

coordination among germplasm conservation, standardized cultivation, and medicinal-material quality stability, and provide technical support for the sustainable utilization and high-quality industrial development of *T. hemsleyanum* resources.

2 Biological Basis of Cutting Propagation in *Tetrastigma hemsleyanum*

2.1 Shoot growth characteristics and regenerative capacity of cuttings

Tetrastigma hemsleyanum has clear regenerative potential, but current production still indicates that conventional cutting propagation yields are limited and require optimization for commercial multiplication (Pang et al., 2024). Evidence from in vitro regeneration shows that its vegetative organs retain strong organogenic competence, since leaves and petioles can regenerate adventitious shoots efficiently and axillary buds can be induced to proliferate rapidly under suitable culture conditions. This broad regenerative capacity supports the biological feasibility of building a cutting-based seedling system, because the species is not regeneration-deficient in principle but instead appears sensitive to the specification of propagule type and culture conditions.

The regenerative performance of cuttings depends strongly on the physiological status of the shoot segment, especially its age, maturity, reserve status, and nodal activity (Wei et al., 2019; Liu et al., 2025). In *T. hemsleyanum*, the strongest direct evidence is that 2-3-year-old cuttings rooted better than other ages, indicating that propagation material must balance juvenility with sufficient tissue maturity. Studies in other medicinal and woody species show similar positional and maturity effects: apical cuttings performed best in *Chrysanthemum indicum* (Ghimire et al., 2022), young apical shoots rooted better than old apical shoots in *Andrographis paniculata* (Hossain et al., 2021), whereas basal or middle segments in moringa often produced stronger shoots, thicker roots, or higher rooting percentages because of greater carbohydrate reserves and different endogenous hormone gradients (Muniandi et al., 2024).

2.2 Adventitious root initiation and formation in cuttings

Adventitious root formation is the developmental prerequisite for survival of detached cuttings and is therefore the core biological event in clonal propagation (Druege et al., 2019; Liu et al., 2025). In mechanistic terms, adventitious rooting is a strictly regulated process that generally proceeds through cell specification and reprogramming, primordium initiation through cell division, and primordium emergence and outgrowth (Wei et al., 2019). Tomato cutting studies further show that founder cells in basal pericycle-associated tissues first form disordered cell clusters, then dome-shaped primordia, and finally mature roots that emerge through the epidermis (Guan et al., 2019). This sequence explains why rooting speed and uniformity often vary among species and genotypes, since each stage depends on the successful completion of a distinct cellular program.

Within this program, auxin is the central regulator of adventitious rooting, while jasmonic acid, ethylene, cytokinins, and other signals modify the response (Wei et al., 2019; Liu et al., 2025). After excision, wound signaling rapidly alters hormone homeostasis, and tomato cuttings showed increased auxin and ethylene in the basal stem within 1 h, followed by auxin accumulation in meristematic founder regions and increased expression of auxin transporter genes during defined rooting phases (Guan et al., 2019). Tea and general rooting reviews likewise identify auxin as the leading hormone controlling root induction, while recent work in grape indicates that auxin and cytokinin are prominent in bud germination and leaf expansion, salicylic acid is associated with callus and root formation, and jasmonic acid and gibberellins are more closely linked to direct rooting (Wei et al., 2019; Zheng et al., 2025). In *T. hemsleyanum*, high rooting competence is also evident in tissue culture, where regenerated shoots formed roots at 100% frequency on media containing NAA or IBA, confirming that the species is highly auxin-responsive once suitable physiological conditions are established (Pang et al., 2024).

2.3 Major factors affecting rooting of cuttings

The main factors affecting rooting of *T. hemsleyanum* cuttings can be grouped into propagule traits, hormonal regulation, and environmental conditions, and this multifactorial control is consistent across diverse cutting systems (Campbell et al., 2021; Liu et al., 2025). For *T. hemsleyanum* specifically, rooting reagent and cutting age significantly affected rooting rate, whereas the tested cutting medium had no obvious effect in one study, and the