



Performance Evaluation of an Automatic Fogging System for Optimized Microclimate Control in Oyster Mushroom (*Pleurotus spp.*) Production under Tropical Conditions

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ABSTRACT

Background: The study evaluated the performance of a locally developed automatic fogging system (AFS) designed to maintain optimal microclimatic conditions for oyster mushroom (*Pleurotus spp.*) production under tropical Philippine settings.

Methods: Using an experimental comparative design, two cultivation systems were assessed: the AFS and the conventional farmers' practice (manual misting). Data were collected on yield, biological efficiency, contamination rate and return on investment (ROI).

Result: The AFS maintained a stable relative humidity range of 82-89% and a temperature of 25-28°C, compared with fluctuations of 65-94% RH and 23-33°C under manual control. Consequently, yield and biological efficiency increased significantly ($P \leq 0.05$) by approximately 30%, contamination decreased by 70% and profitability improved by 18-22%. Moreover, the findings confirm that low-cost automation enhances productivity, consistency and sustainability in small-scale mushroom production. It was concluded that AFS can serve as an educational model for agricultural and science curricula, particularly as a laboratory-based activity that integrates automation, climate control and sustainable production technologies. The system offers a replicable, affordable solution that supports the transition toward smart, climate-resilient agriculture in tropical and ASEAN contexts.

Key words: Automatic fogging system, IoT-based cultivation technology, Microclimate control, Oyster mushroom (*Pleurotus spp.*), Smart and sustainable agriculture.

INTRODUCTION

Globally, the cultivation of oyster mushrooms (*Pleurotus spp.*) has expanded due to their high nutritional value, low production costs and ability to convert agro-industrial waste into high-value food products. Beyond their nutritional role, mushroom cultivation exemplifies circular-economy principles by recycling agricultural residues while generating employment opportunities in rural communities (Chang and Miles, 2004). In tropical developing countries such as the Philippines, oyster mushroom production offers a sustainable livelihood strategy; however, it remains small-scale and labor-intensive, relying heavily on manual watering or misting. These practices often result in inconsistent humidity and temperature levels, leading to uneven fruiting, increased contamination and reduced yields, as mentioned by Tejada *et al.* (2023). Oyster mushrooms require a temperature range of 24-30°C and relative humidity between 80-90% for optimal fruiting (Sher *et al.*, 2010). Deviations from these thresholds affect mycelial respiration, primordia formation and the balance of substrate moisture. Manual humidity control is typically imprecise, leading to either desiccation or excessive moisture that favors the growth of pathogenic organisms. Automated fogging and misting systems, when properly calibrated, can maintain microclimate equilibrium by generating fine droplets and enabling closed-loop regulation of relative humidity and air temperature.

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These factors directly influence biological efficiency, yield stability and product quality as reported by Lenka *et al.* (2022). Recent studies have demonstrated the potential of automation and Internet of Things (IoT)-based systems to optimize environmental control in mushroom production. Chong *et al.* (2023) reported that an IoT-controlled monitoring system significantly enhanced mushroom yield and quality by maintaining consistent temperature and humidity. Similarly, Rukhiran *et al.* (2023) integrated solar

energy with IoT automation for sustainable mushroom cultivation, while Guragain *et al.* (2024) introduced a low-cost, centralized IoT ecosystem designed for small-scale growers. Nguyen *et al.* (2024) employed edge-computing and sensor-camera systems to achieve precision microclimate management and Elewi *et al.* (2024) developed a cost-aware automation model tailored for *Pleurotus ostreatus* cultivation. Collectively, these studies affirm the role of automation in improving productivity, environmental stability and labor efficiency in controlled cultivation systems. In the Philippines, research has primarily focused on optimizing substrates such as rice straw, banana leaves and sawdust (Tejada *et al.*, 2023) or developing postharvest drying technologies (Hung *et al.*, 2020). However, few studies have investigated automated humidity-control systems adapted to tropical mushroom houses and resource-constrained rural settings. Thus, a critical gap remains in locally validated automation models suitable for smallholder operations. This study is among the first to design and evaluate an automatic fogging system (AFS) specifically customized for tropical Philippine conditions. Unlike prior IoT models developed for temperate greenhouses, the AFS integrates locally available components-humidity and temperature sensors, control units and misting modules-engineered for semi-open fruiting houses. The system automates fogging intervals and environmental feedback loops to sustain optimal growth conditions. Therefore, the study aims to (1) assess the efficiency of AFS on oyster mushroom yield, (2) establish control measures for disease occurrence, (3) determine productivity and profitability under AFS, (4) compare performance with traditional farmers' practice and (5) evaluate the biological efficiency and acceptability of *Pleurotus florida* and *P. ostreatus*.

By validating the AFS under real tropical conditions, this research advances innovative and sustainable agriculture in the ASEAN region. Its findings provide an empirical foundation for scalable, low-cost microclimate control technologies that enhance productivity, reduce water use and promote technology adoption among smallholder mushroom growers in the Philippines.

MATERIALS AND METHODS

Research design and location

The study employed a comparative experimental design to assess the performance of an automatic fogging system (AFS) developed for oyster mushroom (*Pleurotus spp.*) production. The experiment was conducted at the mushroom production facility of the Abra State Institute of Sciences and Technology (ASIST), Lagangilang Campus, Abra, Philippines (17°36' N, 120°44' E), from November 2024 to March 2025. The site has a tropical monsoon climate, with average ambient temperatures ranging from 23 to 32°C and relative humidity between 70% and 90%. Two identical culture rooms were used: one equipped with the AFS and another managed through farmers' practice (FP), which involved manual misting. Both chambers

measured 3 m × 4 m × 2.5 m and shared identical ventilation and lighting conditions.

Description of the automatic fogging system (AFS)

The AFS was locally fabricated using low-cost, readily available components. It comprised:

- **Sensors:** DHT22 humidity and temperature sensors continuously monitor microclimate conditions.
- **Control unit:** Arduino Mega 2560 microcontroller programmed to activate fogging when RH < 80% and to deactivate when RH > 90%.
- **Fogging unit:** A six-head ultrasonic fogger (24 V DC, 1.7 MHz piezoelectric transducers) distributing mist through PVC ducts.
- **Power supply:** 12 V/10 A regulated adapter with surge protection.
- **Alarm and display module:** Digital screen with alert buzzer showing real-time readings.

The AFS operated automatically without manual input. The FP control treatment involved hand spraying twice daily (07:00 and 15:00 h) using a pressurized sprayer.

Experimental materials

Two oyster mushroom species were used (Table 1), white oyster (*Pleurotus florida*) and brown oyster (*P. ostreatus*), both obtained from the ASIST Mushroom Laboratory. The substrate mixture consisted of rice straw (80%), sawdust (15%) and rice bran (5%), which was moistened to 65% and sterilized at 100°C for 4 hours. Each 1-kg bag was inoculated with 5% spawn (w/w) and incubated for 15 days before being transferred to fruiting chambers.

Each treatment involved 150 fruiting bags, replicated three times (total = 450 bags per system). Water and substrate sources were standardized across treatments.

Data collection and measurements

Microclimate parameters (temperature and RH) were logged every 30 minutes using digital dataloggers integrated into the AFS and handheld hygrometers for FP. Recorded data were downloaded daily for analysis.

The following indicators were evaluated: Total yield, biological efficiency, average fruit body weight, number of fruit bodies, contamination rate, temperature, relative humidity and return on investment (Table 2).

Data analysis

Data were subjected to Analysis of Variance (ANOVA) using a two-factor factorial design (cultivation system × mushroom species). Mean differences were evaluated using Duncan's multiple range test (DMRT) at 5% significance. The relationships between yield and environmental parameters were analyzed using the Pearson correlation coefficient. All analyses were carried out using Microsoft Excel.

Ethical and safety considerations

The experiment adhered to the Bureau of Plant Industry (BPI) guidelines for mushroom culture sanitation, waste

Table 1: Experimental layout.

Treatment code	System type	Species	Humidity control method	Replicates (bags)	Humidity range (RH%)
T1	AFS	<i>P. florida</i> (White Oyster)	Automatic ultrasonic fogging	3 × 150	80-90
T2	AFS	<i>P. ostreatus</i> (Brown Oyster)	Automatic ultrasonic fogging	3 × 150	80-90
T3	FP	<i>P. florida</i> (White Oyster)	Manual misting (twice daily)	3 × 150	uncontrolled
T4	FP	<i>P. ostreatus</i> (Brown Oyster)	Manual misting (twice daily)	3 × 150	uncontrolled

Table 2: Variable indicators.

Variable	Definition/Formula	Instrument/Method	Unit
Total yield	Cumulative fresh weight of mushrooms harvested per bag	Digital balance (± 0.01 g)	g bag ⁻¹
Biological efficiency (BE)	(Fresh yield/Dry weight of substrate) × 100	Computed at end of fruiting cycle	%
Average fruit body weight	Mean mass of individual fruiting bodies	Digital balance	g
Number of fruit bodies	Total count of mature fruiting bodies per bag	Manual count	count bag ⁻¹
Contamination rate	(No. of contaminated bags/Total bags) × 100	Visual observation	%
Temperature	Mean chamber air temperature	DHT22/hygrometer	°C
Relative humidity	Mean chamber RH	DHT22/hygrometer	%
Return on investment (ROI)	(Gross income - Total cost)/Total cost × 100	Economic computation	%

disposal and workplace safety. Electrical components were enclosed and operated at low voltage (≤ 24 V DC) to minimize the risk of shock and fire.

RESULTS AND DISCUSSION

Microclimate performance

The Automatic Fogging System (AFS) maintained a stable relative humidity (RH) of 82-89% and an average temperature range of 25-28°C throughout the fruiting period, whereas the Farmers' Practice (FP) treatment fluctuated widely between 65-94% RH and 23-33°C. These findings confirm that the AFS effectively regulated the microclimate within the optimal physiological thresholds required for oyster mushroom fruiting, as mentioned by Sher *et al.* (2010). On the other hand, consistent humidity and temperature are critical for maintaining mycelial vigor and primordia formation. Similar outcomes were reported by Chong *et al.* (2023), who demonstrated that IoT-controlled humidity systems significantly reduced environmental variability, thereby increasing fruiting uniformity. Likewise, Nguyen *et al.* (2024) observed that automated systems leveraging sensor feedback loops minimized daily fluctuations by more than 60%, supporting the current study's findings.

Yield and biological efficiency

Table 3 summarizes the mean yield and biological efficiency (BE) of the two species under AFS and FP. Analysis of variance (ANOVA) revealed significant differences ($p < 0.05$) in both yield and BE between AFS and FP. The interaction effect between cultivation system and species was not significant ($p > 0.05$), indicating that both *P. florida* and *P. ostreatus* responded similarly to automated humidity control. The 28-31% increase in BE under AFS aligns with reports by Guragain *et al.* (2024) and Rukhiran *et al.* (2023), who found comparable gains using IoT-regulated environmental systems. These results emphasize that precise humidity regulation enhances substrate metabolism and water-absorption efficiency, both of which are directly proportional to fruit body biomass (Sharma *et al.*, 2020).

Contamination rate and disease control

Contamination rates in the AFS chamber averaged 3.1%, significantly lower than FP's 9.8%. Reduced contamination can be attributed to uniform humidity distribution and minimized surface wetness, which inhibit the proliferation of mold and bacteria. Similar patterns were observed by Elewi *et al.* (2024), who reported that automation reduced disease incidence by maintaining stable vapor pressure differentials within the cultivation area. The reduction in contamination also implies improved air circulation and fewer manual interventions, thereby reducing potential sources of vector contamination (Jha *et al.*, 2025). This finding supports earlier assertions by Rukhiran *et al.* (2023) that automation not only enhances yield but also contributes to biosecurity and consistent product quality.

Table 3: Mean yield and biological efficiency (BE) of the two species under AFS and FP.

Parameter	AFS (Mean±SD)	FP (Mean±SD)	Improvement (%)
Yield (<i>P. florida</i>) (g bag ⁻¹)	695±32	540±48	+28.7
Yield (<i>P. ostreatus</i>) (g bag ⁻¹)	660±37	505±41	+30.7
Biological efficiency (%)	87.2±3.4	66.1±4.9	+31.9

Table 4: Profitability and return on investment (ROI).

Economic indicator	AFS	FP
Average cost per replicate (₹)	6,800	5,900
Average gross income (₹)	13,200	10,200
ROI (%)	94.1	72.9

Profitability and return on investment (ROI)

Economic analysis revealed that the production cost per 150-bag replicate was slightly higher under AFS due to initial hardware expenses; however, the overall ROI increased by 18-22% compared with FP (Table 4). Higher profitability under AFS resulted from increased yield and reduced labor costs (elimination of manual misting). These outcomes corroborate findings by Elewi *et al.* (2024) and Nguyen *et al.* (2024), who documented labor reductions of 30-40% with automated control systems. Thus, while initial investment is higher, the payback period is short, making the AFS economically viable for smallholders.

CONCLUSION

The Automatic Fogging System consistently maintained optimal humidity and temperature, significantly increased yield and biological efficiency, reduced contamination and improved profitability compared with manual practices. These results confirm that low-cost, locally developed automation can effectively address major constraints in mushroom production, particularly unstable microclimatic conditions and labor inefficiency. The technology offers a practical, scalable model for smart, sustainable and climate-resilient mushroom production in the Philippines and across ASEAN. Future studies may evaluate its adaptability for the domestication and controlled cultivation of selected wild edible mushroom species in the Cordillera region to support biodiversity conservation and livelihood development.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent

the views of their affiliated institutions. The authors are responsible for the accuracy of the information provided.

Informed consent

Not applicable.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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