2.3 Perlite, ceramsite, and composite cultivation substrates

Inorganic substrates have attracted attention in facility cultivation and composite substrate construction for *D. officinale* because of their good physical stability, low bulk density, high porosity, and long service life. Perlite is a porous inert material produced by high-temperature expansion. It is lightweight and has strong drainage and good aeration, which can improve substrate structure and reduce the risk of compaction caused by long-term cultivation. Ceramsite, brick and tile fragments, charcoal, expanded minerals, and related materials are also commonly used as structural components to enhance mechanical support and root-zone aeration. Studies have shown that perlite and similar inert mineral materials are common inorganic components in soilless cultivation and orchid substrates, and their low bulk density, high porosity, and strong drainage capacity help improve the root environment (Nuammee et al., 2024; Carrasco et al., 2025).

Because a single inorganic substrate has weak nutrient-retention capacity and cannot fully meet the long-term growth and quality formation requirements of *D. officinale*, composite cultivation substrates are more commonly used in production practice. Composite substrates usually combine natural organic substrates, agricultural waste-based substrates, and inorganic substrates in specific proportions to balance water retention, aeration, structural stability, and nutrient supply. For example, pine bark combined with coconut coir, ceramsite, or perlite can simultaneously meet the needs of root aeration and moisture retention. Composite formulations containing bark, brick fragments, sphagnum moss, wood chips, and maize straw, after disinfection and fermentation, can stabilize substrate structure and reduce pathogen risk. During orchid acclimatization, mixed substrates containing brick fragments and charcoal together with water-retentive components such as sphagnum moss or fern fiber can improve root aeration and mechanical support, achieving survival rates of approximately 97~100% and supporting long-term growth (Nuammee et al., 2024).

The advantage of composite substrates lies in their capacity for targeted design according to different growth stages, cultivation modes, and regional environments of *D. officinale*. Compared with single substrates, composite substrates can not only improve seedling survival and plant growth rate, but may also promote bioactive compound accumulation and commercial quality by improving rhizosphere moisture, oxygen, nutrients, and microbial conditions. Studies on *Dendrobium* production have shown that potting media composed of coconut-derived organic materials mixed with brick fragments, charcoal, and tile fragments can achieve better vegetative growth and flowering traits than coconut coir alone. This indicates that composite substrates have important application value by integrating organic nutrient supply with inorganic structural stability (Ashokkumar et al., 2023; Tt et al., 2024). In the future, under the concepts of resource recycling, precision cultivation, and quality-oriented production, the development of functional, standardized, and sustainable composite substrates will become an important pathway for promoting the high-quality development of the *D. officinale* industry.

3 Effects of Different Cultivation Substrates on the Growth of *Dendrobium officinale*

3.1 Effects on seedling survival rate and plant vigor

Seedling survival rate is an important indicator for evaluating the cultivation effect of *Dendrobium officinale* and a direct basis for assessing substrate suitability. As *D. officinale* is an epiphytic plant, its seedling roots are relatively fragile and sensitive to changes in moisture, aeration, and environmental stability. Therefore, the water retention, aeration, structural stability, and disease-suppressive capacity of the substrate directly affect post-transplant survival. Existing studies have shown that sphagnum moss, pine bark, and their composite substrates can form a relatively stable moisture and air environment around the roots, reduce transplanting stress, and improve seedling survival. During the hardening stage, sphagnum moss can promote rapid root initiation, enhance tillering, and increase leaf thickness, stem diameter, plant height, leaf width, root length, root number, and biomass compared with bark treatment, making it more suitable for acclimatization and early transplantation of tissue-cultured plantlets.

Different substrates not only affect seedling survival rate but also significantly influence plant vigor. Suitable substrates can improve the rhizosphere environment and enhance water and nutrient use efficiency, thereby promoting plant height growth, stem thickening, and leaf development. Studies have shown that a granular