maturation, dry matter transfer to the underground bulbs should be promoted, while suitable light, temperature, water, and soil conditions should be maintained to support secondary metabolic activity. Existing studies have shown that when shading is combined with appropriate potassium fertilization, yield loss in *F. thunbergii* can be alleviated while peimine and related steroidal alkaloids remain at relatively high levels. Moreover, antitussive, expectorant, and anti-inflammatory activities are relatively optimal under moderate potassium treatment (Liu et al., 2025a). Similarly, organic fertilizer treatment can achieve relatively high bulb yield while increasing peimine and peiminine contents, indicating that an appropriate nutrient regime can shift the system from a strict yield-quality trade-off toward a more coordinated outcome (Huang et al., 2024a).

Mechanistic studies on other medicinal plants also support this coordination strategy. Moderate resource supply can generally optimize carbon-nitrogen balance and carbon allocation, thereby promoting both biomass and secondary metabolite accumulation. For example, in *Epimedium pubescens*, moderate nitrogen treatment can produce relatively high total dry weight and higher levels of icariin-type flavonoids, whereas both low and high nitrogen weaken photosynthesis, disrupt carbon-nitrogen homeostasis, reduce soluble sugar and starch contents, and suppress flavonoid biosynthesis (Liu et al., 2025b). Reviews on medicinal plant cultivation have also pointed out that environmental factors such as temperature, light, soil fertility, and water need to be precisely controlled to stabilize secondary metabolite content and yield. At the same time, harvest timing should be regulated so that the peak of secondary metabolite accumulation coincides with an acceptable biomass level, thereby achieving the so-called “optimal harvest time” (Yang et al., 2018; Qaderi et al., 2023). By extension, scientific environmental management for *F. thunbergii* should aim at the coordinated improvement of yield and quality. Through ecological suitability zoning, moderate shading, rational water and fertilizer supply, soil improvement, rotation and intercropping, and disease control, a stable and suitable growth environment can be constructed. On this basis, incorporating bulb yield, marketable traits, dry matter content, peimine content, and safety indicators into comprehensive evaluation will help establish a more scientific cultivation technology system for *F. thunbergii* and achieve coordinated development of medicinal material yield, quality, and industrial benefits.

8 Future Perspectives and Prospects

High-quality and high-yield production of *Fritillaria thunbergii* should first be based on the selection of ecologically suitable areas. Since *F. thunbergii* prefers cool, moist, and well-ventilated environments and is intolerant of high temperature and waterlogging, cultivation areas should preferably be selected in regions with a mild climate, appropriate diurnal temperature difference, relatively balanced precipitation, loose and fertile soil, and favorable irrigation and drainage conditions. The screening of ecologically suitable areas should not rely solely on traditional cultivation experience, but should comprehensively consider factors such as altitude, temperature, light, precipitation, soil texture, pH, disease risk, as well as transportation and processing conditions, so as to form a regionalized cultivation layout. On this basis, standardized cultivation strategies should be promoted, including the selection of high-quality seed bulbs, seed source grading, pre-sowing treatment, rational close planting, scientific fertilization, green pest and disease control, and timely harvesting. By establishing unified production technical procedures and field management standards, differences in management among growers can be reduced, thereby improving yield stability and quality consistency of *F. thunbergii* and laying a foundation for geo-authentic medicinal material brand development and industrial-scale production.

The core of cultivation environment optimization for *F. thunbergii* lies in the comprehensive coordination of light, temperature, water, fertility, and soil conditions. In production, refined management should be carried out according to the requirements of different growth stages. During sprouting and emergence, soil should be kept moderately moist with good aeration to promote uniform emergence and root formation. During vegetative growth, moderate shading, rational irrigation, and balanced fertilization should be used to maintain leaf photosynthetic function and promote assimilate accumulation. During bulb enlargement, stable water and fertilizer supply should be emphasized, while premature senescence of aboveground parts caused by high temperature, drought, or wet injury should be avoided. In the late growth stage, water should be appropriately controlled to promote bulb maturation and stable accumulation of active constituents. In fertilizer management, the principle of