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*Research Article*

# Quality Parameters of Oyster Mushroom (*Pleurotus* Spp.) Under Outdoor Banana Integration Versus Indoor Cultivation

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**Abstract:**

Mushroom cultivation is traditionally practiced indoors under controlled environments, but this method can be costly and land-demanding. This study investigated the effect of outdoor banana integration versus indoor cultivation on the quality parameters of oyster mushrooms (*Pleurotus ostreatus* and *Pleurotus australis*) in Kakamega County, Kenya. A quasi split–split plot design was adopted with two seasons (wet and dry), two cultivation systems (indoor and outdoor under banana canopy), and two genotypes. Quality indicators including mycelial growth rate, incubation time, cap diameter, stalk length, number of fruits, level of contamination, and biological efficiency were measured and analyzed using SAS univariate ANOVA. Results revealed significant differences in mushroom quality between cultivation systems and seasons. Outdoor integration under banana canopies during the wet season enhanced performance of *P. ostreatus*, yielding faster mycelial growth, shorter incubation periods, larger cap diameters, lower contamination rates, and higher biological efficiency compared to indoor cultivation. In contrast, *P. australis* performed poorly under indoor dry season conditions. The findings demonstrate that banana–mushroom integration provides favorable microclimatic conditions that enhance the quality of oyster mushrooms, presenting a low-cost and sustainable alternative to indoor sole cultivation systems.

## 1. Introduction

Mushrooms are increasingly recognized as an important source of food, medicine, and income owing to their high nutritional value, medicinal properties, and low production costs (Niazi and Ghafoor, 2021; Thakur, 2020; Ferdousi et al., 2020). Oyster mushrooms (*Pleurotus* spp.) are among the most widely cultivated species globally due to their adaptability to diverse substrates, rapid growth, and resistance to competitor organisms (El-Ramady, 2022; Raman et al., 2021; Adebayo and Martinez, 2015). They are rich in proteins, vitamins, minerals, and dietary fiber, making them valuable for combating malnutrition, particularly in regions with limited access to animal protein (Losoya et al., 2025; Pandey et al., 2022).

Traditionally, mushrooms are cultivated indoors under controlled environments such as mushroom houses (Ten et al., 2021), tunnels (Rangnamei et al., 2025), or greenhouses (Samseemoung et al., 2024), where temperature, humidity, light, and carbon dioxide levels can be regulated. While indoor systems ensure consistency, they are often costly (Basiri et al., 2017), labor-intensive (Rowley, 2009), and limited by land scarcity (Chang and Wasser, 2017). In many smallholder settings such as Western Kenya, diminishing farm sizes (Tittonell, 2005) and rising input costs (Ariffin et al., 2020), present challenges to sustaining indoor mushroom cultivation.

Integration of mushrooms into existing cropping systems presents a sustainable alternative (Dou et al., 2025). According to Blomme et al. (2016) and Wairegi et al. (2014), banana plantations which are common among smallholder farmers in East Africa, provide a natural shaded environment. Their canopies reduce excessive solar radiation, stabilize soil moisture, and maintain cooler microclimates, potentially creating favorable conditions for other crops to thrive. However, before this study was done, little was known about outdoor banana–mushroom integration system and its effects on key quality parameters of oyster mushrooms compared to conventional indoor systems.

Quality in mushroom production is determined by factors such as mycelial growth rate, incubation time, cap diameter, stalk length, number of fruiting bodies, biological efficiency, and contamination levels (Bandura et al., 2020). These parameters directly influence market acceptability, yield, and profitability (Galano and Santos, 2024). While some of these studies have examined the yield and economics of mushroom cultivation, few have systematically compared the quality performance of oyster mushroom genotypes under integrated outdoor versus indoor systems across different seasons.

This study therefore aimed to evaluate the quality parameters of two oyster mushroom genotypes (*Pleurotus ostreatus* and *Pleurotus australis*) grown under banana-based outdoor integration and indoor sole cultivation systems in Kakamega County, Kenya. Findings from this study provide insights into sustainable mushroom production strategies that optimize quality, optimize land use while reducing production costs for smallholder farmers.

## 2. Materials and Methods

### 2.1. Study Site

The experiment was conducted at Masinde Muliro University farm in Lurambi Sub-County, Kakamega County, Kenya. The area has a tropical rainforest climate with bimodal rainfall (peaks in April and August) and average temperatures ranging from 18–29 °C. The county's humid environment provides favorable conditions for mushroom production.

### 2.2. Experimental Materials

Two oyster mushroom genotypes (*Pleurotus ostreatus* and *Pleurotus australis*) were obtained from a certified spawn supplier in Nairobi. Substrates were prepared using sugarcane bagasse supplemented with chick mash, molasses, and lime. Sorghum grains were used for spawn multiplication. Mature banana plants on the farm were used to provide shaded outdoor conditions.

### 2.3. Cultivation Techniques

Spawn was prepared by inoculating sterilized sorghum grains with actively growing mycelia and incubating at 23 ± 2 °C for 21 days. Substrates were sterilized by steaming for 2 hours, cooled overnight, and packed into polypropylene bags. Each bag was inoculated with spawn at approximately 5% (w/w) and tightly sealed.

For indoor cultivation, inoculated bags were suspended in a mud-walled mushroom house with iron-sheet roofing. For outdoor integration, bags were suspended on wooden racks beneath banana canopies and protected with plastic covers and nets against rain and pests.

### 2.4. Experimental Design

A quasi split–split plot design was used. Seasons (wet and dry) represented the whole plots, cultivation systems (indoor vs. outdoor integration) were subplots, and mushroom genotypes were sub-subplots.

### 2.5. Data Collection

Quality parameters were monitored from spawn inoculation to harvest. The following were recorded: Mycelial growth rate (cm/day), Incubation period (days to full colonization), fructification phase (days from first harvest to last harvest), Fruiting body traits: stalk length (cm), cap diameter (cm), number of fruits, and number of deformed fruits, Level of contamination (length of infected bags), Biological efficiency (BE%) calculated as:

$$\boldsymbol{BE} = \frac{Fresh\,Weight\ of\ mushroom}{Dry\ weight\ of\ substrate} \times 100\%$$

Environmental conditions (temperature, relative humidity, light intensity, and $CO_2$ concentration) were recorded thrice daily using a thermometer, hygrometer, lux meter, and $CO_2$ sensor.

### 2.6. Statistical Analysis

Data were subjected to univariate analysis of variance (ANOVA) using SAS software (version 9.4). Means were separated using least square means (LSM) tests at 5% significance level.

## 3. Results

### 3.1. Mycelial Growth and Incubation

Table 1 summarizes the growth parameters of oyster mushrooms, including mycelium size, incubation time, and fructification phase, under different seasons, conditions, and genotypes, with values expressed as means ± standard errors (SE).

Significant differences were observed in mycelial growth rates and fructification phase between cultivation systems and seasons. *Pleurotus ostreatus* under outdoor banana integration during the wet season exhibited the fastest mycelial growth and shortest incubation period. By contrast, *P. australis* under indoor dry season conditions recorded the slowest growth and prolonged incubation (> 30 days). These findings suggest that the shaded microclimate beneath banana canopies provided stable humidity and moderated temperatures, which are favorable for rapid colonization. Similar observations were reported by Abdel et al. (2018), who noted temperature and humidity as critical determinants of vegetative growth in oyster mushrooms.

**Table 1.** Growth and incubation traits of oyster mushrooms under different cultivation systems and seasons

| Season | Condition | Genotype | Mycelium Size (cm) | Incubation Time (days) | Fructification Phase (days) |
|---|---|---|---|---|---|
| Wet | Indoor | *P. ostreatus* | $4.0 \pm 1.4^{b}$ | $44.7 \pm 1.2^{b}$ | $94.6^{ce}$ |
| Wet | Indoor | *P. australis* | $8.3 \pm 1.4^{b}$ | $46.6 \pm 1.2^{b}$ | $97.5 \pm 2.4^{bcd}$ |
| Wet | Outdoor | *P. ostreatus* | $32.3 \pm 1.4^{a}$ | $22.2 \pm 1.2^{c}$ | $71.3 \pm 2.4^{ef}$ |
| Wet | Outdoor | *P. australis* | $28.0 \pm 1.4^{a}$ | $24.3 \pm 1.2^{c}$ | $68.5 \pm 2.4^{de}$ |
| Dry | Indoor | *P. ostreatus* | $4.2 \pm 1.4^{b}$ | $112.8 \pm 1.2^{a}$ | $126.4 \pm 2.4^{a}$ |
| Dry | Indoor | *P. australis* | $0.1 \pm 1.4^{b}$ | $110.9 \pm 1.2^{a}$ | $123.6 \pm 2.4^{ab}$ |
| Dry | Outdoor | *P. ostreatus* | $2.4 \pm 1.4^{b}$ | $112.4 \pm 1.2^{a}$ | $114.8 \pm 2.4^{abc}$ |
| Dry | Outdoor | *P. australis* | $6.7 \pm 1.4^{b}$ | $114.3 \pm 1.2^{a}$ | $117.6 \pm 2.4^{abc}$ |

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

Figure 1 graphical representation complements the summary in Table 1 by providing a clearer visualization of treatment effects. The data indicates a clear inverse relationship between mycelium growth and the time-based metrics. Conditions that favor rapid mycelial colonization (like wet outdoor) lead to a shorter overall growth cycle (shorter incubation and fructification times). Conversely, conditions that inhibit initial mycelial growth (like dry indoor conditions) seem to prolong the other two phases of the cycle.

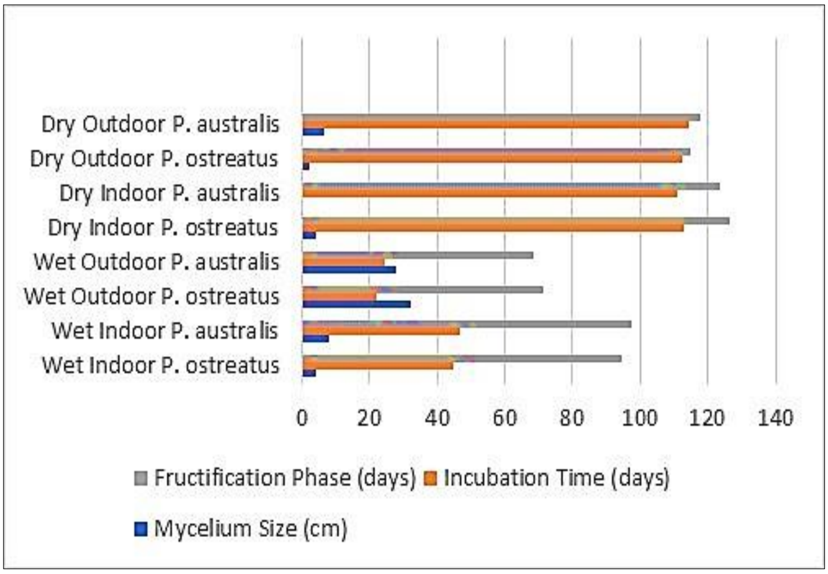


**Figure 1.** Growth parameters (mycelium size, incubation period, fructification phase) of oyster mushrooms under different seasons, conditions, and genotypes.

### 3.2. Morphological and Quality Traits

Table 2 presents the effects of season, growing condition, and genotype on the morphological characteristics, contamination levels, and biological efficiency of oyster mushrooms, with means and their corresponding standard errors (SE) shown.

**Table 2.** Morphological and quality traits of oyster mushrooms under different cultivation systems and seasons.

| Season | Condition | Genotype | Stalk Length (cm) | Cap Diameter (cm) | Number of Fruits | Number of Deformities | Contamination Levels (%) | Biological Efficiency (%) |
|---|---|---|---|---|---|---|---|---|
| Wet | Indoor | *P. ostreatus* | 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. australis* | 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* | 2.52±0.2$^{bc}$ | 13.1±0.4$^{a}$ | 38.2 ±1.6$^{a}$ | 14.0±0.83$^{a}$ | 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$^{bcd}$ |

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

Outdoor banana integration significantly improved morphological quality traits. *P. ostreatus* produced larger cap diameters (≈ 13.1 cm), shorter stalks (≈ 2.5 cm), and higher numbers of fruits compared to indoor cultivation. Indoor conditions during the dry season led to smaller caps and elongated stalks, traits that reduce consumer preference and market value. These results align with findings by Myronycheva et al. (2017), who reported that strain-specific responses to microclimatic variation strongly influence mushroom quality.

#### *3.2.1. Contamination Levels*

Contamination was markedly lower in outdoor conditions compared to indoor systems, particularly during the wet season. The natural aeration and balanced humidity under banana canopies may have reduced the buildup of competitive microorganisms that thrive in poorly ventilated indoor environments. High contamination rates indoors reflect common challenges faced by smallholder farmers lacking modern ventilation systems, as highlighted by Ghimire et al. (2021).

#### *3.2.2. Biological Efficiency (BE%)*

Biological efficiency varied across treatments, with the highest BE (≈ 693.7%) recorded in *P. ostreatus* under outdoor wet season conditions, compared to only 110.3% in *P. australis* grown indoors during the dry season. The enhanced BE in integrated systems indicates optimal substrate utilization, translating into better quality harvests. Similar trends were reported by Sobieralski et al., (2011) who demonstrated that environmental stability and substrate–genotype interactions significantly influence BE outcomes.

Figure 2 is a radar chart patterns reinforcing the observations in Table 2. The radar illustrates clear differences in mushroom quality across treatments. Outdoor cultivation, especially under wet season conditions, produced larger caps, more fruits, and higher biological efficiency, as shown by the broader spread along those axes. In contrast, indoor cultivation, particularly during the dry season, was associated with smaller fruit bodies, lower biological efficiency, and higher contamination levels, reflected by shorter radii on the respective axes. Genotypic variation was also evident, with *P. ostreatus* generally outperforming *P. australis* across most traits. Larger distances from the center indicate higher values for the corresponding trait.

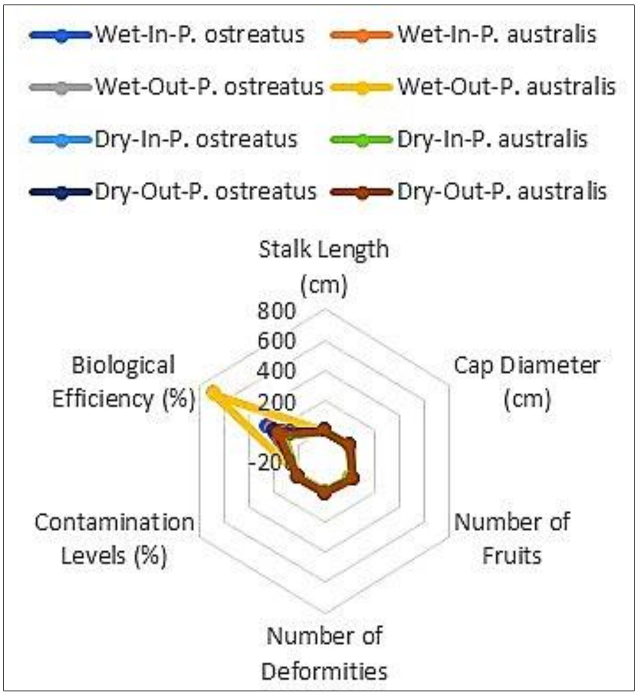


**Figure 2.** Radar chart showing the performance of oyster mushrooms (*Pleurotus ostreatus* and *P. australis*) under different seasons (wet and dry) and cultivation systems (indoor and outdoor).

## 4. Discussion

The results demonstrate that outdoor banana integration offers a viable alternative to indoor mushroom cultivation by enhancing critical quality parameters such as faster colonization, larger cap size, reduced contamination, and higher biological efficiency. These improvements are attributed to the microclimatic benefits of banana canopies, which provide natural shading, moderated temperatures, and higher relative humidity. Importantly, *P. ostreatus* consistently outperformed *P. australis*, suggesting it is better suited for integrated outdoor systems in Western Kenya.

These findings corroborate earlier intercropping studies (Hamed et al., 2021; Mohapatra and Chinara, 2014) which demonstrated that crop integration not only optimizes land use but also enhances productivity and quality. The integration of mushrooms under banana plantations thus presents an ecologically and economically sustainable approach for smallholder farmers, reducing reliance on costly indoor infrastructure while maintaining high-quality yields and maximizing limited agricultural lands.

## 5. Conclusions

This study highlights the potential of integrating mushrooms into existing cropping systems as an innovative approach for sustainable agriculture. By utilizing shaded spaces beneath banana canopies, farmers can expand mushroom production without additional land investment or heavy infrastructure costs. The integration approach also presents an opportunity to diversify farm enterprises, lower input requirements, and contribute to rural food and nutrition security.

From a research perspective, the outcomes provide a framework for exploring crop–fungus synergies in smallholder settings. This model demonstrates that microclimate management through natural crop integration can be as effective as, or superior to, conventional controlled environments. Expanding such strategies across diverse agro-ecological regions could offer scalable solutions to land scarcity and production inefficiencies.

In practice, promoting banana–mushroom integration may empower smallholder farmers by enhancing livelihoods while aligning with broader goals of sustainable intensification and climate-smart agriculture.

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**Institutional Review Board Statement**: This mushroom 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.

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

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**Conflicts of Interest**: The authors declare no conflict of interest.

**Appendix A:** Analysis of variance (ANOVA) table.

| Source of variation | Degrees of Freedom (df) |
|---|---|
| Replicate | $r-1$ |
| A | $a-1$ |
| $\boldsymbol{Error\ (a) = Rep \times A}$ | $(r-1)\,(a-1)$ |
| $\boldsymbol{B}$ | $b-1$ |
| $\boldsymbol{A \times B}$ | $(a-1)\,(b-1)$ |
| $\boldsymbol{Error(b) = Rep \times B(A)}$ | $a(r-1)\,(b-1)$ |
| $\boldsymbol{C}$ | $c-1$ |
| $\boldsymbol{A \times C}$ | $(a-1)\,(c-1)$ |
| $\boldsymbol{B \times C}$ | $(b-1)\,(c-1)$ |
| $\boldsymbol{A \times B \times C}$ | $(a-1)\,(b-1)\,(c-1)$ |
| $\boldsymbol{Error(c) = Rep \times C(A \times B)}$ | $ab(r-1)\,(c-1)$ |
| **Total** | $\boldsymbol{rabc-1}$ |

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