nutrient supply. Under traditional open-field cultivation or simple greenhouse cultivation, *G. lucidum* production is easily affected by seasonal changes, climatic fluctuations, and natural disasters, often resulting in slow mycelial growth, abnormal fruiting body morphology, unstable yield, and fluctuations in active component contents. Meanwhile, the scarcity and instability of wild resources, high dependence on wood-based substrates, and obvious batch-to-batch differences in active components further highlight the need to establish efficient, controllable, and sustainable production systems. With the development of modern agricultural facility technologies and bioprocessing technologies, facility-based cultivation has gradually become an important direction for the transformation and upgrading of the *G. lucidum* industry. Indoor mushroom houses, environmentally controllable "mushroom factories," liquid spawn systems, and submerged fermentation technologies can precisely regulate temperature, humidity, gas composition, light, and nutritional conditions, thereby improving production stability and quality consistency (Feng et al., 2024; Ghafoor et al., 2024; Liu et al., 2024). In addition, facility-based cultivation can reduce the risks associated with heavy metals, toxic residues, and competitive microorganisms by separating substrates from soil, while also supporting standardized operations that comply with pharmacopoeial requirements and good manufacturing practices (Wu et al., 2024).

In facility-based *G. lucidum* cultivation, environmental control technology is a core factor affecting production performance and product quality. Temperature and humidity are directly related to mycelial expansion, primordium formation, and fruiting body development; ventilation affects changes in CO_2 concentration and plays an important role in pileus formation, stipe elongation, and morphogenesis; light conditions are closely associated with primordium differentiation, color formation, and the accumulation of bioactive substances. Studies have shown that controlled environments can optimize fruiting body morphology, yield, and the accumulation of bioactive components such as polysaccharides and triterpenoids by regulating key factors such as light spectrum, temperature profiles, and oxygen supply. Improper environmental regulation can easily lead to contamination, excessive stipe elongation, malformed pilei, and insufficient accumulation of active components. Therefore, establishing a scientific, stable, and reproducible environmental control system is an important basis for improving the level of facility-based *G. lucidum* cultivation. Meanwhile, the application of low-cost IoT-based temperature and humidity sensing, automatic control, and real-time monitoring technologies has further enhanced environmental management during *G. lucidum* production, helping to achieve contaminant control, compliance with quality indicators, and standardized whole-process management (Nguyen et al., 2023; Liu et al., 2024).

This study will explore the key technical pathways for environmental control and standardized production in facility-based *G. lucidum* cultivation. It will focus on the environmental regulation points, key production procedures, and quality control systems of facility-based *G. lucidum* cultivation; examine the application value of intelligent and digital technologies in *G. lucidum* production; and propose development pathways for standardized production in light of the current industrial context. The study aims to integrate the development needs of the *G. lucidum* industry with modern controllable cultivation technologies. By summarizing research progress in facility design, temperature, humidity, CO_2, light quality, ventilation regulation, liquid spawn, and fermentation processes, it seeks to provide technical references for stable and high-quality *G. lucidum* production. This study will also examine how precise environmental regulation can support emerging quality standards, increase the yield of fruiting bodies and bioactive metabolites, reduce contamination and resource consumption, and thereby promote *G. lucidum* production toward precision, standardization, and intelligentization, enhance product quality and industrial competitiveness, and facilitate the sustainable and high-quality development of the *G. lucidum* industry.

2 Basic Characteristics of Facility-Based *Ganoderma lucidum* Cultivation

2.1 Specific environmental requirements for *Ganoderma lucidum* growth

Ganoderma lucidum is a thermophilic wood-decaying fungus. Its mycelial growth, primordium differentiation, and fruiting body formation show distinct stage-specific requirements for temperature, humidity, light, CO_2 concentration, pH, and substrate conditions. Studies have shown that *G. lucidum* mycelia generally grow well at 25℃~32℃, under near-neutral to slightly acidic pH and relatively high humidity, whereas fruiting body formation depends more on stable temperature and humidity, appropriate light, and favorable gas exchange