2.3 Sugar metabolic pathways

After photosynthetic fixation, carbon enters the sugar metabolic network that directly supplies precursors for polysaccharide assembly. Current pathway models divide DOP biosynthesis into three major steps: sucrose is first converted into intermediates such as glucose-1-phosphate and fructose-6-phosphate, these are then transformed into nucleotide-diphospho sugars, and finally glycosyltransferases polymerize these activated donors into macromolecular polysaccharides in the Golgi apparatus. Within this framework, sucrose synthase is a central enzyme because it cleaves sucrose with UDP to generate UDP-glucose and fructose, thereby linking source carbohydrate turnover to precursor supply for cell wall and storage polysaccharide synthesis (Chen et al., 2024). Transcriptomic studies support this model by showing that starch and sucrose metabolism is repeatedly enriched during developmental transitions associated with stem polysaccharide change, and that candidate biosynthetic genes co-vary with polysaccharide content (Yang et al., 2025).

The physiological basis of polysaccharide accumulation therefore lies in coordinated regulation of precursor formation, sugar transport, and polymer assembly. Diurnal temperature difference alters the expression of genes involved in polysaccharide metabolism, including *SUS, SUT, HKL1, HGL, AMY1*, and *SS3*, indicating that carbon partitioning among sucrose turnover, hexose generation, and starch-related metabolism is environmentally responsive (Chen et al., 2024). Seasonal transcriptomics likewise shows that sugar accumulation in stems is coordinated with abiotic-stress adaptation, suggesting that low temperature and humidity shifts reshape sugar metabolism rather than simply increasing total soluble sugars passively. At the polymerization step, mannan synthesis depends on CSLA-family mannan synthases, especially DoCSLA6, which is implicated in mannose production and mannan polysaccharide biosynthesis, providing a direct mechanistic link between upstream sugar metabolism and the formation of the mannose-rich polysaccharides that dominate *D. officinale* stems (He et al., 2017).

3 Effects of Light and Temperature Regulation on Polysaccharide Accumulation in *Dendrobium officinale*

3.1 Effects of light intensity and light quality on photosynthesis and polysaccharide formation

Light intensity and light quality directly regulate photosynthesis in *D. officinale*, a facultative CAM species whose carbon-assimilation pattern shifts with environmental conditions (Zhang et al., 2014). Early physiological work showed that leaf CO_2 uptake was highest at 500 μmol·m^{-2}·s^{-1} and 20℃, whereas net photosynthesis approached zero at 35℃, indicating that light response is constrained by temperature and stomatal behavior. The same study found that irradiance above 500 μmol·m^{-2}·s^{-1} induced photoinhibition, and prior high-light exposure reduced apparent quantum yield and CO_2 uptake, showing that stronger light is not universally beneficial. However, light regime also changes pathway use: shortening the light–dark cycle to 4 h/4 h induced a C_3 pattern, and 2 h/2 h or 4 h/4 h cycles improved photosynthetic apparatus status, doubled daily net CO_2 exchange and biomass gain relative to 12 h/12 h, and increased soluble polysaccharide yield, especially under 2 h/2 h aeroponic cultivation (Cheng et al., 2019).

Light quality further affects polysaccharide formation by simultaneously altering photosynthetic performance and precursor metabolism. Under different spectral treatments, red, blue, and yellow light all increased stem polysaccharide content relative to natural light, with the order red>yellow>blue>natural light, and red light showed the strongest promotion of UGPase expression, a key step in UDP-glucose formation for polysaccharide biosynthesis (Wang et al., 2024). In protocorms, a red:blue ratio of 1:3 promoted biomass and polysaccharide accumulation, and this effect depended on Ca^{2+}-CaM signaling, improved photosynthetic apparatus development, higher CaM content and Ca^{2+}-ATPase activity, enhanced sucrose phosphatase and sucrose synthase activity, and greater glucose and fructose precursor supply (Lei et al., 2021). However, within a physiologically tolerable range, relatively high light can also promote quality formation rather than only causing stress: in stems, high light increased polysaccharide accumulation, particularly mannose, activated flavonoid and polysaccharide biosynthesis, and induced DoHY5, which directly activates *DoGMPP2* and *DoPMT28* to enhance polysaccharide synthesis (Li et al., 2023). Related Dendrobium evidence is directionally similar, with intermediate red-blue light intensity around 400 μmol·m^{-2}·s^{-1} supporting chlorophyll accumulation, soluble sugar buildup, antioxidant stability, and