Journal of Agriculture and Environment for International Development - JAEID 2026, 120 (1): 87 – 98
DOI: 10.36253/jaeid-19238

Microclimate Modulation by Banana Canopy: Seasonal Implications for Integrated Mushroom

GLADWEL CHEPNG'ETICH NG'ENO[1], MARY GORETTI KARIAGA[2], ASENATH JEROTICH SIGOT[3], JOB SIRENGO LUSWETI[4], EVELYNE MMBONE MULEKE[2]

[1] *School of Agriculture Veterinary Science and Technology, Masinde Muliro University of Science and Technology, Kakamega. Kenya*

[2] *Department of Agriculture and Land Use Management, Masinde Muliro University of Science and Technology, Kakamega. Kenya*

[3] *Department of Nutritional Sciences, Masinde Muliro University of Science and Technology, Kakamega. Kenya*

[4] *Department of Mathematics, Masinde Muliro University of Science and Technology, 190-50100, Kakamega. Kenya*

**Correspondence details: gladwelngeno@gmail.com*

Submitted on: 2025, 23 November; accepted on 2026, 10 March. Section: Research Papers

Abstract: Mushroom cultivation is highly sensitive to microclimatic conditions, which determine colonization, fruiting, and quality. In tropical regions, seasonal variability in temperature, humidity, light, and carbon dioxide often constrains production, particularly for smallholder farmers who lack the resources to maintain controlled environments. Banana (*Musa spp.*) plantations provide natural shade and buffering effects that may serve as low-cost alternatives to indoor cultivation, yet empirical evaluations remain limited. This study investigated the influence of season (wet and dry), cultivation environment (indoor vs. outdoor under banana canopy), and species (*Pleurotus ostreatus* and *Pleurotus australis*) on microclimate dynamics at Masinde Muliro University farm, Kakamega County, Kenya. A split–split plot design with three replicates was used, and air temperature, relative humidity, light intensity, and carbon dioxide concentration were monitored at mushroom canopy height. Data were analyzed using ANOVA, with treatment means separated by Tukey's HSD at $P \leq 0.05$. Results showed significant seasonal variation in all parameters. During the dry season, indoor conditions maintained higher humidity and lower temperatures than outdoors. However, in the wet season, humidity and temperature did not differ significantly between indoor and outdoor setups, demonstrating the buffering effect of the banana canopy. Outdoor environments consistently recorded higher light intensity and lower CO_2 levels compared to indoor systems. These findings highlight banana canopies as effective natural microclimate regulators, offering a sustainable and low-input alternative to controlled indoor cultivation in tropical smallholder systems.

Keywords: Banana canopy; Microclimate; Mushroom cultivation; Pleurotus spp; Seasonal variation; Sustainable farming

Introduction

Oyster mushrooms (*Pleurotus* spp.) are among the most widely cultivated edible fungi worldwide (Raman et al., 2021) due to their short production cycle, high nutritional and medicinal value, and ability to grow on a wide range of lignocellulosic substrates (Devi et al., 2023; Adebayo & Martinez-Carrera, 2015). Their cultivation has expanded globally as a low-input and sustainable enterprise, contributing to food security and income generation in both rural and urban settings (De Cianni, 2025; Bringye et al., 2021). However, successful production is highly dependent on microclimatic conditions, particularly temperature, relative humidity, light intensity, and carbon dioxide concentration, which directly influence mycelial colonization, fruiting initiation, and morphogenesis (Patil et al., 2024; Pathmashini et al., 2008).

In tropical regions, where ambient conditions fluctuate markedly between wet and dry seasons, maintaining optimal microclimate for target mushroom species remains a major challenge. Indoor mushroom cultivation spaces allow for precise environmental control, they often require substantial investment in infrastructure and continuous regulation, making them costly and difficult to sustain for smallholder farmers (Almeida et al., 2022). This limitation has stimulated growing interest in low-cost, ecologically integrated cultivation systems that utilize naturally moderated environments.

Banana (*Musa* spp.) plantations represent a promising option for such integration. The broad banana canopy intercepts solar radiation, reduces wind speed, and enhances localized humidity through transpiration, creating shaded and buffered microenvironments beneath the plants (Blomme et al., 2020; Tanny, 2013). These natural modifications may partially mimic the stable conditions of controlled indoor systems, with potential implications for mushroom growth and productivity.

Accordingly, rather than merely comparing microclimatic differences between indoor and outdoor environments, this study evaluated how seasonal variation and cultivation conditions translate into measurable cultivation outcomes. Specifically, it assessed mycelial growth rate, incubation period, fruiting performance, yield, biological efficiency, and contamination levels of *Pleurotus ostreatus* and *P. australis* under indoor and banana-shaded outdoor systems across wet and dry seasons. By linking environmental conditions to quantitative indicators of cultivation success, the study aimed to identify species- and system-specific performance patterns that are directly relevant to sustainable mushroom production under smallholder farming conditions.

Materials and methods

Study Site Description

The research was carried out at the Masinde Muliro University of Science and Technology (MMUST) farm. The farm is situated in Lurambi Sub-County, Kakamega County, in western Kenya. This site lies at approximately 0°17′ N and 34°45′ E, with an average elevation of about 1,520 meters above sea level. The region is known for its humid tropical rainforest climate characterized by two distinct rainy seasons. The long rains normally occur around April, with an average monthly rainfall of about 240 mm, while a shorter rainy period peaks in August with approximately 180 mm. The driest months extend from December to February, when rainfall declines to between 60 and 80 mm. Average daily temperatures range from 18 °C to

28 °C, and relative humidity generally remains high, which mostly fluctuate between 70 % and 90 % throughout the year.

Outdoor cultivation was conducted under an established banana (*Musa* spp.) plantation at the study site. The plantation exhibited a relatively uniform canopy structure, and cultivation units were placed within a single plot to minimize variation in shading intensity. Irrigation was applied uniformly to all outdoor treatments three times per day to maintain adequate substrate moisture, particularly during the dry season. Other agronomic factors, such as banana plant age, height, spacing, soil surface cover, organic debris, and wind protection structures, were not experimentally controlled and were assumed to be consistent across the cultivation area. These factors were therefore considered potential sources of background variation rather than treatment effects.

Indoor cultivation was conducted in a conventional mushroom house with enclosed walls and limited natural ventilation. Environmental conditions were regulated using routine management practices typical of smallholder production systems, including manual watering to maintain substrate moisture. No automated climate-control systems were employed, and temperature, humidity, light, and carbon dioxide levels varied naturally within the enclosed space in response to ambient conditions. All indoor cultivation units were maintained under similar structural and management conditions, and no additional shading, forced ventilation, or artificial lighting was applied beyond background ambient light.

Experimental Materials

Microclimate measurements were undertaken using calibrated digital thermo-hygrometers for air temperature (°C) and relative humidity (% RH) [Digital thermo-hygrometer, ThermoPro TP50, ThermoPro LLC, China], a handheld lux meter for light intensity [Handheld digital lux meter, Testo 545, Testo SE & Co. KGaA, Germany], and a portable non-dispersive infrared (NDIR) CO_2 sensor for carbon dioxide concentration [Portable NDIR CO_2 monitor, Tekcoplus Portable CO_2 Monitor, Tekcoplus, China]. Instruments were used according to the manufacturer's guidelines, which include factory calibration and recommended procedures for accurate measurements. Indoor sensors were positioned at the level of the mushroom bags (approximately 0.2–0.5 m above the floor) to accurately capture the microclimate conditions experienced by the mushrooms. Outdoor sensors were positioned at the same height as the indoor sensors (0.2–0.5 m above the mushroom bags) to ensure comparable microclimate measurements between indoor and outdoor plots.

Experimental Design

The study employed a split–split plot factorial design to evaluate the effects of season (whole plot: wet and dry), cultivation environment (subplot: outdoor banana-integrated system [OUT] and indoor mushroom house [IN]), and species (sub-subplot: *Pleurotus ostreatus* and *Pleurotus australis*) on oyster mushroom performance. The experiment was established using three spatially separated blocks, which served as independent replicates.

Two commercially cultivated oyster mushroom species, *Pleurotus ostreatus* and *Pleurotus australis*, were used in this study. Pure cultures were obtained from Nature Niche Spawn Sellers Company (Kileleshwa, Nairobi, Kenya), a commercial spawn producer. The strains were commercial production strains and were not sourced from an official culture collection; therefore, formal strain accession numbers were not available. The cultures were multiplied in the laboratory to produce sorghum-based grain spawn, which was used for substrate inoculation.

A uniform substrate composed of sugarcane bagasse supplemented with chick mash, molasses, and lime was prepared and sterilized prior to spawning. Each cultivation bag contained 4 kg of substrate and was inoculated using the layered spawning method with grain spawn.

Following inoculation, substrate bags assigned to the indoor treatment were incubated under dark conditions to allow for complete spawn run. In contrast, substrate bags assigned to the outdoor banana-integrated treatment underwent spawn run under ambient outdoor light conditions beneath the banana canopy, rather than in complete darkness. During the spawn-run phase in both environments, the bags remained sealed and no watering was applied.

After substantial mycelial colonization, the cultivation bags were cut open upon the appearance of primordia to initiate the fruiting phase. Within each environment, the two species were randomly assigned to sub-subplots, with one cultivation bag per species per block. This arrangement provided three independent replicates per treatment combination (one per block), resulting in 12 bags per season (3 blocks × 2 environments × 2 species × 1 bag) and a total of 24 bags across both seasons. Bags were randomly arranged within subplots, and buffer zones of at least one meter were maintained between subplots to minimize cross-contamination and microclimate interference.

Data Collection

Microclimate data (air temperature, relative humidity, light intensity, and CO_2 concentration) were recorded three times daily (08:00, 13:00, and 17:00) during both the spawn run and cropping phases.

Statistical Analysis

Microclimate data (air temperature, relative humidity, light intensity, and CO_2 concentration) were analyzed using analysis of variance (ANOVA) in SAS version 9.4 (SAS Institute, Cary, NC, USA). The model tested the effects of season (wet and dry), cultivation environment (indoor vs outdoor), species (*P. ostreatus* and *P. australis*), and their interactions. Treatment means were separated using Tukey's Honest Significant Difference (HSD) test at $P \leq 0.05$. The assumptions of ANOVA were evaluated by inspecting residual plots and conducting Shapiro–Wilk and Levene's tests for normality and homogeneity of variance, respectively.

Results and Discussion

The effects of season, cultivation environment, and species on microclimate parameters (humidity, temperature, light intensity, and CO_2 concentration) were evaluated. Table 1 presents the mean values (±SEM) of these variables across treatments. Significant differences were observed among seasons and environments, with superscripts indicating comparisons at $p \leq 0.05$.

Table 1. Microclimate parameters (mean ± SEM) under different seasons, cultivation environments, and oyster mushroom species.

SEASON	CONDITION	SPECIES	HUMIDITY (%RH)	TEMPERATURE (^{O}C)	LIGHT INTENSITY (LUX)	CO_2 (PPM)
Dry,	Indoor	*P.ostreatus*	65.4 ± 0.9^{c}	29.9 ± 0.6^{b}	211.5 ± 0.5^{c}	455.1 ± 0.9^{a}
Dry	Indoor	*P.australis*	63.8 ± 0.9^{cd}	30.8 ± 0.6^{ab}	211.4 ± 0.5^{c}	455.0 ± 0.9^{a}
Dry	Outdoor	*P.ostreatus*	59.2 ± 0.9^{e}	33.3 ± 0.6^{a}	246.5 ± 0.5^{a}	413.2 ± 0.9^{b}
Dry	Outdoor	*P.australis*	61.9 ± 0.9^{d}	32.2 ± 0.6^{ab}	245.5 ± 0.5^{a}	412.6 ± 0.9^{b}
Wet	Indoor	*P.ostreatus*	77.0 ± 0.9^{b}	21.9 ± 0.6^{c}	203.3 ± 0.5^{d}	455.3 ± 0.9^{a}
wet	Indoor	*P.australis*	79.8 ± 0.9^{a}	20.9 ± 0.6^{c}	202.3 ± 0.5^{d}	454.8 ± 0.9^{a}
Wet	Outdoor	*P.ostreatus*	79.2 ± 0.9^{ab}	21.2 ± 0.6^{c}	235.3 ± 0.5^{b}	416.8 ± 0.9^{b}
Wet	Outdoor	*P.australis*	77.7 ± 0.9^{ab}	22.0 ± 0.6^{c}	235.2 ± 0.5^{b}	416.7 ± 0.9^{b}

Note. Superscripts indicate statistical differences: values sharing at least one letter are not significantly different at $p < 0 .05$.

Humidity

Humidity levels showed clear seasonal and conditional variation (Table 1). In the dry season, indoor conditions supported higher relative humidity for *P. ostreatus* and *P. australis* compared to outdoor setups. These differences were significant, highlighting the drying effect of direct exposure outdoors during the hot season.

In contrast, during the wet season, humidity levels were considerably higher across all treatments, ranging from 77.0–79.8%. Importantly. Although statistical analysis indicated significant differences between *P. ostreatus* and *P. australis* during the wet season, the magnitude of these differences was small and largely within the associated standard error margins. This suggests that the observed significance is likely influenced by increased day-to-day variability in microclimatic conditions rather than a biologically meaningful divergence in average environmental conditions between the two species. Consequently, while distributional differences were detected statistically, the similarity in mean values indicates that both species experienced comparable microclimatic environments during the wet season. The canopy effect can be attributed to the large leaf area of bananas, which intercepts rainfall and dew, reduces wind-driven moisture loss, and enhances localized humidity through transpiration. These processes minimize fluctuations in relative humidity around the cultivation bags, especially during the wet season when ambient moisture is already high. Thus, while indoor systems provided stable humidity control, the outdoor banana canopy offered a natural equivalent without the need for artificial humidification.

Pleurotus species are known to perform optimally under moderate temperatures (20–30 °C), high relative humidity (70–90%), low but sufficient light intensity (approximately 200–500 lux), and carbon dioxide concentrations below 1,000 ppm during fruiting (Kashangura, 2012). The microclimatic conditions recorded in both indoor and banana-canopy systems during the wet season fell within these established physiological requirements, indicating that the observed differences between species occurred under generally suitable and non-limiting environmental conditions (Blomme et al., n.d.; Kamaliah et al., 2022).

Temperature

Temperature varied significantly across seasons and conditions (Table 1). In the dry season, outdoor conditions recorded the highest values, compared to indoor. In the wet season, however, temperatures were lower and more stable, ranging between 20.9–22.0 °C across all treatments. Notably, the last four treatments (wet season, both indoor and outdoor for the two species) did not differ significantly, indicating that outdoor conditions under banana canopy were statistically similar to indoor environments in controlling temperature.

This observation highlights the buffering capacity of the banana canopy. During the dry season, outdoor setups recorded higher temperatures than indoor systems, reflecting stronger solar radiation and heat accumulation. Nevertheless, the broad banana leaves intercepted direct radiation and, through transpiration-driven cooling, mitigated excessive heating around the cultivation bags. As a result, while absolute values were slightly higher outdoors, the canopy substantially reduced the difference relative to fully indoor setups.

In the wet season, when ambient conditions were cooler and more humid, the banana canopy's microclimate regulation became even more evident. Since no significant differences were observed between indoor and outdoor setups, the canopy effectively mimicked the stable environment usually associated with controlled indoor conditions. This convergence suggests that under favorable seasonal conditions, banana-based systems can provide natural thermal regulation comparable to artificial enclosures, thus serving as a low-cost, climate-smart alternative (Kashyap et al., 2022; Blazy et al., 2009).

Light Intensity

The results showed clear differences in light intensity across seasons and environments (Table 1). Outdoor conditions, particularly under banana canopies, recorded higher light intensities compared to indoor setups. During the dry season, outdoor values peaked at 246.5 lux, while indoor conditions remained lower and more stable, averaging around 211 lux. In the wet season, overall light intensity decreased due to increased cloud cover, with outdoor values remaining consistently higher than indoors.

Biologically, light acts as a critical environmental cue for mushroom morphogenesis, particularly for primordia initiation and cap development, although it is not essential for vegetative mycelial growth. *Pleurotus* species are known to require only low light levels (≈2–10 $\mu mol\ m^{-2}\ s^{-1}$, equivalent to 200–500 lux) as noted by De Bonis et al., (2024) and Medany, (2014). Our observed values (202–246 lux) were in line with this threshold, indicating that both indoor and outdoor environments provided adequate illumination.

The role of the banana canopy is particularly noteworthy. By filtering direct solar radiation, the canopy reduced excessive light exposure that could otherwise desiccate the substrate, while still allowing sufficient illumination. This shading effect created a moderated and stable light environment outdoors, contrasting with the slightly lower but more uniform indoor values. Such canopy-mediated moderation aligns with earlier reports that natural shading balances the trade-off between illumination and stress (Valladares et al., 2016).

While microclimate is primarily determined by external environmental factors, it was hypothesized that different *Pleurotus* species might indirectly influence local microclimatic conditions through physiological activity, particularly CO_2 production and moisture dynamics, although to a limited extent.

In summary, outdoor banana canopies provided moderate but sufficiently high light intensities across seasons. This suggests that natural canopy shading can effectively mimic the stable illumination of indoor systems thereby demonstrating its value as a passive microclimate regulator.

Carbon Dioxide Concentration

The results revealed significant differences in CO_2 concentrations across seasons and environments (Table 1). Indoor conditions consistently recorded higher CO_2 levels (454.8–455.3 ppm) compared to outdoor setups (412.6–416.8 ppm). These differences were evident in both dry and wet seasons.

From a biological standpoint, CO_2 concentration is a critical environmental signal for fungal physiology (Gunko et al., 2021). During mycelial colonization, as shown in table 2, elevated CO_2 can promote vegetative growth, whereas fruiting initiation and normal morphology are favored at lower concentrations, typically below 1,000 ppm. The values observed in this study ranging between 413ppm and 455 ppm were well below inhibitory thresholds, indicating that both indoor and outdoor environments provided atmospheres suitable for development.

Nevertheless, the consistent accumulation of higher CO_2 in indoors reflects limited air exchange compared to outdoor systems. By contrast, outdoor cultivation under banana canopies benefited from natural airflow and gas diffusion, which maintained CO_2 levels close to ambient atmospheric concentrations. This suggests that banana canopies, beyond regulating light and temperature, also contribute to a moderate gaseous microclimate.

Normalized Profiling of Key Environmental Factors in Mushroom Cultivation Systems

The chart figure one compares the normalized values of four environmental factors humidity, temperature, light intensity, and carbon dioxide across eight different mushroom cultivation conditions. Each condition represents a unique combination of moisture level (dry or wet), location (indoor or outdoor), and species (*Pleurotus ostreatus* or *Pleurotus australis*). By normalizing the data, the chart allows for direct comparison of how each environmental variable contributes to the overall growth conditions. The visualization highlights that wet environments generally have higher humidity and lower temperatures, while dry conditions tend to have higher temperatures and light intensity, providing insights into the distinct environmental profiles required for optimal mushroom growth.

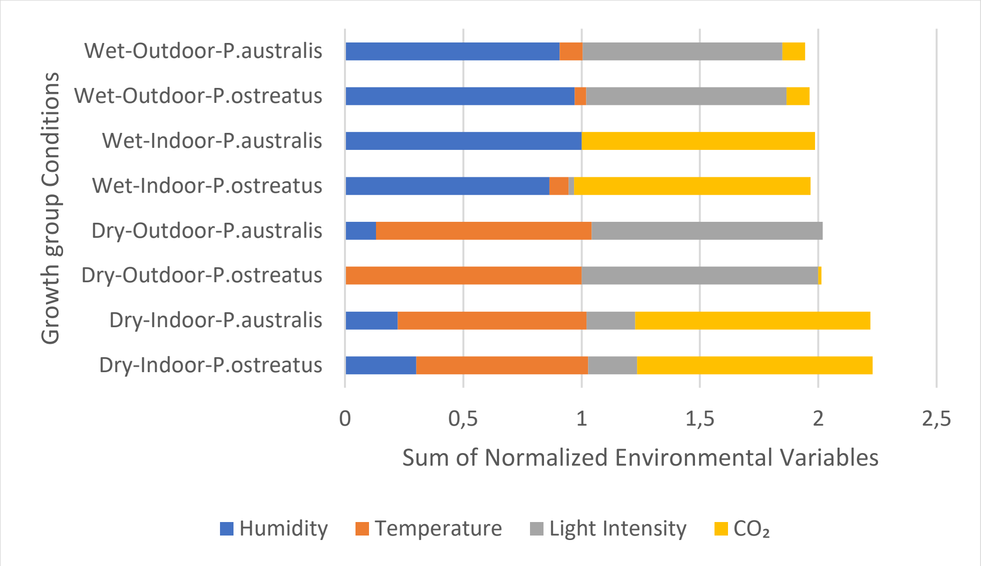

Figure 1: Normalized Stacked Bar Chart Showing Environmental Conditions in Various Mushroom Growth Setups

Combined Influence of Season, Cultivation Environment, and Species on Mushroom Yield and Quality Parameters.

Following the observed differences in microclimatic conditions between cultivation environments and seasons, mushroom yield and quality parameters were assessed to evaluate the biological response of the species to these conditions. Yield performance and quality traits varied across environments, seasons, and species, reflecting the influence of temperature, relative humidity, light intensity, and carbon dioxide concentration on mushroom growth and development.

Table 2: Least Square Means Comparisons of Mycelium Development, Incubation Time and Fruiting Phase

SEASON× CONDITION × SPECIES	MYCELIUM SIZE (CM)	INCUBATION TIME (DAYS)	FRUITING PHASE (DAYS)
Wet×Indoor×*P.ostreatus*	4.0 ± 1.4^{b}	44.7 ± 1.2^{b}	94.6± 2.4 ^{ce}
Wet×Indoor×*P.australis*	8.3 ± 1.4^{b}	46.6 ± 1.2^{b}	97.5 ± 2.4^{bcd}
Wet×Outdoor×*P.ostreatus*	32.3 ± 1.4^{a}	22.2 ± 1.2^{c}	71.3 ± 2.4^{ef}
Wet×Outdoor×*P.australis*	28.0 ± 1.4^{a}	24.3 ± 1.2^{c}	68.5± 2.4^{de}
Dry×Indoor×*P. ostreatus*	4.2 ± 1.4^{b}	112.8 ± 1.2^{a}	126.4 ± 2.4^{a}
Dry×Indoor×*P. australis*	0.1± 1.4^{b}	110.9 ± 1.2^{a}	123.6 ± 2.4^{ab}
Dry×Outdoor×*P.ostreatus*	2.4 ± 1.4^{b}	112.4 ± 1.2^{a}	114.8 ± 2.4^{abc}
Dry×Outdoor×*P.australis*	6.7 ± 1.4^{b}	114.3 ± 1.2^{a}	117.6± 2.4^{abc}

Table 3: Least Square Means Comparisons of Stalk Length, Cap Diameter, Number of Fruits, Number of Deformities, Contamination Levels and Biological Efficiency (%)

Season × Condition × Species	Stalk Length (cm)	Cap Diameter (cm)	Number of Fruits	Number of Deformities	Contamination Levels (%)	Biological Efficiency (%)
Wet × Indoor × *P.australis*	2.2 ± 0.2^{c}	7.2 ± 0.4^{b}	28.0±1.6^{ab}	2.3 ± 0.8^{b}	2.3 ±1.4^{b}	267.4±13.6^{b}
Wet × Indoor × *P. ostreatus*	2.5 ± 0.2^{bc}	6.1 ± 0.4^{b}	30.0±1.6^{ab}	0.4 ± 0.8^{b}	0.4 ±1.4^{b}	223.8±13.6^{ba}
Wet ×Outdoor × *P. ostreatus*	2.5 ±0.2^{bc}	13.1 ± 0.4^{a}	38.2 ±1.6^{a}	14.0 ±0.8^{a}	0.3 ±1.4^{b}	693.8 ±13.6^{a}
Wet ×Outdoor × *P. australis*	2.8 ±0.2^{abc}	12.8 ±0.4^{a}	31.3 ± 1.6^{ab}	12.3 ± 0.8^{a}	1.3 ±1.4^{b}	670.8 ±13.6^{a}
Dry × Indoor × *P. ostreatus*	1.8 ±0.2^{c}	5.0 ± 0.4^{b}	16.8±1.6^{bc}	1.3 ± 0.8^{b}	14.0±1.4^{a}	133.3 ±13.6^{cd}
Dry × Indoor × *P. australis*	2.1 ±0.2^{c}	4.7 ± 0.4^{b}	10.2 ±1.6^{c}	0.3 ± 0.8^{b}	12.3±1.4^{a}	110.4 ±13.6^{d}
Dry ×Outdoor ×*P. ostreatus*	3.3±0.2^{ab}	7.44 ± 0.4^{b}	29.3±1.6^{ab}	11.4 ± 0.8^{a}	11.4±1.4^{b}	200.7±13.6^{bcd}
Dry ×Outdoor ×*P. australis*	3.6 ± 0.2^{a}	6.2 ± 0.4^{b}	31.5±1.6^{ab}	9.6 ± 0.8^{a}	9.6 ±1.4^{a}	157.1±13.6^{bcd}

Table 4 shows how the interaction of seasons, conditions, and Pleurotus species influenced yield of oyster mushroom.

Season × Condition × Species	Yields
Dry ×Indoor× *P.ostreatus*	276.50 ± 82.85^{bcde}
Dry× Indoor × *P.australis*	480.98 ± 82.85^{bef}
Dry × Outdoor× *P.ostreatus*	1291.25 ± 82.85^{bd}
Dry ×Outdoor × *P.australis*	689.22 ± 82.85^{cef}
Wet × Indoor × *P.ostreatus*	1620.12 ± 82.85^{b}
Wet × Indoor ×*P.australis*	970.96 ± 82.85^{bef}
Wet× Outdoor ×*P.ostreatus*	2582.01 ± 82.85^{a}
Wet ×Outdoor × *P.australis*	1411.88 ± 82.85 ^{abc}

Conclusions

This study offers valuable insights into how banana-based agroforestry systems can benefit society, particularly in promoting sustainable and low-cost mushroom cultivation. By demonstrating that banana canopies effectively regulate crucial environmental factors like humidity, temperature, light, and CO_2, the study presents an alternative to traditional indoor cultivation, which often requires significant energy inputs for climate control. As such, it provides an environmentally friendly solution to reduce energy consumption and the carbon footprint associated with indoor farming systems.

For rural and resource-limited communities, integrating mushrooms into banana agroforestry systems could offer a dual benefit enhancing food security while providing a sustainable income source. Mushrooms are highly nutritious, and growing them in banana plantations maximizes land use and offers a low-cost cultivation method with minimal reliance on artificial resources. Moreover, this practice supports biodiversity and sustainable land management by encouraging natural shade and reducing the need for chemical inputs, which can harm the environment.

Additionally, the findings can help small-scale farmers and communities adapt to climate change. As banana canopies buffer temperature extremes and enhance microclimate stability, they offer a practical solution to the challenges posed by fluctuating weather patterns, ensuring more reliable crop yields. Overall, the study promotes sustainable agriculture that could lead to greater food sovereignty, economic resilience, and environmental stewardship, benefiting society at large.

Institutional Review Board Statement

This mushroom-banana integrated cultivation study received ethical approval from Masinde Muliro University Institutional Scientific and Ethics Review Committee (MMUST-ISERC). The approval, designated by the code MMUST/IERC/141/2023, was valid from March 14th, 2023, to March 14th, 2024. The research, which focused on edible mushroom-banana integration as an alternative plant shelter, was reviewed and approved under the university's strict ethical guidelines, ensuring all aspects of the study adhere to established scientific and ethical standards.

Acknowledgments

The authors wish to thank Masinde Muliro University of Science and Technology for offering us the space and permission to conduct this research.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

References

Adebayo, E., & Martinez-Carrera, D. (2015). Oyster mushrooms (Pleurotus) are useful for utilizing lignocellulosic biomass. African Journal of Biotechnology, 14(1), 52–67. DOI 10.5897/AJB2014.14249

Almeida, D., Cardoso, R. V., Pereira, C., Alves, M. J., Ferreira, I. C., Zied, D. C., Junior, W. G. V., Caitano, C. E., Fernandes, Â., & Barros, L. (2022). Biochemical approaches on commercial strains of Agaricus subrufescens growing under two environmental cultivation conditions. Journal of Fungi, 8(6), 616. DOI: 10.3390/jof8060616

Blazy, J.-M., Dorel, M., Salmon, F., Ozier-Lafontaine, H., Wery, J., & Tixier, P. (2009). Model-based assessment of technological innovation in banana cropping systems contextualized by farm types in Guadeloupe. European Journal of Agronomy, 31(1), 10–19. https://doi.org/10.1016/j.eja.2009.02.001

Blomme, G., Ntamwira, J., Kearsley, E., Bahati, L., Amini, D., Safari, N., & Ocimati, W. (2020). Sensitivity and tolerance of different annual crops to different levels of banana shade and dry season weather. Frontiers in Sustainable Food Systems, 4, 545926. https://doi.org/10.3389/fsufs.2020.545926

Blomme, G., Ocimati, W., Groot, J., Ntamwira, J., Bahati, L., & Kantungeko, D. (n.d.). Agroecological integration strategies for optimal exploitation of available land spaces under banana. Sustainability of Banana-Based Agroecosystems Affected by Xanthomonas Wilt Disease of Banana,181.https://doi.org/10.17660/ActaHortic.2018.1196.5

Bringye, B., Fekete-Farkas, M., & Vinogradov, S. (2021). An analysis of mushroom consumption in Hungary in the international context. Agriculture, 11(7), 677. https://doi.org/10.3390/agriculture11070677

De Bonis, M., Locatelli, S., Sambo, P., Zanin, G., Pecchia, J. A., & Nicoletto, C. (2024). Effect of different led light wavelengths on production and quality of Pleurotus ostreatus grown on different commercial substrates. Horticulturae, 10(4), 349. DOI 10.3390/horticulturae10040349

De Cianni, R. (2025). Developing a mushroom supply chain for food purposes in the European perspective: Companies’ competitiveness and consumer behaviour. https://hdl.handle.net/20.500.14242/218333

Devi, K. B., Malakar, R., Kumar, A., Sarma, N., & Jha, D. K. (2023). Ecofriendly utilization of lignocellulosic wastes: Mushroom cultivation and value addition. In Value-addition in agri-food industry waste through enzyme technology (pp. 237–254). Elsevier. https://doi.org/10.1016/B978-0-323-89928-4.00016-X

Gunko, S., Trynchuk, O., Naumenko, O., Podpriatov, H., Khomichak, L., Bober, A., Zavhorodnii, V., Voitsekhivskyi, V., Zavadska, O., & Bondareva, L. (2021). The effect of carbon dioxide on the quality of the mushrooms. Slovak Journal of Food Sciences, 15. https://doi.org/10.5219/1634

Kamaliah, N., Salim, S., Abdullah, S., Nobilly, F., Mat, S., Norhisham, A. R., Tohiran, K. A., Zulkifli, R., Lechner, A. M., & Azhar, B. (2022). Evaluating the experimental cultivation of edible mushroom, Volvariella volvacea underneath tree canopy in tropical agroforestry systems. Agroforestry Systems, 96(1), 35–47. https://doi.org/10.1007/s10457-021-00685-9

Kashangura, C. (2012). Optimisation of the growth conditions and genetic characterisation of Pleurotus species.

MEDANY, G. M. (2014). Cultivation possibility of golden oyster mushroom (Pleurotus citrinopileatus) under the Egyptian conditions. Egyptian Journal of Agricultural Research, 92(2), 749–762. https://doi.org/10.21608/ejar.2014.155474

Pathmashini, L., Arulnandhy, V., & Wijeratnam, R. (2008). Cultivation of oyster (Pleurotus ostreatus) mushroom on sawdust with different types of spawns. DOI: 10.4038/cjsbs.v37i2.505

Patil, S., Chonde, S., & Pathade, G. (2024). Production of mushrooms: A short Review. Ecology, Environment and Conservation, 30, 296–304.

Raman, J., Jang, K.-Y., Oh, Y.-L., Oh, M., Im, J.-H., Lakshmanan, H., & Sabaratnam, V. (2021). Cultivation and nutritional value of prominent Pleurotus spp.: An overview. Mycobiology, 49(1), 1–14. DOI: 10.1080/12298093.2020.1835142

Tanny, J. (2013). Microclimate and evapotranspiration of crops covered by agricultural screens: A review.Biosystems Engineering, 114(1), 26–43. DOI: 10.1016/j.biosystemseng.2012.10.008

Valladares, F., Laanisto, L., Niinemets, Ü., & Zavala, M. A. (2016). Shedding light on shade: Ecological perspectives of understorey plant life. Plant Ecology & Diversity, 9(3), 237–251. DOI: 10.1080/17550874.2016.1210262