

deficiency, or growth stagnation. Empirical comparisons further show that mixed substrates with complementary properties often perform better than single materials, indicating that rational substrate design and precise management are essential for achieving stable, high-yield, and high-quality production of *D. officinale*.

In addition to affecting growth, cultivation substrates also significantly influence the accumulation of key bioactive constituents and the overall medicinal quality of *D. officinale*. Variations in substrate nutrient supply, organic matter composition, and associated microbial communities can regulate primary metabolism and redirect carbon and nitrogen fluxes toward secondary metabolite biosynthesis, thereby altering the contents of polysaccharides, flavonoids, alkaloids, and other functional components. Studies have shown that substrates with moderate nutrient levels, good aeration, and may promote the accumulation of certain bioactive constituents and improve pharmacologically relevant indicators, whereas overly fertile or unsuitable substrates may lead to excessive vegetative growth, which is unfavorable for the accumulation of effective constituents. Moreover, substrate-induced changes in stem morphology, tissue density, appearance, and storage properties can also affect commercial grade and market acceptance. Therefore, the scientific selection and formulation of cultivation substrates that coordinate robust growth with enhanced bioactive compound accumulation represent an important approach for improving both the medicinal and economic value of artificially cultivated *D. officinale*.

Looking ahead, systematic optimization of composite substrates and in-depth clarification of the mechanisms by which substrates regulate growth and quality formation will become important directions in *D. officinale* research. At the applied level, multiple organic materials, agricultural by-products, and inorganic materials should be integrated to develop green, environmentally friendly, cost-controllable, and easily standardized substrate systems suitable for different cultivation modes and regional conditions, supported by unified evaluation criteria and long-term production validation. At the theoretical level, greater attention should be paid to the interactions among substrate physicochemical properties, rhizosphere microbial communities, plant nutrient uptake, signal transduction, and secondary metabolism. Systematic studies should be conducted using omics technologies, metabolite profiling, and microecological analysis. By combining substrate optimization with mechanistic elucidation and integrating these advances into facility cultivation, precision management, and breeding of substrate-adapted varieties, efficient and sustainable production models can be established to further support the high-quality development of the *D. officinale* industry.

Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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