a result, scale-based rapid multiplication is highly useful for nursery expansion of seed bulbs and for bridging field production with laboratory propagation, but it still requires precise control of medium composition, explant physiological state, and dormancy management before it can be stably translated into year-round industrial production (Marković et al., 2021).

3.3 Tissue culture propagation and rapid expansion technology for high-quality planting materials

Tissue culture propagation provides the most promising route for rapid expansion of high-quality *F. thunbergii* planting materials because it enables aseptic, season-independent, and large-scale clonal multiplication from small