Research and Efficacy Analysis of High-efficiency Intelligent Facility Cultivation Techniques for *Hericium erinaceus* in Changshan County

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Abstract [**Objectives**] To systematically investigate the high-efficiency intelligent facility cultivation techniques for *Hericium erinaceus*. [**Methods**] A three-layer intelligent regulation system encompassing "perception-execution-control" was established to enable precise monitoring and stage-specific automatic adjustment of key environmental parameters, including temperature, humidity, CO_2 concentration, and light intensity. Combined with integrated green pest management practices, the effects of intelligent cultivation on mycelial growth, yield, marketable product rate, contamination rate, and overall economic benefits were systematically evaluated. [**Results**] Compared with traditional facility cultivation, the intelligent cultivation system shortened the time to full mycelial colonization of the substrate bag by 2 – 3 d, increased the average yield per artificial log by over 30%, achieved a marketable product rate of 92%, reduced the contamination rate to 2.23%, and significantly decreased labor input, resulting in an overall economic benefit increase exceeding 30%. [**Conclusions**] This technical system effectively addresses the production bottlenecks posed by high humidity and large temperature fluctuations during spring in the Changshan region, thereby achieving stable, high-quality, and efficient cultivation of *H. erinaceus*. The system demonstrates considerable feasibility for extension and application in regions with similar climatic conditions across the South Yangtze River area and provides a technical reference for the digital and intelligent transformation of the traditional edible mushroom industry.

Key words *Hericium erinaceus*, Intelligent facility cultivation, Internet of things (IoT), Precise control

1 Introduction

Hericium erinaceus, belonging to the phylum Basidiomycota, family Hydnaceae, and genus *Hericium*, is a precious edible and medicinal fungus named for its distinct resemblance to a monkey's head[1]. It is distributed in broad-leaved or mixed broadleaf-conifer forests across the northern temperate zone. In China, it is primarily found in the northeastern and southwestern regions, as well as in provinces including Hebei, Henan, Guangxi, Gansu, Sichuan, Yunnan, and Tibet[2]. *H. erinaceus* is rich in polysaccharides, proteins, amino acids, trace elements, and vitamins B_1 and B_2[3 – 4]. It exhibits multiple pharmacological effects, such as gastroprotective and stomach-nourishing properties, neuroprotection, immunomodulation, antitumor activity, antioxidation, antiaging, anti-fatigue, and hypoglycemic effects[5 – 11].

Changshan County serves as the primary production hub for the nationally recognized geographical indication product, "Changshan *H. erinaceus*." Esteemed as one of Quzhou's "Six Renowned Medicinal Herbs," this mushroom boasts remarkable medicinal and edible properties along with strong brand recognition[12]. Nevertheless, conventional cultivation methods remain heavily dependent on experiential management, causing significant variability in key environmental controls, namely temperature, humidity, ventilation, and CO_2 levels. Such instability frequently compromises mycelial vigor, induces fruiting body deformities, and triggers recurrent Trichoderma infections. Concurrently, escalating labor expenses have precipitated a critical bottleneck for the sector, manifesting in unstable production volumes, inconsistent product quality, and constrained profitability.

Zhejiang Province's recent efforts to promote digital transformation in agriculture have laid the groundwork for shifting *H. erinaceus* facility cultivation from reliance on empirical methods toward intelligent, data-driven practices. Building upon the mushroom's specific growth requirements and the region's climatic profile, this study explores high-efficiency intelligent cultivation technologies under protected structures. By leveraging precise IoT-enabled environmental controls, implementing stage-specific management protocols, and adopting green prevention measures, the research aims to overcome critical bottlenecks in conventional production and foster the standardization, digitization, and long-term sustainability of the *H. erinaceus* sector.

2 Materials and methods

2.1 Experimental site and facility conditions The study was conducted at the Edible Fungi Intelligent Demonstration Base in Qiuchuan Town, Changshan County, Quzhou, Zhejiang Province. Situated in a subtropical monsoon climate zone, the site experiences an average annual temperature of 17.8 ℃ and annual rainfall of 1 680 mm, with particularly rainy and humid conditions prevailing in spring. The experimental setup included ten standardized steel-frame intelligent greenhouses (each 320 m^2) housing a total of 6 000 cultivation bags, supported by a dedicated digital control center. The integrated intelligent system is structured into three functional layers. Perception layer: Comprising sensors that monitor temperature, humidity, CO_2 levels, and light intensity. Actuation layer: Encompassing heat pump-based temperature regulation, variable-frequency high-pressure misting, fresh air exchange systems, thermal curtain rollers, and LED grow lights.

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Control layer: Consisting of an IoT gateway, a local controller, and a cloud-based management platform.

2.2 Test variety and strain The variety selected for this study was "Changshan Houtou 99". This strain is characterized by vigorous mycelial vitality, regular fruiting body morphology, and high polysaccharide content. The spawn was provided by the Changshan Tianle Edible Fungi Research Institute through a three-stage propagation system.

2.3 Substrate formulation and treatment The cultivation substrate formulation consisted of: 65% cottonseed hulls (medium shell and medium lint), 14% hardwood sawdust, 20% high-quality wheat bran, and 1% gypsum. The substrate-to-water ratio was 1 : 1.3, yielding a moisture content of 60% - 62% and a pH range of 7.0 - 7.5. The production process included: raw material preparation → mixing → bag filling → high-pressure sterilization (121 ℃, 2 h) → cooling → inoculation → mycelial incubation.

2.4 Intelligent staged cultivation management Mycelial incubation period: Temperature 22 - 24 ℃, relative humidity 80% - 85%, $CO_2 \leq 1\,500$ ppm, complete darkness. The system automatically collected data every 10 min; upon detecting anomalies, it autonomously adjusted conditions and sent alert notifications to mobile devices. Fruiting induction period: Temperature 16 - 18 ℃, diurnal temperature fluctuation 2 - 3 ℃, relative humidity 85% - 90%, low light intensity 300 - 500 lx, CO_2 700 - 900 ppm. Fruiting body development period: Temperature 18 - 20 ℃, relative humidity 88% - 92%, light intensity 800 - 1 000 lx, $CO_2 \leq 1\,200$ ppm. Variable-frequency high-pressure misting was employed for supplemental hydration to prevent water accumulation and subsequent fruit body decay. Full-process data logging was implemented, enabling one-code-per-batch traceability.

2.5 Experimental design Two treatment groups were established: a conventional facility cultivation group and an intelligent facility cultivation group. Each group comprised 6 000 cultivation bags and was replicated three times. The following parameters were recorded: time to full mycelial colonization, average yield, agronomic traits, marketable product rate, and spawn bag contamination rate.

3 Results and analysis

3.1 Effects of different cultivation facilities on mycelium growth and yield of *H. erinaceus* As shown in Table 1, differences in mycelial growth rate were observed between the two cultivation facility types. The time to full mycelial colonization was significantly shorter in the intelligent facility cultivation group compared with the conventional facility group, indicating a markedly faster growth rate. Relative to the control group, the intelligent facility group exhibited a 3-day reduction in the time required for complete substrate colonization, superior mycelial vigor, and a 31.99% increase in yield per cultivation bag.

Table 1 Mycelium growth and yield of traditional and intelligent facility cultivation groups

Cultivation group	Full colonization period//d	Mean mycelial extension rate//cm/d	Mycelial growth vigor	Mean yield//kg/bag
Traditional facility	31.33 ± 0.46	0.205 ± 0.026	+ + + +	0.497 ± 0.027
Intelligent facility	28.33 ± 0.37	0.287 ± 0.035	+ + + + +	0.656 ± 0.019

3.2 Effects of different cultivation facilities on the commodity rate and quality of *H. erinaceus* As shown in Table 2, the intelligent facility cultivation group produced fruiting bodies with a larger average cap diameter (8.62 cm), higher individual fresh weight, and shorter spine length (0.83 cm). The marketable yield rate reached 92.00%, which was significantly higher than the 78.33% recorded for the conventional facility cultivation group. In the conventional facility group, agronomic traits exhibited instability and a higher incidence of malformed fruiting bodies, attributable to limitations in facility conditions and cultivation environment. In contrast, the intelligent facility cultivation group yielded fruiting bodies with uniform morphology and no surface blemishes, fully conforming to the quality standards established for the Changshan Geographical Indication product.

Table 2 Quality and commodity rate of *Hericium erinaceus* in traditional and intelligent facility cultivation groups

Cultivation group	Fruiting body morphology	Pileus diameter//cm	Firmness/Tightness of fruiting body	Spine/Tooth length//cm	Fresh weight per individual sporophore//g	Commodity rate//%
Traditional facility	Round	7.63 ± 0.67	Yes	1.21 ± 0.10	87.89 ± 2.78	78.33 ± 1.97
Intelligent facility	Relative round	8.62 ± 0.45	Yes	0.83 ± 0.04	96.76 ± 3.24	92.00 ± 2.24

3.3 Effects of miscellaneous bacteria contamination in different facilities As shown in Table 3, the intelligent facility cultivation group achieved an average spawn survival rate of 95.27%, with a contamination rate of only 2.23%. In contrast, the conventional facility cultivation group exhibited an average survival rate of 89.33% and a contamination rate of 12.10%, representing a statistically significant difference. The primary reason for this discrepancy lies in the precision environmental control afforded by the intelligent system, which maintained humidity within a deviation of ≤2% and CO_2 concentration within ±50 ppm of setpoints, thereby effectively precluding infections by Trichoderma spp. (green mold), *Mucor* spp., and other contaminants typically exacerbated by excessive heat, high humidity, and inadequate ventilation. In addition, the integration of an ozone disinfection system coupled with a fresh air exchange mechanism further mitigated contamination risks.

Table 3 Inoculation survival rate and contamination rate of traditional and intelligent facility cultivation groups %

Cultivation group	Inoculation survival rate	Contamination rate
Traditional facility	89.33 ±0.98	12.10 ±0.59
Intelligent facility	95.27 ±1.39	2.23 ±0.16

3.4 Economic benefits The intelligent facility cultivation group required only two personnel for routine inspection and data monitoring, whereas the conventional facility cultivation group required six personnel, representing a substantial reduction in labor input and associated costs. Although the initial capital investment for intelligent equipment was higher, with the total annual cost per greenhouse unit (comprising equipment depreciation and energy consumption) exceeding that of the conventional group by 8%, the overall economic benefit increased by over 30% relative to the conventional group, driven by enhanced yield and improved product quality. The economic benefits were therefore significant.

The growth of *H. erinaceus* is highly sensitive to environmental parameters. The mycelial incubation stage requires stable temperature and humidity conditions; the fruiting induction stage demands precise diurnal temperature fluctuation and light exposure; and the fruiting body development stage necessitates stringent control of CO_2 concentration and relative humidity. Conventional cultivation relies heavily on operator experience, resulting in issues such as delayed responses to environmental shifts and substantial parameter fluctuations. In contrast, the intelligent system employs a fully closed-loop control architecture comprising "sensor acquisition—cloud-based decision-making—actuator execution," thereby enabling stage-specific precision regulation. This approach effectively addresses the longstanding vulnerabilities associated with "weather-dependent cultivation" and "experience-based farming".

Intelligent technology, through precise environmental regulation, has effectively resolved production challenges in the Changshan region arising from extreme climatic conditions such as high humidity, abundant rainfall, and wide diurnal temperature fluctuations, thereby enabling stable and consistent output. The intelligent system overcomes the limitations inherent in conventional manual management, namely, slow response times, substantial operational errors, and significant environmental fluctuations, and provides a standardized, replicable technical pathway for the *H. erinaceus* industry.

This technology is fully adapted to the environmental characteristics of Changshan County, Zhejiang Province, and the broader mountainous regions of Jiangnan (south of the Yangtze River), which are typified by high humidity in spring and freezing conditions in winter. Moreover, the technology complies with the quality specifications mandated for Geographical Indication (GI) products, thereby achieving an integrated convergence of ecological benefits, economic returns, and brand value enhancement.

4 Conclusions

The high-efficiency intelligent facility cultivation technology system for *H. erinaceus* developed in Changshan County has significantly enhanced yield, quality, and marketable product rate while concurrently reducing contamination incidence and labor input. The system is optimally adapted to the local climatic conditions of Changshan. This technology is suitable for large-scale extension and adoption within Changshan County and other regions of the South Yangtze River area sharing analogous climatic profiles, thereby providing robust technical support for the digital transformation and upgrading of the mushroom industry and for the broader objectives of rural revitalization.

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