and cloud platforms such as Blynk can already monitor temperature, humidity, light, and substrate moisture simultaneously, and automatically control fans, humidifiers, heaters, and lighting equipment according to user-defined thresholds (Chong et al., 2023). Such systems show that automated control is not only applicable to large *G. lucidum* factories, but can also be extended to medium- and small-scale facility-based production scenarios.

More advanced automated systems further introduce fuzzy logic, predictive control, machine learning, and industrial automation technologies to improve regulation precision and resource-use efficiency. Intelligent substrate management frameworks can use multi-source sensor data, including soil moisture, temperature and humidity, light, and pest movement, and apply fuzzy rules to determine watering, ventilation, light regulation, and pest alert needs, thereby improving environmental stability (Irwanto et al., 2024). Sustainable mushroom house systems using IoT sensors, Raspberry Pi-based actuator control, fuzzy logic, and predictive analytics can control temperature within±0.5°C and humidity within ±2%, while reducing water use by approximately 30% and energy consumption by 20% compared with manual systems (Kavaliauskas et al., 2022). In factory-based edible mushroom production, electrical automation combined with fuzzy PID control can reduce contamination rates and significantly increase fresh mushroom yield. These studies provide a technical pathway for the transition of *G. lucidum* production from experience-based manual regulation to integrated, algorithm-driven, and precise environmental control.

6.3 Production data analysis and intelligent management of *Ganoderma lucidum*

The development of digital technologies is gradually transforming *G. lucidum* production from experience-based management to data-driven and model-based management. In modern facility-based cultivation, sensor networks and automated systems continuously generate large amounts of time-series data, including temperature, humidity, CO_2, light, water flow, equipment status, cultivation bag batches, growth cycles, contamination rates, yield, and quality testing results. Through cloud platforms or IoT platforms such as NETPIE 2020, ThingSpeak, and Blynk, these data can be centrally stored, visualized as trends, used for remote regulation, and analyzed for resource consumption, helping producers understand environmental changes and management effects at different production stages (Kavaliauskas et al., 2022). Cloud-connected systems can also export data in CSV format for further calibration, performance evaluation, and optimization of control rules (Chong et al., 2023).

Data analysis technologies can help producers promptly identify abnormal problems in *G. lucidum* production and provide decision-making support for process optimization. For example, by comparing spawn-running time, fruiting cycle, contamination rate, yield, and active component contents among different batches of *G. lucidum*, producers can analyze deficiencies in environmental control, substrate formulation, ventilation regime, or spraying frequency, and thereby optimize production processes. Edge-cloud architectures further support real-time anomaly detection and quality control. AI models can be used to identify abnormal environmental patterns or abnormal growth conditions while reducing bandwidth and storage costs (Nguyen et al., 2024). With the long-term accumulation of production data, *G. lucidum* production can gradually establish correlation models linking “environmental parameters-growth performance-yield and quality,” providing a scientific basis for facility design, parameter setting, and standardized production.

From a broader perspective, artificial intelligence and big data technologies are reshaping edible mushroom cultivation and can be further extended to factory-based *G. lucidum* production. Reviews have noted that combining IoT-based environmental monitoring with machine learning models such as LSTM can predict diurnal temperature and humidity changes and guide proactive regulation of ventilation, humidification, and heating, thereby achieving a more stable microclimate and reducing energy consumption (Jacob et al., 2025). Adaptive control models based on fuzzy logic, reinforcement learning, and sensor data can also be used to optimize resource allocation and maintain stable growth conditions in commercial farms (Chen et al., 2022). Computer vision and machine learning technologies can further be applied to species identification, quality grading, digital phenotyping, automatic yield estimation, and harvest timing judgment. Therefore, intelligent management systems for *G. lucidum* should build integrated data pipelines from cultivation rooms to central databases, and use AI for