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Study on the Correlation Between the Physiological Characteristics of *Dendrobium officinale* and Optimal Cultivation Conditions

Zhenyuan Zhang, Lingjuan Wang, Xiangqian Fan
Yiwu Senyu Agricultural Technology Co., Ltd., Yiwu, 322000, Zhejiang, China
Corresponding email: 18657909933@163.com

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Abstract This study explores the correlation between the physiological characteristics of *Dendrobium officinale* and its cultivation conditions, with a focus on analyzing the effects of environmental factors such as temperature, light intensity, and nutrient supply on growth rate, photosynthetic efficiency, and accumulation of active compounds in *D. officinale*. The study found that appropriate light and potassium treatments significantly increase anthocyanin content, enhancing the plant's metabolic properties. Additionally, the application of mycorrhizal fungi improved *D. officinale*'s resistance to drought and disease, effectively enhancing growth quality. Case analysis further indicated that pine bark substrate exhibits a high potential for flavonoid accumulation, and different cultivation modes (such as greenhouse and bionic cultivation) also impact the active components of *D. officinale* in varying ways. This study provides a scientific basis for sustainable cultivation of *D. officinale*, revealing approaches to optimize cultivation conditions to further enhance its medicinal value in clinical applications.

Keywords *Dendrobium officinale*; Physiological characteristics; Cultivation conditions; Photosynthesis; Mycorrhizal symbiosis

1 Introduction

Dendrobium officinale, a perennial epiphytic herb belonging to the Orchidaceae family. As a valuable traditional Chinese medicinal herb, *D. officinale* is highly regarded for its health-promoting properties, including immune system enhancement, anti-inflammatory effects, and antioxidant potential (Zhang et al., 2014; Liu et al., 2020; Ji et al., 2022). Due to overharvesting and environmental changes, the natural resources of *D. officinale* are increasingly diminishing, making cultivation a sustainable approach to meet this demand. Optimizing cultivation not only aids in conserving the species but also ensures a steady supply of high-quality raw materials to maintain its medicinal value. Cultivating *D. officinale* presents specific challenges, as it has stringent and sensitive requirements regarding growth conditions. Unlike many crops, *D. officinale* requires a unique combination of factors, including suitable humidity, temperature, and light intensity, to ensure successful growth and production of medicinal compounds (Wang et al., 2017; Yuan et al., 2020). Given its high economic value and ecological importance, determining optimal cultivation strategies is essential.

The physiological characteristics of *D. officinale*, such as its photosynthetic pathways, nutrient uptake, and stress responses, play a crucial role in its growth and quality. As an epiphytic orchid, *D. officinale* has evolved unique adaptations, such as specialized root structures and Crassulacean Acid Metabolism (CAM) photosynthesis, enabling it to survive in nutrient-poor environments (Zhang et al., 2014). Light intensity, temperature, and nutrient availability significantly affect its growth and physiological traits. For instance, appropriate light intensity can enhance seedling growth and physiological characteristics, leading to better quality plants (Li, 2014). Additionally, nutrient management, such as potassium and nitrogen supply, influences the accumulation of active compounds and overall plant health (Jia et al., 2022; Wu et al., 2023).

This study systematically analyzes the correlation between the physiological characteristics of *D. officinale* and its cultivation environment, exploring in depth the effects of various environmental factors on plant growth and quality to identify key physiological traits and cultivation conditions that contribute to the optimal cultivation of *D.*

officinale. This study expected to provide valuable insights for cultivation practices aimed at enhancing the medicinal value of *D. officinale*, thereby supporting its sustainable production and clinical application.

2 Physiological Characteristics of *Dendrobium officinale*

2.1 Overview of physiological traits in *Dendrobium officinale*

Dendrobium officinale exhibits several physiological adaptations that enable it to thrive under specific environmental conditions (Figure 1). For instance, the plant's ability to form associations with mycorrhizal fungi significantly enhances its tolerance to environmental stressors, such as drought and pathogenic attacks. Studies have shown that mycorrhizal fungi like *Hyphomycete* sp., *Umbelopsis* sp., and *Ceratorhiza* sp. can improve the survival rate and fresh weight of *D. officinale* by increasing its resistance to root rot pathogens and enhancing its drought tolerance (Yan et al., 2015; Li et al., 2021a). Additionally, the plant's growth and quality are influenced by ecological factors such as humidity, temperature, and soil nutrients, which are critical for optimizing its medicinal properties (Yuan et al., 2020).

The medicinal properties of *D. officinale* are largely attributed to its unique metabolic traits, including the biosynthesis of polysaccharides, alkaloids, and flavonoids. These compounds are influenced by various cultivation conditions. For example, light and potassium treatments have been shown to increase the anthocyanin content in the pseudobulbs, contributing to the plant's medicinal quality (Jia et al., 2022). Furthermore, the plant's ability to accumulate significant amounts of polysaccharides, alkaloids, and flavonoids in different organs, such as stems and leaves, underscores its therapeutic potential (Wang et al., 2021b).

Figure 1 The actual scene of *Dendrobium officinale* stone pillar cultivation in the Senshan Guocao Expo Garden Base of Yiwu Senyu Agricultural Science and Technology Co., Ltd

2.2 Photosynthesis and its role in plant growth

Photosynthesis plays a crucial role in the growth and development of *D. officinale*. The plant's photosynthetic efficiency is highly responsive to light conditions. For instance, the use of red-blue LED light has been shown to enhance the photosynthetic activity and overall quality of *D. officinale* by optimizing the expression of genes involved in flavonoid biosynthesis (Jia et al., 2022). Blue light and blue laser irradiation can significantly increase the activity of superoxide dismutase (SOD) and catalase (POD) in *D. officinale* and significantly promote the accumulation of flavonoids and polysaccharides (Li et al., 2022). These indicate that controlled light conditions can significantly impact the plant's growth and medicinal properties.

The efficiency of photosynthesis directly contributes to biomass accumulation in *D. officinale*. Enhanced photosynthetic activity leads to increased production of essential metabolites, which are crucial for the plant's growth and medicinal value. For example, the accumulation of polysaccharides and other secondary metabolites is closely linked to the plant's photosynthetic performance under optimal light conditions (Yang et al., 2023). This relationship highlights the importance of photosynthesis in supporting the overall biomass and quality of *D. officinale*.

2.3 Nutrient absorption and water relations

Nutrient uptake and utilization in *D. officinale* are facilitated by its symbiotic relationship with mycorrhizal fungi. These fungi enhance the plant's ability to absorb essential nutrients, particularly nitrogen. Studies have shown that the fungus *Mycena* sp. (MF23) can promote nitrogen uptake and $NH4^+$ assimilation in *D. officinale*. MF23 upregulates the expression levels of nitrogen transport-related genes in *D. officinale*, such as *DoNAR2.1* and *DoAMT11*, thereby enhancing nitrogen metabolism efficiency and ultimately promoting plant growth and yield (Shan et al., 2021). MF23 has also been found to increase the content of polysaccharides and secondary metabolites (such as dendrobine) in *D. officinale*. Research indicates that MF23 promotes polysaccharide accumulation by regulating gene expression of key enzymes in polysaccharide and metabolic pathways, and it may also increase carbon nutrient acquisition in the plant by enhancing photosynthetic capacity (Li et al., 2017).

D. officinale exhibits efficient water use and robust drought response mechanisms, which are critical for its survival and growth under varying environmental conditions. The plant's association with mycorrhizal fungi enhances its water use efficiency and drought tolerance. For instance, plants treated with specific mycorrhizal fungi showed stronger drought tolerance and improved water use efficiency compared to untreated plants (Li et al., 2021a). These adaptations enable *D. officinale* to maintain its physiological functions and medicinal quality even under water-limited conditions.

3 Environmental Factors Influencing Cultivation

3.1 Light and photoperiod requirements

Light plays a crucial role in the photosynthetic rate and overall growth of *Dendrobium officinale*. Studies have shown that varying light intensities can significantly impact the biomass and growth rate of this medicinal plant. For instance, shading treatments of 50% and 70% were found to significantly influence growth and biomass accumulation, with red light being particularly effective in enhancing growth and increasing the contents of polysaccharides and alkaloids (Van-Nguyen et al., 2023). Additionally, the use of red-blue LED light has been shown to increase anthocyanin content and improve the quality of *D. officinale* by optimizing transcriptomic and metabolomic alterations. The study by Jia et al. (2022) showed that, compared to the pseudobulbs under natural light (control group), those in the red-blue LED light treatment group and potassium treatment group turned purple, with anthocyanin content significantly increasing from 7.48 μg/g to 11.74 μg/g and 12.65 μg/g, respectively, displaying a statistically significant difference ($p < 0.05$) (Figure 2). Furthermore, short light/dark cycles (e.g., 4 h/4 h) can switch the photosynthetic pathway from CAM to C3, thereby enhancing daily net CO_2 absorption and biomass accumulation (Cheng et al., 2019b).

The photoperiod, or the duration of light exposure, is another critical factor influencing the flowering and development of *D. officinale*. Short light/dark cycles have been shown to improve the photosynthetic apparatus state and increase the accumulation of biomass and soluble polysaccharides (Cheng et al., 2019b). Moreover, manipulating the light/dark cycle can regulate the photosynthetic pathway, switching it between C3 and CAM, which in turn affects the plant's growth and development (Cheng et al., 2019a). The use of far-red light has also been found to promote the accumulation of flavonoids, alkaloids, carotenoids, and polysaccharides, thereby enhancing the plant's shade-avoidance response and overall production efficiency (Li et al., 2021b).

3.2 Temperature ranges for optimal growth

Temperature is a vital environmental factor that influences the vegetative growth of *D. officinale*. Optimal temperature conditions are necessary to ensure healthy growth and high yield (Figure 3). The ideal temperature range for the vegetative growth of *D. officinale* has been found to be between 20 °C and 30 °C. This range supports the plant's physiological processes, including photosynthesis and nutrient uptake, thereby promoting robust vegetative growth (Ding et al., 2018). Additionally, maintaining a stable temperature within this range helps in achieving higher biomass and better quality of medicinal components (Yuan et al., 2020).

Temperature fluctuations can have adverse effects on the health of *D. officinale*. Sudden changes in temperature can stress the plant, leading to reduced growth rates and lower quality of medicinal components. For instance, high temperatures combined with low humidity can cause drought stress, while low temperatures can slow down metabolic processes and reduce growth (Li et al., 2021a). Therefore, it is crucial to maintain a stable temperature environment to prevent stress and ensure optimal growth conditions for *D. officinale* (Ding et al., 2018).

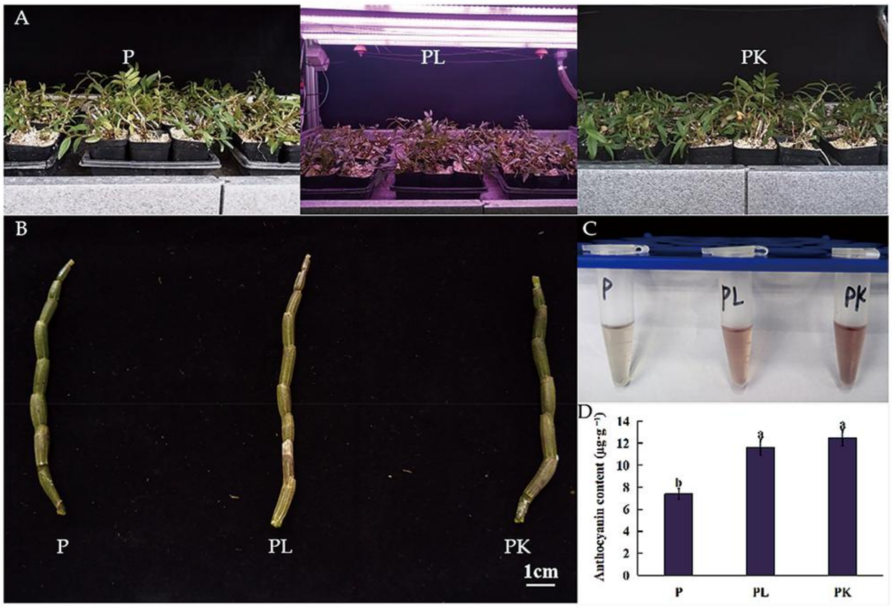

Figure 2 The changes in phenotype and anthocyanin content of *D. officinale* post light- or K-treatment (Adopted from Jia et al., 2022)
Image caption: (A) The pseudobulbs, (P) under natural light were used as the control, light-treated pseudobulbs, (PL) were treated with red and blue light in 5:1, and K-treated pseudobulbs, (PK) were treated with 3 mM KCl. (B) The phenotype of *D. officinale* pseudobulbs. (C) Anthocyanin extracted from pseudobulb of *D. officinale*. (D) The content of anthocyanins in *D. officinale* pseudobulbs post light- or K-treatment. The different letters represent significant difference at $p < 0.05$ (Adopted from Jia et al., 2022)

Figure 3 The actual scene of *Dendrobium officinale* facility cultivation in the Senshan Guocao Expo Garden Base of Yiwu Senyu Agricultural Science and Technology Co., Ltd

3.3 Humidity and air circulation considerations

Humidity is another critical factor that affects the physiological functioning of *D. officinale*. The plant requires a high humidity environment to maintain its physiological processes, such as transpiration and nutrient uptake. Studies have shown that maximum and minimum relative humidity levels are key factors influencing the quality of medicinal components in *D. officinale* (Yuan et al., 2020). Maintaining an optimal humidity level helps in preventing water loss and ensures the efficient functioning of the plant's physiological processes (Ding et al., 2018).

Air circulation is essential for preventing diseases and promoting healthy growth in *D. officinale*. Proper air circulation helps in reducing the humidity around the plant, thereby preventing the growth of pathogens that thrive in high humidity conditions. For instance, the presence of mycorrhizal fungi has been shown to improve the plant's tolerance to environmental stress and reduce the incidence of root rot caused by pathogens (Li et al., 2021a). Additionally, good air circulation ensures that the plant receives adequate CO_2 for photosynthesis, thereby promoting healthy growth and higher biomass accumulation (Ding et al., 2018).

4 Nutritional Requirements and Fertilization Strategies

4.1 Essential macro and micronutrients

Nitrogen (N), phosphorus (P), and potassium (K) are critical macronutrients that significantly influence the growth and medicinal quality of *D. officinale*. Nitrogen is essential for vegetative growth and is positively correlated with morphological indicators and polysaccharide content in *D. officinale* (Fan et al., 2023). Phosphorus plays a crucial role in energy transfer and root development, with optimal levels enhancing polysaccharide and flavonoid content. Potassium is vital for enzyme activation and osmoregulation, and its application has been shown to increase anthocyanin content and improve the overall quality of *D. officinale* (Jia et al., 2022).

Micronutrients such as calcium (Ca), magnesium (Mg), and iron (Fe) are also essential for the optimal growth of *D. officinale*. Calcium is important for cell wall stability and signal transduction, while magnesium is a central component of chlorophyll and is crucial for photosynthesis. Iron is necessary for chlorophyll synthesis and various enzymatic functions. In samples of *D. officinale* cultivated in different regions in the north and south, variations in nutrient content were observed based on growth duration and geographic location. *D. officinale* cultivated in southern regions showed higher levels of nutrients such as polysaccharides and total phenols, while *D. officinale* grown in northern regions was richer in alkaloids. These findings highlight the potential impact of elements like calcium and magnesium on the growth and nutritional value of *D. officinale* in different environments (Guo et al., 2021).

4.2 Fertilizer types and application schedules

Both organic and inorganic fertilizers can be used to meet the nutritional needs of *D. officinale*. Organic fertilizers, such as compost and manure, provide a slow-release source of nutrients and improve soil structure. In contrast, inorganic fertilizers offer precise nutrient formulations and immediate availability. Studies on varying concentrations of nitrogen, phosphorus, and potassium fertilizers found that nitrogen had the greatest impact on plant growth. Appropriate levels of nitrogen and phosphorus contributed to increasing polysaccharide and flavonoid content in plants. The optimal combination (nitrogen 1 500 mg/L, phosphorus 3 000 mg/L, potassium 500 mg/L) significantly enhanced plant growth and the accumulation of medicinal components (Fan et al., 2023).

The fertilization schedule for *D. officinale* should be tailored to its growth stages. During the vegetative stage, higher nitrogen levels are recommended to promote leaf and stem growth. As the plant transitions to the reproductive stage, the focus should shift to phosphorus and potassium to support flower and pseudobulb development. An optimal schedule might include higher nitrogen application early on, followed by balanced NPK ratios as the plant matures (Fan et al., 2023; Wu et al., 2023).

4.3 Effects of nutrient deficiencies and toxicities

Nutrient deficiencies can severely impact the health and quality of *D. officinale*. Research has found that under low nitrogen conditions, the growth and photosynthesis of *D. officinale* are inhibited, but its polysaccharide and flavonoid content increase (Wu et al., 2023). Phosphorus deficiency can lead to poor root development and delayed maturity, while potassium deficiency often manifests as leaf chlorosis and necrosis, affecting overall plant vigor and anthocyanin accumulation (Jia et al., 2022; Fan et al., 2023).

Excessive nutrient levels can be just as detrimental as deficiencies. Over-fertilization with nitrogen can lead to excessive vegetative growth at the expense of medicinal component accumulation. High phosphorus levels can cause micronutrient imbalances, particularly with zinc and iron, leading to chlorosis and poor plant health. Excess potassium can interfere with the uptake of other essential nutrients, potentially causing nutrient imbalances and toxicity symptoms (Wu et al., 2023).

5 Watering and Irrigation Techniques

5.1 Water quality and its effect on growth

The quality of irrigation water, particularly its pH and mineral content, plays a crucial role in the growth and development of *D. officinale*. Optimal pH levels ensure the availability of essential nutrients and prevent toxicities. For instance, soil pH was identified as a key ecological factor influencing the medicinal quality of *D. officinale*, affecting the availability of soil nutrients such as nitrogen and phosphorus (Yuan et al., 2020). Additionally, the presence of essential minerals in irrigation water can enhance plant growth, as seen in studies where potassium supplementation improved the quality of *D. officinale* by optimizing transcriptomic and metabolomic alterations (Jia et al., 2022).

Salinity and contaminants in irrigation water can have detrimental effects on the health of *D. officinale*. High salinity levels can lead to osmotic stress, ion toxicity, and nutrient imbalances, which adversely affect plant growth and productivity. For example, studies have found that under salt stress, *D. officinale* initiates a series of stress response mechanisms, including the inhibition of the synthesis of growth-related hormones, such as auxins and cytokinins (Zhang et al., 2022a).

5.2 Optimal watering frequency and methods

The watering frequency for *D. officinale* should be carefully adjusted according to the plant's growth stage to ensure optimal development. During the early stages of growth, frequent watering may be necessary to support root establishment and seedling vigor. As the plant matures, the watering intervals can be extended to prevent waterlogging and promote healthy root development. The relationship between ecological factors, such as soil moisture, and the quality of *D. officinale* underscores the need for tailored irrigation practices (Yuan et al., 2020).

Different irrigation methods can significantly impact the growth and health of *D. officinale*. Drip irrigation is often preferred for its efficiency in delivering water directly to the root zone, minimizing water loss and reducing the risk of foliar diseases. Sprinkler irrigation, while effective for larger areas, may lead to higher evaporation rates and potential disease spread. Manual watering allows for precise control but is labor-intensive. The choice of irrigation method should consider the specific needs of *D. officinale* and the cultivation environment (Elhindi et al., 2020; Yuan et al., 2020).

5.3 Impact of overwatering and drought stress

Overwatering can lead to waterlogging, which deprives the roots of oxygen and promotes the growth of pathogenic fungi. Symptoms of waterlogging in *D. officinale* include yellowing leaves, stunted growth, and root rot. The presence of mycorrhizal fungi has been shown to enhance the plant's tolerance to water stress by improving root health and reducing the incidence of root rot caused by pathogens (Li et al., 2021a).

Drought stress in *D. officinale* manifests as wilting, reduced leaf size, and decreased biomass. The plant's adaptive responses to drought include the accumulation of osmoprotectants and the activation of stress-responsive genes. Mycorrhizal associations can also enhance drought tolerance by improving water uptake and nutrient acquisition. Understanding these adaptive mechanisms is essential for developing effective irrigation strategies that mitigate the impact of drought stress on *D. officinale*.

6 Case Studies

6.1 Study on the impact of different cultivation modes on the medicinal components of *D. officinale*

The accumulation of medicinal components in *D. officinale* is influenced by various ecological factors in its cultivation environment, making it essential to study how these factors impact medicinal components under different cultivation modes. Yuan et al. (2022) focused on the effects of ecological factors on the main medicinal components of *D. officinale* across different cultivation modes. The study selected greenhouse, bionic, and wild cultivation modes to analyze the contents of polysaccharides, total alkaloids, and total flavonoids. Results showed that the highest levels of medicinal components were found in the wild cultivation mode, while the greenhouse mode had the lowest (Figure 4). These differences correlate with ecological factors in each mode, where humidity, temperature, light exposure, and soil nutrients significantly affect the accumulation of medicinal components. Multivariate statistical analysis indicated that high humidity, lower temperature, and moderate light in the wild mode are most conducive to the accumulation of active ingredients, with total soil nitrogen, phosphorus, and pH especially impacting flavonoids.

Correlation analysis under different cultivation modes further revealed the influence of specific ecological factors on component accumulation. For instance, ammonium nitrogen showed a significant negative correlation with polysaccharides and alkaloids in the greenhouse mode, while soil pH in the wild mode was positively correlated with polysaccharides and alkaloids. These findings suggest that the bionic cultivation mode, which preserves the characteristics of the wild environment, can effectively enhance medicinal component levels, providing a scientific basis for optimizing cultivation conditions.

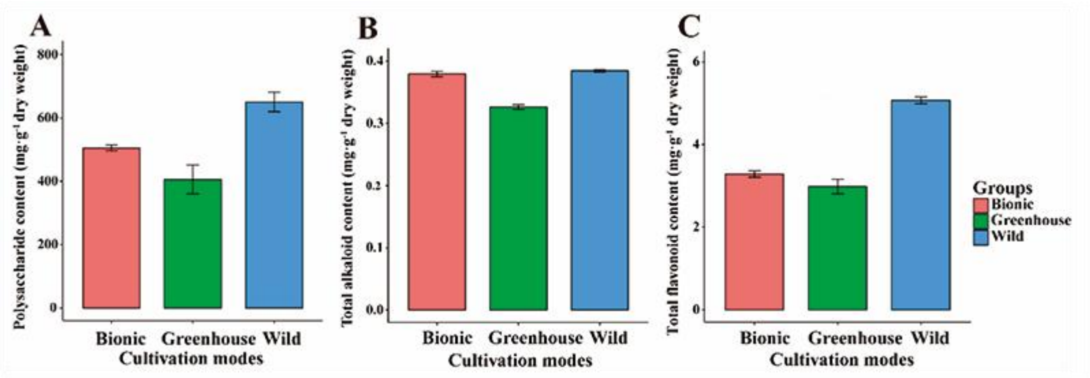

Figure 4 Main medicinal components variation in different cultivation modes. (A) Polysaccharide content variation in different cultivation modes. (B) Total alkaloid content variation in different cultivation modes. (C) Total flavonoid content variation in different cultivation modes (Adopted from Yuan et al., 2022)

Image caption: The figure shows the variation in the main medicinal components (polysaccharides, alkaloids, and flavonoids) of *D. officinale* under three cultivation modes: greenhouse, bionic, and wild. (A) illustrates that polysaccharide content is highest in the wild mode and lowest in the greenhouse mode; (B) displays a similar trend for alkaloid content; (C) indicates that flavonoid content is significantly higher in the wild cultivation mode compared to other modes. The results suggest that natural ecological conditions are more favorable for the accumulation of medicinal value in *D. officinale* (Adapted from Yuan et al., 2022)

6.2 Optimizing cultivation substrates to enhance active compounds in *D. officinale*

Studies have shown that different cultivation environments, such as substrate, light, and temperature, significantly affect the quality and active compound content of *D. officinale*. Among these, cultivation substrates are considered key factors influencing the types and concentrations of its metabolites (Zuo et al., 2020; Jia et al., 2022; Yuan et al., 2022). Therefore, an in-depth analysis of the metabolic characteristics of *D. officinale* under various substrate conditions can provide a theoretical basis for selecting the optimal substrate to enhance the accumulation of its active compounds and improve product quality.

Using a widely targeted metabolomics approach, Zuo et al. (2020) applied UPLC-MS/MS to analyze the metabolites of *D. officinale* cultivated in different substrates—pine bark, coconut coir, and a 1:1 mixture of the two. Results indicated that *D. officinale* grown in pine bark substrate exhibited the highest flavonoid content, with a more significant accumulation of active compounds compared to other substrates. Multivariate statistical analysis and KEGG pathway enrichment analysis further demonstrated that different substrates notably affect the biosynthesis pathways of flavonoids, lipids, and other metabolites. Notably, flavonoid accumulation showed a marked increase in the pine bark substrate, suggesting that pine bark may be the optimal choice for enhancing the active compounds of *D. officinale*.

6.3 Disease control in high-density cultivation of *Dendrobium officinale*
D. officinale is prone to significant economic losses under high-density cultivation due to biotic (e.g., fungal diseases) and abiotic (e.g., drought) stresses. Research has shown that mycorrhizal fungi can form symbiotic relationships with orchid species, enhancing nutrient absorption and stress resistance, making them a promising means of improving *D. officinale* yield (Zhang et al., 2020; Li et al., 2021a; Shan et al., 2021).

A study investigated the growth-promoting and stress-resistance-enhancing effects of mycorrhizal fungi derived from orchid species on *D. officinale*. Four mycorrhizal fungi isolated from orchids (GDB254, MLX102, GS222, GDB162) were used in trials, demonstrating that these fungi significantly promoted *D. officinale* growth, increasing fresh weight, chlorophyll content, and polysaccharide accumulation (Li et al., 2021a) (Figure 5). Additionally, under drought and pathogen stress, *D. officinale* inoculated with mycorrhizal fungi exhibited higher survival rates and resistance, markedly reducing root rot incidence. Notably, MLX102 displayed the strongest disease resistance, effectively suppressing root rot caused by *Fusarium solani* and *Fusarium graminearum*. Furthermore, mycorrhizal fungi showed a competitive advantage when coexisting with pathogenic fungi, reducing the infection risk in *D. officinale* by inhibiting pathogen growth. This study provides new strategies for artificial cultivation of *D. officinale*, demonstrating that mycorrhizal fungi can enhance plant growth and reduce disease losses in agricultural production through increased stress tolerance, supporting sustainable medicinal plant cultivation.

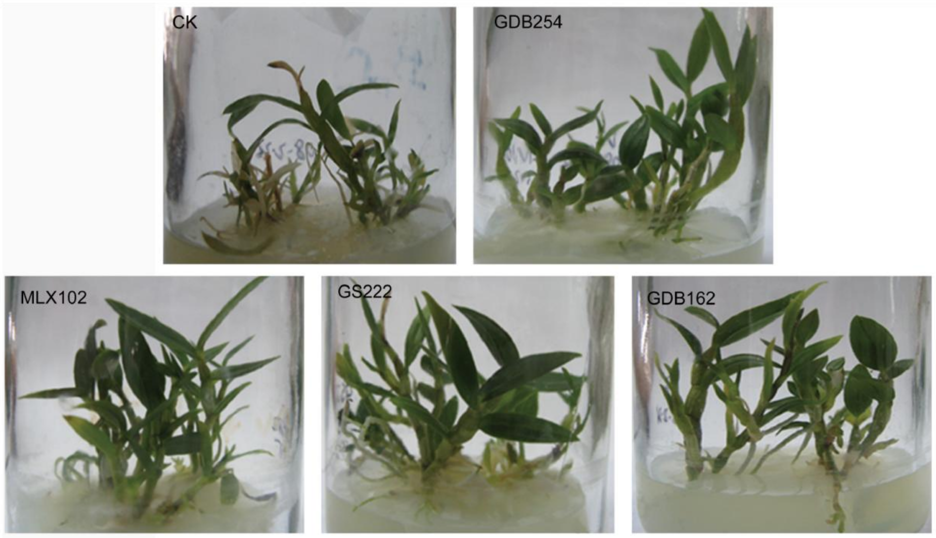

Figure 5 Mycorrhizal fungi promote the growth of tissue culture seedlings of *Dendrobium officinale* (Adopted from Li et al., 2021a)
Image caption: GDB254, MLX102, GS222, and GDB162 were inoculated into *D. officinale* seedlings for 60 days and were associated with increased weight acquisition compared to that in the control group (CK) (Adopted from Li et al., 2021a)

7 Challenges and Limitations in Cultivation
7.1 Common challenges in *Dendrobium officinale* cultivation
Cultivating *D. officinale* presents several challenges primarily due to its specific environmental requirements and susceptibility to various stresses. One of the major challenges is the plant's sensitivity to ecological factors such as humidity, temperature, and soil composition, which significantly affect its medicinal quality (Yuan et al., 2020). Additionally, *D. officinale* is prone to both biotic and abiotic stresses, including drought and root rot caused by pathogens like *Fusarium solani* and *Fusarium graminearum*, which can lead to significant production losses (Li et al., 2021a). Cao et al. (2022) reported stem rot disease in *D. officinale* in the Wenzhou region of Zhejiang, primarily caused by *Fusarium kyushuense*, with an incidence rate as high as 30%. The slow growth rate and scarcity of wild populations further complicate cultivation efforts, necessitating intensified cultivation practices.

7.2 Limitations of current cultivation practices
Current cultivation practices for *D. officinale* are limited by several factors. Traditional methods often fail to provide the precise environmental control needed for optimal growth, leading to variations in plant quality and

yield (Ding et al., 2018). Genomic studies of *D. officinale* have revealed gene expansions related to fungal symbiosis and drought resistance, which may play a significant role in the plant's environmental adaptability and the biosynthesis of secondary metabolites. However, the specific mechanisms by which genes and environmental factors influence biomass allocation remain incompletely understood, limiting the development of effective management strategies (Niu et al., 2021; Zhang et al., 2021). The lack of efficient and scalable methods for mycorrhizal association, which is crucial for nutrient uptake and stress tolerance, also poses a significant limitation (Shan et al., 2021; Zhang et al., 2022b). Furthermore, the chemical composition of *D. officinale* can vary significantly depending on the cultivation method, affecting its medicinal properties (Yang et al., 2023).

7.3 Potential solutions and innovations

To address these challenges, several innovative approaches have been proposed. The use of mycorrhizal fungi, such as those from the genera *Hyphomycete*, *Umbelopsis*, and *Ceratorhiza*, has shown promise in enhancing the growth and stress tolerance of *D. officinale* (Li et al., 2021a; Zhang et al., 2022b). Advanced cultivation techniques, including the use of red-blue LED light and potassium fertilizers, have been found to improve the quality of *D. officinale* by optimizing its metabolomic and transcriptomic profiles (Jia et al., 2022). Additionally, precise control systems using PLC and SCADA technologies can help maintain optimal growing conditions, thereby improving plant quality and yield (Ding et al., 2018). The development of fungus-seed bags for restoration-friendly cultivation offers a low-cost, scalable solution for propagating *D. officinale* in its natural habitat, promoting both conservation and commercial production (Wang et al., 2021a). These innovations collectively provide a comprehensive strategy to overcome the current limitations in *D. officinale* cultivation.

8 Concluding Remarks

The study found that light exposure and potassium treatment enhanced the quality of *Dendrobium officinale* by increasing anthocyanin levels and activating flavonoid and jasmonic acid metabolic pathways. Environmental factors such as humidity, temperature, and soil nutrients significantly influenced the accumulation of medicinal compounds. A short light/dark cycle promoted the shift from CAM to C3 pathways, which facilitated biomass and polysaccharide accumulation. Additionally, precise environmental control technologies optimized cultivation conditions. Although low nitrogen stress inhibited growth, it increased polysaccharide and flavonoid content, while a pine bark substrate significantly raised flavonoid levels. *D. officinale* cultivated in greenhouses showed the best health benefits, especially in terms of anti-aging properties.

Future research should further elucidate the molecular mechanisms of *D. officinale*'s responses to various environmental factors. Studies on gene expression profiles and metabolic pathways activated under different cultivation conditions could help identify key regulatory genes and metabolites. Exploring interactions between *D. officinale* and mycorrhizal fungi may provide insights into enhancing its resilience and growth rate, which are essential for large-scale cultivation. Practical applications should consider integrating advanced environmental control systems, such as PLC and SCADA, to maintain optimal growth conditions and improve yield and quality. Developing standardized cultivation protocols that incorporate key ecological factors and optimal light/dark cycles could also significantly enhance the medicinal quality of *D. officinale*. Further research into the health benefits of its polysaccharides, particularly their anti-aging and stress-resistant properties, may open new avenues for therapeutic applications.

The findings of this study provide a comprehensive understanding of the optimal cultivation conditions for *D. officinale* and their impact on its physiological traits and medicinal quality. Integrating advanced cultivation technologies and understanding the plant's adaptive mechanisms can significantly improve the yield and quality of this valuable medicinal plant. Future research and practical applications should continue to build on these insights to optimize cultivation practices and fully harness the therapeutic potential of *D. officinale*.

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Conflict of Interest Disclosure

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

Reference

Cheng Y., He D., He J., Niu G., and Gao R., 2019a, Effect of light/dark cycle on photosynthetic pathway switching and CO_2 absorption in two *Dendrobium* species, Frontiers in Plant Science, 10: 659.
https://doi.org/10.3389/fpls.2019.00659

Cheng Y., He D., He J., Niu G., and Ji F., 2019b, Effects of short light/dark cycles on photosynthetic pathway switching and growth of medicinal *Dendrobium officinale* in aeroponic cultivation, International Journal of Agricultural and Biological Engineering, 12(5): 38-43.
https://doi.org/10.25165/IJABE.V12I5.4864

Cao P., Zheng Z., Fang Y., Han X., Zou H., and Yan X., 2022, First report of stem rot caused by *Fusarium kyushuense* on *Dendrobium officinale* in China, Plant Disease, 106(8): 2257.
https://doi.org/10.1094/PDIS-12-21-2719-PDN

Ding J.T., Tu H.Y., Zang Z.L., Huang M., and Zhou S.J., 2018, Precise control and prediction of the greenhouse growth environment of *Dendrobium candidum*, Computers and Electronics in Agriculture, 151: 453-459.
https://doi.org/10.1016/j.compag.2018.06.037

Elhindi K.M., Al-Mana F.A., Algahtani A.M., and Alotaibi M.A., 2020, Effect of irrigation with saline magnetized water and different soil amendments on growth and flower production of *Calendula officinalis* L. plants, Saudi Journal of Biological Sciences, 27(11): 3072-3078.
https://doi.org/10.1016/j.sjbs.2020.09.015

Fan Y.J., Xu E.Y., Wang G., He D.X., Ma J., Liu Y.Y., Li X.B., and Luo A.X., 2023, Transcriptional and physiological analysis reveal new insights into the regulation of fertilization (N, P, K) on the growth and synthesis of medicinal components of *Dendrobium denneanum*, International Journal of Molecular Sciences, 24.
https://doi.org/10.3390/ijms24021522

Guo X., Zhang S., Yan T., Yuan G., Dai Y., Dong L., and Wang Z., 2021, Comparative analysis of nutritional quality of *Dendrobium officinale* Kimura et Migo after transplantation of artificially cultivated plants from South to North China during different growing years.
https://doi.org/10.21203/RS.3.RS-521625/V1

Ji W.N., Yan M.Q., Su J., Yu J.J., Chen S.H., Lyu G.Y., and Chen J.Z., 2022, Effects of different extracts of *Dendrobium officinale* on rats with chronic pharyngitis induced by pepper water combined with ammonia, Zhongguo Zhong Yao Za Zhi (China Journal of Chinese Materia Medica), 47(9): 2525-2532.
https://doi.org/10.19540/j.cnki.cjcmm.20211223.703

Jia Y., Liu J., Xu M., Chen G., Tan M., and Xiang Z., 2022, Light and potassium improve the quality of *Dendrobium officinale* through optimizing transcriptomic and metabolomic alteration, Molecules, 27(15): 4866.
https://doi.org/10.3390/molecules27154866

Li Q., Li B., Zhou L.S., Ding G., Li B., and Guo S.X., 2017, Molecular analysis of polysaccharide accumulation in *Dendrobium nobile* infected with the mycorrhizal fungus *Mycena* sp., RSC Advances, 7(42): 25872-25884.
https://doi.org/10.1039/C7RA02010D

Li Y., Kang Z., Zhang X., Sun P., Jiang X., and Han Z., 2021a, The mycorrhizal fungi of Cymbidium promote the growth of *Dendrobium officinale* by increasing environmental stress tolerance, PeerJ, 9: e12555.
https://doi.org/10.7717/peerj.12555

Li H., Ye W., Wang Y., Chen X., Fang Y., and Sun G., 2021b, RNA sequencing-based exploration of the effects of far-red light on lncRNAs involved in the shade-avoidance response of *Dendrobium officinale*, PeerJ, 9: e10769.
https://doi.org/10.7717/peerj.10769

Li W., 2014, Effect of light intensity on seedling growth and physiological characteristics of *Dendrobium officinale* Kimura et Migo in vitro, Chinese Journal of Tropical Crops.

Li H., Qiu Y., Sun G., and Ye W., 2022, RNA sequencing-based exploration of the effects of blue laser irradiation on mRNAs involved in functional metabolites of *Dendrobium officinale*, PeerJ, 10: e12684.
https://doi.org/10.7717/peerj.12684

Liu C.Z., Chen W., Wang M.X., Wang Y., Chen L.Q., Zhao F., Shi Y., Liu H., Dou X., Liu C., and Chen H., 2020, *Dendrobium officinale* Kimura et Migo and American ginseng mixture: a Chinese herbal formulation for gut microbiota modulation, Chinese Journal of Natural Medicines, 18(6): 446-459.
https://doi.org/10.1016/s1875-5364(20)30052-2

Niu Z., Zhu F., Fan Y., Li C., Zhang B., Zhu S., Hou Z., Wang M., Yang J., Xue Q., Liu W., and Ding X., 2021, The chromosome-level reference genome assembly for *Dendrobium officinale* and its utility of functional genomics research and molecular breeding study, Acta Pharmaceutica Sinica B, 11(7): 2080-2092.
https://doi.org/10.1016/j.apsb.2021.01.019

Shan T., Zhou L., Li B., Chen X., Guo S., Wang A., Tian L., and Liu J., 2021, The plant growth-promoting fungus MF23 (*Mycena* sp.) increases production of *Dendrobium officinale* (Orchidaceae) by affecting nitrogen uptake and NH^{4+} assimilation, Frontiers in Plant Science, 12: 693561.
https://doi.org/10.3389/fpls.2021.693561

Van-Nguyen H., Quang-Le U., and Huu-Nguyen T., 2023, Effects of light on growth and biomass of *Dendrobium officinale* (Kimura et Migo) grown in Thai Nguyen province, Vietnam, World Journal of Advanced Research and Reviews, 19(3): 524-531.
https://doi.org/10.30574/wjarr.2023.19.3.1809

Wang X.J., Wu Y.H., Ming X.J., Wang G., and Gao J.Y., 2021a, Isolating ecological-specific fungi and creating fungus-seed bags for epiphytic orchid conservation, Global Ecology and Conservation, 28: e01714.
https://doi.org/10.1016/j.gecco.2021.e01714

Wang Z., Jiang W., Liu Y., Meng X., Su X., Cao M., Wu L., Yu N., Xing S., and Peng D., 2021b, Putative genes in alkaloid biosynthesis identified in *Dendrobium officinale* by correlating the contents of major bioactive metabolites with gene expression between protocorm-like bodies and leaves, BMC Genomics, 22: 1-17.
https://doi.org/10.1186/s12864-021-07887-6

Wu H., Li J., Pu Q., Mi C., Zeng G., Chen Y., Kong D., Zuo X., Hu X., and Li O., 2023, Physiological and transcriptome analysis of *Dendrobium officinale* under low nitrogen stress, Functional Plant Biology, 50(4): 314-334.
https://doi.org/10.1071/FP22061

Wang Y., Tong Y., Chu H., Chen X., Guo H., Yuan H., Yan D., and Zheng B., 2017, Effects of different light qualities on seedling growth and chlorophyll fluorescence parameters of *Dendrobium officinale*, Biologia, 72(7): 735-744.
https://doi.org/10.1515/biolog-2017-0081

Yan L., Wang X., Liu H., Tian Y., Lian J., Yang R., Hao S., Wang X., Yang S., Li Q., Qi S., Kui L., Okpekum M., Ma X., Zhang J., Ding Z., Zhang G., Wang W., Dong Y., and Sheng J., 2015, The genome of *Dendrobium officinale* illuminates the biology of the important traditional Chinese orchid herb, Molecular Plant, 8(6): 922-934.
https://doi.org/10.1016/j.molp.2014.12.011

Yang D., Song Y., Lu A., Qin L., Tan D., Zhang Q., He Y., and Lu Y., 2023, Metabolomics-based analysis of the effects of different cultivation strategies on metabolites of *Dendrobium officinale* Kimura et Migo, Metabolites, 13(3): 389.
https://doi.org/10.3390/metabo13030389

Yuan Y., Tang X., Jia Z., Li C., Ma J., and Zhang J., 2020, The effects of ecological factors on the main medicinal components of *Dendrobium officinale* under different cultivation modes, Forests, 11(1): 94.
https://doi.org/10.3390/f11010094

Zhang Y., Li Y.Y., Chen X.M., Guo S.X., and Lee Y.I., 2020, Effect of different mycobionts on symbiotic germination and seedling growth of *Dendrobium officinale*, an important medicinal orchid, Botanical Studies, 61: 1-10.
https://doi.org/10.1186/s40529-019-0278-6

Zhang J., Li T., Cai Y., and Wang Y., 2021, Genetic and environmental effects on allometry of the medicinal plant *Dendrobium officinale* (Orchidaceae) from Yunnan, southwest China, Pak. J. Bot., 53(5): 1675-1682.
https://doi.org/10.30848/PJB2021-5(14)

Zhang M., Liu N., Silva J., Liu X., Deng R., Yao Y., Duan J., and He C., 2022a, Physiological and transcriptomic analysis uncovers salinity stress mechanisms in a facultative crassulacean acid metabolism plant *Dendrobium officinale*, Frontiers in Plant Science, 13: 1028245.
https://doi.org/10.3389/fpls.2022.1028245

Zhang Y., Huo W., Hou J., Liu L., Yu X., and Xu L., 2022b, Effects and benefits of orchid mycorrhizal symbionts on *Dendrobium officinale*, Horticulturae, 8(10): 861.
https://doi.org/10.3390/horticulturae8100861

Zhang Z., He D., Niu G., and Gao R., 2014, Concomitant CAM and C3 photosynthetic pathways in *Dendrobium officinale* plants, Journal of the American Society for Horticultural Science, 139(3): 290-298.
https://doi.org/10.21273/JASHS.139.3.290

Zuo S., Yu H., Zhang W., Zhong Q., Chen W., Chen W., Yun Y., and Chen H., 2020, Comparative metabolomic analysis of *Dendrobium officinale* under different cultivation substrates, Metabolites, 10(8): 325.
https://doi.org/10.3390/metabo10080325