6 Application of Intelligent and Digital Technologies in *Ganoderma lucidum* Cultivation

6.1 Real-time monitoring of environmental data in *Ganoderma lucidum* cultivation

In facility-based cultivation of *Ganoderma lucidum*, the stability of environmental conditions such as temperature, humidity, CO_2, light, substrate moisture, pH, and air circulation directly affects mycelial growth rate, fruiting body formation, and final product quality. Traditional manual management mainly relies on empirical judgment and is prone to delayed monitoring, discontinuous data collection, and imprecise regulation, making it difficult to meet the needs of modern large-scale and standardized *G. lucidum* production. With the development of Internet of Things (IoT) technology, sensor-network-based environmental monitoring systems have gradually been applied to edible mushroom and *G. lucidum* cultivation. These systems can continuously collect environmental data inside mushroom houses or cultivation rooms through temperature and humidity sensors, CO_2 sensors, light sensors, substrate or soil moisture sensors, and pH sensors, and upload the data to digital platforms via microcontrollers and wireless communication modules (Chong et al., 2023; Nguyen et al., 2023; Adebayo et al., 2025).

In indoor *G. lucidum* cultivation, low-cost IoT monitoring systems have been used for real-time monitoring of temperature and humidity changes. The study by Nguyen et al. (2023) showed that although temperature and humidity fluctuated with external weather conditions, real-time monitoring could still help maintain the cultivation environment within the required production range and ensure that *G. lucidum* product quality met relevant standards. Other edible mushroom production systems commonly use DHT or AM2301 temperature and humidity sensors, SCD30 CO_2 sensors, MQ-135 gas sensors, soil moisture probes, and light sensors, and upload data to cloud platforms through ESP8266, ESP32, and similar modules to enable remote access and environmental alerts (Chong et al., 2023). Calibration results between sensors and reference instruments generally show only small deviations, indicating that low-cost sensors have good practical applicability in facility-based environmental monitoring.

In addition to real-time recording, emerging technologies such as edge computing and TinyML are also improving the intelligence level of environmental monitoring systems. TinyML-based monitoring devices can integrate CO_2, temperature and humidity, light, soil moisture, soil pH, and soil temperature sensors at the microcontroller end, and directly control actuators such as humidifiers, heaters, coolers, and fans through local models, thereby reducing dependence on cloud communication and improving response speed (Adebayo et al., 2025). Edge-cloud collaborative architectures can also combine IoT sensor data with RGB images, completing data compression, anomaly detection, and real-time recognition at the edge end. This saves network resources while retaining key environmental information (Nguyen et al., 2024). Therefore, embedding real-time monitoring, edge computing, and cloud platform management into dedicated *G. lucidum* cultivation rooms or “mushroom factories” can provide a stable data foundation for precise environmental control and standardized production.

6.2 Construction of automated regulation systems for *Ganoderma lucidum* production

Automated regulation systems are an important technical foundation for achieving precise management in facility-based *G. lucidum* cultivation. Based on continuous environmental sensing, automated systems can connect data such as temperature, humidity, CO_2, light, and substrate moisture with control algorithms and actuators, enabling automatic control of spraying, ventilation, heating, cooling, shading, and supplementary lighting equipment. This reduces manual regulation errors and improves production management efficiency. IoT-based climate control systems for mushroom houses can automatically turn spraying, irrigation, and ventilation equipment on or off according to feedback from temperature, humidity, and CO_2 sensors, keeping temperature within a suitable biological range, such as 25℃~33℃, and maintaining humidity within an appropriate range, while also supporting remote monitoring and management (Chong et al., 2023).

In terms of temperature and humidity regulation, automated systems can dynamically adjust the internal environment of facilities through heating equipment, cooling fans, wet-pad systems, automatic spraying devices, and circulation fans. When humidity is lower than the set value, the system can automatically activate spraying or humidification equipment; when humidity is too high or CO_2 concentration is elevated, ventilation equipment can be automatically activated for air exchange. Small-scale cultivation systems based on NodeMCU microcontrollers