respiration (Sunoj et al., 2020). Taken together, the *D. officinale* evidence supports an intermediate, physiologically coordinated DIF that enhances daytime carbon gain while limiting nighttime carbon loss and redirecting assimilates toward polysaccharide accumulation.

3.3 Integrated regulation of polysaccharide synthesis and quality formation by light-temperature interactions

Light and temperature act jointly because both determine whether *D. officinale* operates closer to CAM, C_3, or an intermediate photosynthetic mode, and this sets the overall carbon supply for polysaccharide synthesis (Zhang et al., 2014). In natural and controlled conditions alike, CO_2 exchange patterns vary across sunny, cloudy, and rainy days, reflecting combined effects of irradiance, humidity, and air temperature rather than any single factor alone. Ecological-factor analysis likewise identified maximum temperature and sunshine duration among the key variables influencing medicinal quality in cultivated *D. officinale*, showing that light and thermal conditions are already coupled at the production scale. Recent reviews reach the same conclusion more broadly, noting that light, temperature, and water significantly affect the synthesis and accumulation of functional components across growth stages.

Mechanistically, light-temperature interactions converge on photosynthesis, sugar metabolism, and quality gene networks. Light quality regulates UGPase expression and Ca^{2+}-CaM-mediated sucrose metabolism, whereas high light activates DoHY5-dependent transcription of polysaccharide biosynthetic genes; temperature and DIF regulate SUS-centered sugar turnover, chlorophyll status, and abiotic-stress pathways (Lei et al., 2021; Chen et al., 2024; Wang et al., 2024). This means polysaccharide accumulation is determined not only by how much carbon is fixed, but also by how efficiently assimilated carbon is retained, transported, and converted into mannose- and glucose-rich polymers that define medicinal quality (Lai et al., 2024). For controlled cultivation, the practical implication is that light and temperature should be co-optimized rather than regulated independently, because suitable spectral composition, moderate effective irradiance, and an appropriate day-night temperature regime together promote biomass, sugar precursor supply, and stable quality formation (Li et al., 2023).

4 Effects of Water, Humidity, and Nutrient Conditions on Polysaccharide Accumulation in *Dendrobium officinale*

4.1 Effects of water supply and air humidity on carbon assimilation and sugar metabolism

Water supply and air humidity regulate carbon assimilation in *D. officinale* largely by altering photosynthetic behavior and internal sugar balance. *D. officinale* is a facultative CAM plant, and decreasing substrate water content shifts it toward a more typical CAM pattern, whereas rewatering restores mixed C_3/CAM behavior. As the substrate dries, nocturnal leaf titratable acidity increases and then declines again after rewatering, indicating that plant water status directly changes nighttime carbon fixation and acid metabolism (Zhang et al., 2014). Seasonal evidence likewise shows that sugar accumulation patterns in stems and leaves are influenced by temperature and humidity variation, with stem sugars accumulating mainly from October to April and especially rapidly from October to February.

Humidity is also an ecological determinant of medicinal quality rather than only a background climate factor. In cultivation-scale analyses, maximum and minimum relative humidity were identified among the key ecological factors influencing the medicinal quality of cultivated *D. officinale* together with maximum temperature, sunshine duration, and soil nutrients. Physiological and transcriptomic results further indicate that humidity-linked seasonal change affects sugar metabolism through pathways involving photosynthesis and starch–sucrose metabolism, while hub genes appear to maintain sugar metabolism under low-temperature and drought conditions. At the transport level, orchid mycorrhizal colonization creates an additional carbon sink in roots, increases allocation of photosynthates belowground, and raises glucose, fructose, and sucrose levels, showing that water- and humidity-sensitive root environments can reshape whole-plant carbon distribution rather than only leaf assimilation.