

redox homeostasis, thereby providing a physiological basis for enhanced stress resistance and stable medicinal quality formation.

5 Effects of Shading Environment on Substance Metabolism and Active Component Accumulation in *Tetragastria hemsleyana*

5.1 Effects on carbohydrate accumulation and transport

Carbohydrates are an important material basis for the growth, development, and medicinal organ formation of *Tetragastria hemsleyana*. Their accumulation level is directly affected by photosynthetic intensity, sugar metabolic activity, and the transport efficiency of assimilates. By altering the light intensity received by leaves, the shading environment further affects the synthesis, allocation, and transport of carbohydrates such as soluble sugars, sucrose, and starch. Studies on light-regulated sugar metabolism indicate that light intensity and light quality can influence starch granule formation, sucrose synthesis, and vascular transport, thereby determining the amount of carbon sources available for plant growth, storage organ development, and secondary metabolism. Under moderate shading conditions, leaves of *T. hemsleyana* are expected to maintain relatively stable photosynthetic activity while reducing physiological consumption caused by strong light and high temperature, which is conducive to the continuous formation and effective transport of photosynthetic products. At this stage, leaves function as “source” organs and can provide sufficient carbon support for vine growth and underground tuberous root enlargement.

Carbohydrate accumulation is highly sensitive to shading intensity. If shading is excessive, insufficient photosynthetically active radiation restricts carbon assimilation, reducing the production of photosynthetic products in leaves and subsequently affecting sucrose transport to underground tuberous roots and the accumulation of storage substances. In medicinal underground bud plants such as *Bletilla striata* and *Bletilla ochracea*, moderate shading or medium light intensity can increase aboveground and tuber dry weight, net photosynthetic rate, and total polysaccharide content, whereas excessive shading leads to a significant decline in these indicators (Xu et al., 2024). Suitable light intensity can promote sucrose production in leaves and improve its transport efficiency to storage organs. In storage organs, sucrose is further converted into key intermediates such as sucrose-6-phosphate, fructose-6-phosphate, glucose-6-phosphate, GDP-mannose, and UDP-glucose, which subsequently participate in polysaccharide biosynthesis (Zhu et al., 2024; Zhu et al., 2025). Conversely, under low-light or long-term shading conditions, glycolysis, galactose metabolism, the pentose phosphate pathway, and the tricarboxylic acid cycle are inhibited in many plants, resulting in reduced sugar reserves and causing plants to shift toward consuming stored carbohydrates (Liu et al., 2020; Shao et al., 2022). Therefore, the regulation of carbon metabolism by shading in *T. hemsleyana* is not simply promotive or inhibitory; rather, it depends on whether shading intensity can maintain a balance among photosynthesis, respiratory consumption, and assimilate transport.

5.2 Effects on nitrogen metabolism and carbon-nitrogen balance

Nitrogen metabolism is an important basis for vegetative growth and physiological function maintenance in *T. hemsleyana*, and it is closely associated with chlorophyll synthesis, protein formation, enzyme activity regulation, and secondary metabolism. Under shading conditions, *T. hemsleyana* often needs to adjust leaf structure and photosynthetic pigment composition to adapt to weak-light environments, while chlorophyll, Rubisco, and other photosynthesis-related proteins all require nitrogen for their formation. General studies on carbon-nitrogen regulation have shown that increasing nitrogen allocation in leaves can enhance chlorophyll and Rubisco contents, photosynthetic nitrogen-use efficiency, and carbon assimilation capacity, and can help improve plant growth and carbon storage even under nitrogen-limited conditions (Perchlik and Tegeder, 2018). Therefore, under moderate shading conditions, *T. hemsleyana* may enhance light absorption and utilization under weak light by optimizing nitrogen allocation for leaf functional maintenance and photosynthetic system construction, thereby providing a metabolic basis for subsequent substance synthesis and medicinal component accumulation.

Shading can also reshape nitrogen metabolism and carbon-nitrogen (C-N) balance, both of which jointly determine photosynthetic capacity, vegetative growth, and secondary metabolite biosynthesis in plants. In tea