higher-order conformations vary substantially among fractions and preparations, and these structural differences are closely associated with biological activity (He et al., 2022; Guo et al., 2025). This complexity creates a key quality-control challenge: bioactivity differs with source, cultivation condition, extraction process, processing method, and storage condition, because each of these factors can alter polysaccharide yield, composition, and physicochemical properties (Xu et al., 2022). Consistent with this, substantial variation in polysaccharide content has been reported across regions, tissues, developmental stages, and cultivation years, with stems generally richer than leaves and flowers, and with content changing across flowering and seasonal cycles.

Because wild *D. officinale* is scarce, slow-growing, and no longer economically reliable as the main source, artificial cultivation has become the dominant production mode, making environmental regulation a practical route for improving both yield and medicinal quality. Multiple studies show that ecological factors are tightly linked to the accumulation of medicinal components in *D. officinale*, and that light, temperature, humidity, radiation, and nutrient-related variables jointly shape polysaccharide formation (Okoro et al., 2023). In field and semi-artificial systems, maximum and minimum relative humidity, maximum temperature, sunshine duration, soil pH, and soil nitrogen and phosphorus status have been identified as key ecological drivers of medicinal quality, while soil factors overall show significant positive relationships with polysaccharide content. Controlled-environment studies provide more direct mechanistic clues. Light quality regulates growth and polysaccharide synthesis, with red light significantly promoting UGPase expression, and a red:blue ratio of 1:3 enhancing biomass and polysaccharide accumulation through Ca^{2+}-CaM signaling, improved photosynthetic performance, increased sucrose phosphatase and sucrose synthase activities, and greater glucose and fructose precursor supply (Wang et al., 2024). High light also increases polysaccharide accumulation, especially mannose, and activates a DoHY5-dependent regulatory pathway in which DoHY5 directly induces polysaccharide biosynthetic genes such as *DoGMPP2* and *DoPMT28*. Temperature regulation is similarly important: diurnal temperature difference favors polysaccharide accumulation in protocorm-like bodies and changes the expression of sugar-metabolism genes including *SUS, SUT, HKL1, HGL, AMY1*, and *SS3*, while seasonal low temperature and drought are associated with sugar accumulation and stress-responsive hub genes in stems and leaves (Chen et al., 2024). Related evidence from *Dendrobium nobile* further supports the carbohydrate-promoting role of temperature regulation, as short-term 0℃ treatment increased polysaccharide accumulation by 56.18% and upregulated genes in starch and sucrose metabolism (Fan et al., 2024).

This study investigates the mechanisms by which controlled-environment regulation affects polysaccharide accumulation in *Dendrobium officinale*, with particular emphasis on the effects of light, temperature, water availability, humidity, nutrient supply, and the rhizosphere environment on polysaccharide formation and accumulation. The underlying relationships are analyzed from the perspectives of photosynthesis, carbon allocation, sugar precursor formation, regulation of sugar metabolism, stress adaptation, and signal transduction. Existing studies indicate that polysaccharide accumulation in *D. officinale* results from the combined effects of aboveground environmental conditions and the belowground rhizosphere environment, with pronounced synergistic and interactive effects among different environmental factors. However, current findings remain relatively fragmented, and a systematic understanding of how multiple environmental factors jointly regulate polysaccharide formation through physiological and metabolic processes is still lacking. Therefore, this study aims to clarify the regulatory pathways linking environmental signals, physiological metabolism, and polysaccharide accumulation, and identify the key processes through which controlled environments influence quality formation in *D. officinale*. The findings are expected to provide a theoretical basis for optimizing controlled cultivation conditions, enhancing polysaccharide accumulation, and stabilizing medicinal quality, while also providing guidance for the efficient utilization of *D. officinale* resources, standardized production, and the development of medicinal and functional food products.