fungus MF23 can increase root dry weight, root length, and seedling height in *D. officinale*, and upregulate genes related to nitrate, ammonium, amino acid, and peptide transporters, thereby promoting nitrogen uptake and assimilation (Figure 2) (Shan et al., 2021). Other mycorrhizal fungi can also enhance carbon acquisition from substrates, improve photosynthetic efficiency, and increase seedling biomass and polysaccharide content.

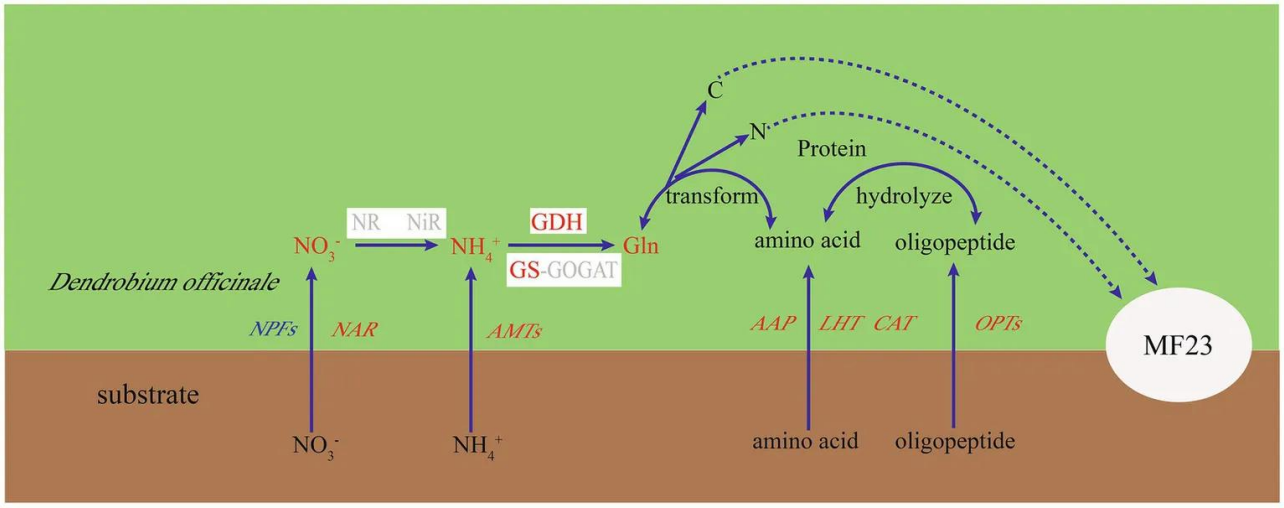

Figure 2 Putative nitrogen uptake and metabolism in the *D. officinale*-MF23 symbiosis (Adopted from Shan et al., 2021)
Image caption: Black font represents the background subjects; red, blue, and gray font represent up-, down-, and undifferentiated-regulated genes or metabolites, respectively. White boxes represent enzymes (Adopted from Shan et al., 2021)

3.3 Effects on biomass accumulation and dry matter distribution

Biomass accumulation is the result of the combined effects of photosynthesis, nutrient uptake, and material metabolism, and it is also an important indicator for evaluating substrate performance. Suitable substrates can provide stable moisture, oxygen, and nutrient conditions for *D. officinale*, promote the formation and transport of photosynthetic products, and thereby increase plant fresh weight and dry weight. Studies have shown that granular substrates rich in organic residues can produce an average yield of approximately 580 kg/mu in *D. officinale*, with a polysaccharide content of 42.5%, indicating that optimized substrates with high nutrient density are conducive to the synchronized accumulation of stem biomass and medicinal components. Pine bark seedbed cultivation can increase growth rate, advance flowering and stem formation by 1~3 years, and produce more than 250 kg/mu, suggesting that coarse, durable bark substrates can sustain high aboveground biomass accumulation over multiple years when combined with appropriate fertilization and management.

Different cultivation substrates also affect the distribution of dry matter among roots, stems, and leaves. The main medicinal part of *D. officinale* is the fleshy stem; therefore, the extent of dry matter accumulation in the stem is closely related to medicinal material yield and quality. Under suitable substrate conditions, plants can maintain high photosynthetic efficiency and nutrient transport capacity, allowing more assimilates to be transported to and stored in the stems, thereby promoting stem thickening and improving medicinal yield. Container cultivation studies have shown that turf-bark substrates can significantly increase the fresh weight and dry matter content of tissue-cultured plantlets, while sphagnum moss substrates not only promote growth but also increase polysaccharide content. This suggests that different substrates may guide biomass allocation toward structural growth or toward storage and medicinal component accumulation, respectively.

In addition, biomass accumulation is closely related to the formation of bioactive components. Sufficient dry matter accumulation not only provides a material basis for plant growth, but also supplies carbon sources and energy for the synthesis of polysaccharides, alkaloids, and other secondary metabolites. Mycorrhizal cultivation studies have shown that MF23 inoculation significantly increases root and stem dry weight, root length, and seedling height compared with axenic culture, and its promoting effect becomes stronger over time (Shan et al., 2021). Compared with non-mycorrhizal controls, ex vitro seedlings associated with mycorrhizal fungi have