rhizome fresh weight and polysaccharide content, linking ecological adaptability directly to both yield and quality. Common-garden work further shows that *Polygonatum* species differ significantly in yield, stem and leaf traits, and rhizome saponin and polysaccharide contents, so understory suitability is real but species and provenance selection remains essential (Liao et al., 2023; Cheng et al., 2026).

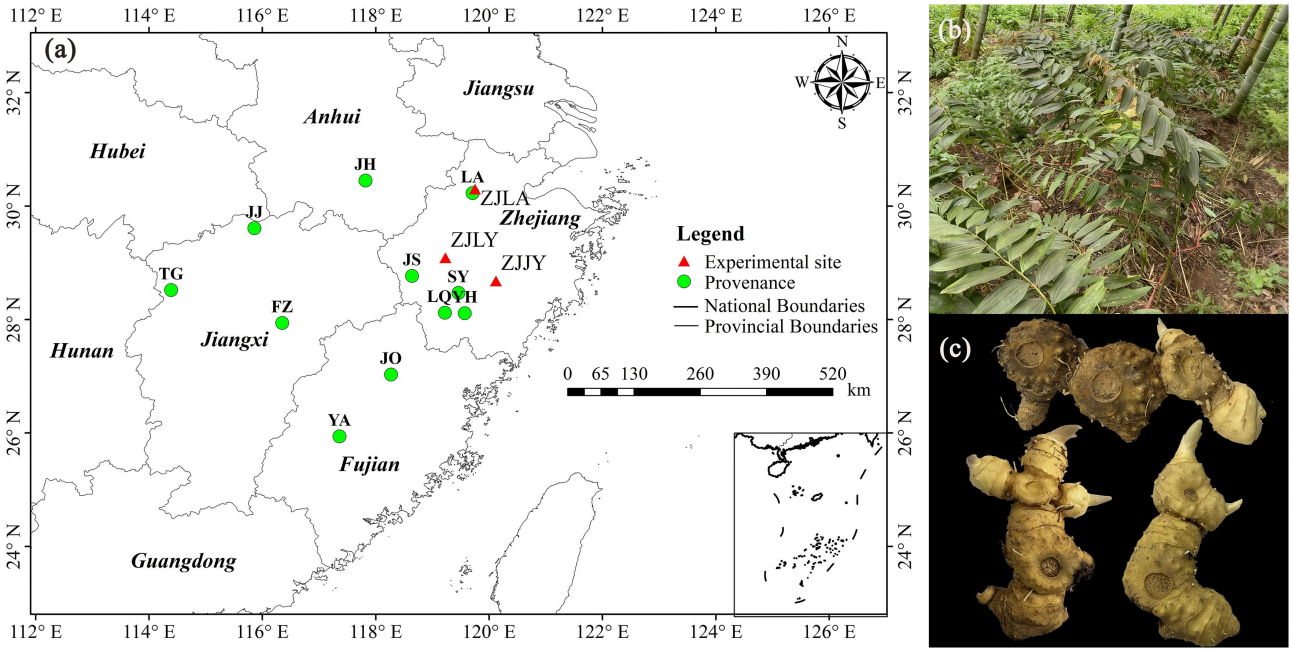


Figure 1 Distribution map of provenance collection sites and experimental sites for *P. cyrtonema* (Adopted from Cheng et al., 2026)
Image caption: (a) collection sites and experimental sites; (b) *P. cyrtonema* in Jinyun sites; (c) Rhizomes (Adopted from Cheng et al., 2026)

### 3.2 Effects of understory environmental factors on yield and quality formation of *Polygonatum*

Light is the most direct understory factor shaping *Polygonatum* growth. Shading experiments on *P. cyrtonema* show that shaded conditions increased chlorophyll a and b, net photosynthetic rate, stomatal conductance, transpiration, PSII efficiency, and total biomass, while reducing oxidative stress indicators, indicating that moderate shade improves physiological performance rather than suppressing it. The same study concluded that shading benefits rhizome yield and quality formation, with 65% light transmittance identified as especially suitable (Liang et al., 2019). Agroforestry evidence is consistent with this pattern: intercropping alters photosynthetic radiation and microclimate in ways that matter particularly for shade-tolerant *P. cyrtonema*, but excessive shading can cause lodging and inhibit growth, so canopy regulation is more important than maximizing shade (Xu et al., 2023).

Soil, altitude, moisture, pH, and rhizosphere biology jointly shape quality formation. Provenance trials found that saponin content increased with altitude and temperature, while flavonoid accumulation was promoted under drier conditions, showing that different active compounds respond to different environmental drivers (Cheng et al., 2026). Soil studies on *P. cyrtonema* showed that polysaccharides were associated with nutrient-rich soils and specific endophytic bacteria, whereas flavonoids were associated with relatively nutrient-poor soils, and Jingning material had the highest polysaccharide and saponin contents under higher AN, AP, and AK conditions (Zhang et al., 2024). Genotype-by-site adaptation studies further found that rhizome fresh weight and polysaccharide content peaked at soil pH 7.48~7.95 and declined with acidification, while beneficial rhizosphere microorganisms were associated with high-yield, high-quality materials and pathogenic taxa with poor performance. More generally, canopy plants can ameliorate solar radiation and heat stress while increasing understory soil moisture and carbon and nitrogen levels, which helps explain why forest microhabitats can favor shade-adapted medicinal plants when the tree layer is ecologically compatible (Abd-ElGawad et al., 2020; Shi et al., 2025).