ENHANCING WHITE OYSTER MUSHROOM CULTIVATION THROUGH LIGHT STIMULATION USING WHITE LED

Siti Nur Fathiha Abdullah[1], Hamid Yusoff[1,*], Sh Mohd Firdaus Sh Abdul Nasir[1]

Mechanical Engineering Studies, College of Engineering, Universiti Teknologi MARA, Cawangan Pulau Pinang, Kampus Permatang Pauh, Penang, Malaysia.

[*]Corresponding email: hamidyusoff@uitm.edu.my

Article history
Received
5th May 2023
Revised
27th October 2023
Accepted
26th November 2023
Published
1st December 2023

ABSTRACT

This study aims to investigate the impact of different illumination durations on the yield of white oyster mushrooms cultivated in a controlled environment mushroom chamber, with a focus on the advantages of LED lighting over conventional lighting methods. The experiment considered various time exposures: 3, 6, 9, 12, 15, and 24 hours per day, while fluorescent light exposure for 12 hours per day served as the control group. Parameters such as mushroom weight, pileus diameter, stipe diameter, and stipe length were measured. Results indicated that the most significant fruiting bodies in terms of pileus diameter (105.76 mm) and stipe diameter (15.26 mm) were observed with a 15-hour illumination exposure. Conversely, the 12-hour exposure using fluorescent lamps resulted in the smallest pileus diameter, averaging 79.70 mm. Notably, a 3-hour exposure demonstrated the most substantial impact on yield, resulting in 182.4 g over two harvest cycles. In conclusion, treating white oyster mushrooms with white LED lighting can enhance productivity. This is primarily due to the excessive heat and higher light intensity generated by fluorescent lights, which can inhibit growth during the fruiting development stage. Therefore, adopting white LED lighting systems offers greater control over the ideal light intensity required for optimal mushroom growth

Keywords: *White LED lighting, white oyster mushrooms, mushroom growth, light duration, indoor cultivation*

1.0 INTRODUCTION

Oyster mushrooms, including white oyster mushrooms, are known for their sensitivity to environmental factors, and achieving optimal temperature and moisture conditions positively influences fruit body development and yield [1]. While grey oyster mushrooms are commonly cultivated, there is a growing interest in white oyster mushrooms among growers and food entrepreneurs. The appeal of white oyster mushrooms to food entrepreneurs lies in their desirable crunchiness when transformed into dry food products like chips and crackers [2]. With their high caloric content, carbohydrate abundance, and rich nutrient profile, mushrooms have become a sought-after crop [3]. In addition to its popularity among food entrepreneurs, white oyster mushrooms have recently garnered attention from growers for their versatility and shorter cultivation cycles compared to other mushroom varieties [4]. These qualities make them an attractive option for cultivators seeking to optimize their production processes.

Mushroom cultivation occupies around 340 hectares and involves a limited number of farmers and entrepreneurs, with Selangor region exhibiting the highest yields [5], [6]. Currently,

 DOI: https://doi.org/10.11113/jm.v46.496

per capita mushroom consumption averages 1 kilogram per year, and it is projected to reach 2.4 kilograms by 2020 [5]. As population increases and health consciousness grows, the demand for mushrooms is expected to rise significantly.

However, Malaysia faces the challenge of inadequate mushroom supply to meet domestic needs, as the current output falls short [7]. Furthermore, white oyster mushrooms, a popular variety, exhibit relatively slow growth [8]. To address these issues, a novel approach has emerged, involving the use of specific lighting conditions to stimulate the fruiting body production of white oyster mushrooms [9]. Light exposure has been shown to trigger and enhance mushroom growth, offering a potential solution for accelerating cultivation.

In this study, we investigate the effects of white LED lighting with varying durations on the growth of white oyster mushrooms. The duration time exposure of LED lightings plays a significant role in determining the growth and development of white oyster mushrooms. By optimizing the lighting conditions and exploring different duration time exposures, we aim to improve yield and efficiency in mushroom production, thereby meeting the increasing demand and addressing supply challenges in Malaysia. The findings of this research can contribute to the development of sustainable and effective cultivation practices for white oyster mushrooms, benefiting both farmers and consumers.

The study also explores the implementation of LED lighting systems to enhance mushroom cultivation processes. To better understand the impact of lighting on the growth of white oyster mushrooms, it is important to delve into the anatomical structure of these mushrooms. The mushroom comprises three primary parts: the stipe, the cap, and the pileus[10]. The stipe, also known as the stem[11], provides structural support to the mushroom and connects the cap to the substrate. The cap, which is often umbrella-shaped, expands to expose the gills underneath [12], [13]. These gills house the mushroom's spores, which are released [14] into the environment for reproduction. The pileus refers to the upper surface of the cap [15], which protects the delicate gills and aids in the dispersal of spores. Understanding these anatomical features is crucial for comprehending how light exposure can influence the growth patterns and development of white oyster mushrooms.

Moreover, the mechanical engineering facet extends to the design and implementation of the mushroom chamber itself. Achieving precise control over environmental factors, including temperature and humidity, is paramount for successful mushroom cultivation. The chamber's cooling system, air circulation mechanisms, and irrigation systems all constitute critical components of the cultivation process[16]. By incorporating mechanical engineering principles, we aim to establish an efficient and controlled environment that maximizes mushroom growth.

2.0 METHODOLOGY

2.1 Experimental Setup

In this study, the cultivation of white oyster mushrooms was carried out in an open-circuit mushroom chamber, which incorporated a mechanical engineering system for environmental control. The chamber has a rectangular shape with measures 1.04 m in width by 1.2 m in height and overall length of 1.35 m. In addition, there are six sections in the mushroom chamber designated with one white LED light in each section with varying time periods. This chamber was equipped with an evaporative cooling pad system (Figure 1), designed to regulate temperature and humidity conditions.

 DOI: https://doi.org/10.11113/jm.v46.496

(a) (b) (c)

Figure 1: Images of the mushroom chamber with evaporative cooling pad system: (a) front; (b) left; (c) right

The cooling pad, composed of cellulose and measuring 150 mm in thickness with a surface area of 1.0 x 0.6 m² (Figure 2), was strategically positioned on the left side of the chamber. To effectively reduce heat inside the chamber, a 6-inch exhaust fan was placed opposite the cooling pad in each treatment partition. The airflow velocity was maintained at 0.3 m/s, with an air volume of 0.0683 m³/s. The air velocity in the mushroom chamber was calculated using the formula:

$$\text{Volume of air} = \text{cross-sectional area x air velocity} \quad (1)$$

Figure 2: The cellulose pad, manufactured by CELdek brand

An irrigation pipe with a valve was used to spray water onto the cooling pad at a steady flow rate in order to maintain uniform moisture distribution. An electric submersible water pump facilitated the transport of water from the tank to the cooling pad, with excess water draining out through a bottom drain.

Temperature and humidity measurements were conducted using a Benetech GM1365 digital humidity and temperature data logger, which offered an accuracy of 2°C. Data loggers were strategically placed inside and outside the chamber, 1 m away from the cooling pads. Prior to the experiments, temperature and humidity readings were recorded to verify the proper functioning of the system. The cooling pads were soaked for 24 hours to ensure complete saturation before the start of the experiment.

 DOI: https://doi.org/10.11113/jm.v46.496

A waiting period of at least 10 minutes was observed to allow for equilibrium between the room air conditions and the cooling pad before placing the mushroom block samples. Steady-state conditions were confirmed by monitoring temperature and humidity at the inlet and outlet of the cooling pads. The environmental conditions within the mushroom chamber were maintained at 21±4°C and a relative humidity of 92.5±2.5% (Table 1). The experimental setup is illustrated in Figure 3.

Table 1: Mushroom chamber's performances

Parameter	Value
Air velocity (m/s)	0.3
Inside temperature (°C)	17 – 25
Outside temperature (°C)	27 – 30
Inside relative humidity (%)	90 – 95
Outside relative humidity (%)	70 – 80
Pad water usage flow rate (L/min)	13.3

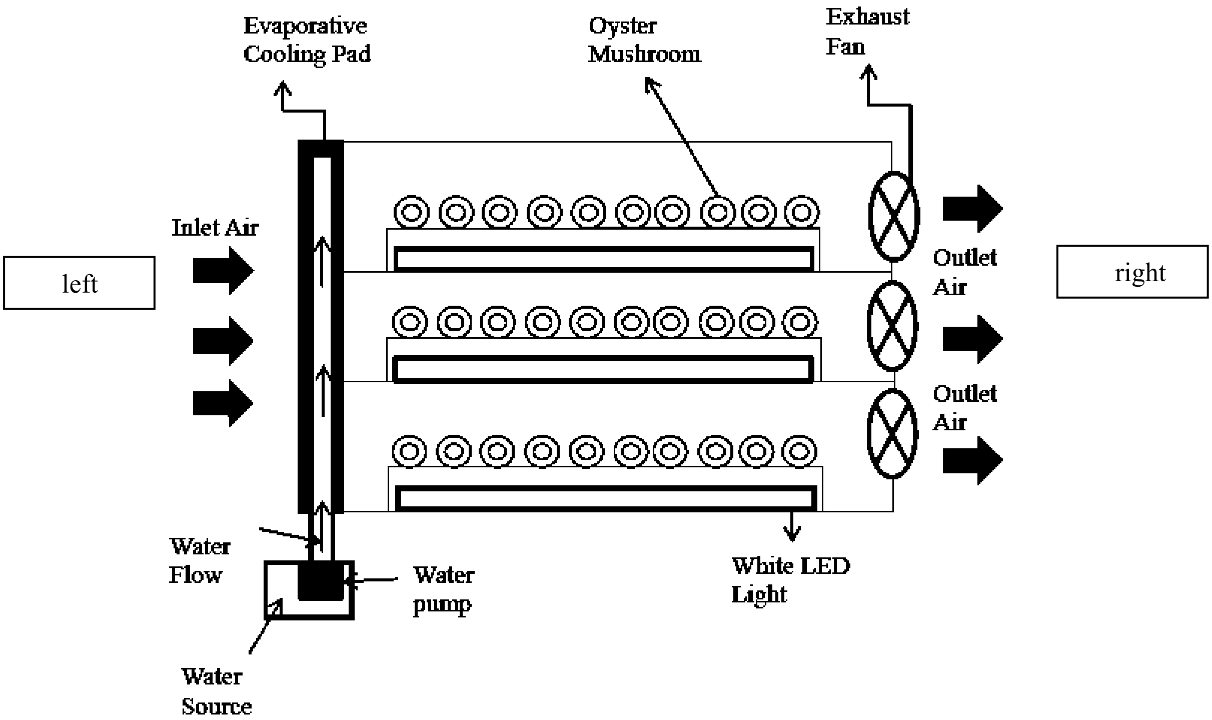

Figure 3: Schematic diagram of mushroom chamber

The cooling efficiency (η) of the cooling pad was determined using the formula:

$$\eta = [T_{db,i} - T_{db,o}]/[T_{\omega,i} - T_{wb,i}] \cdot 100 \quad (2)$$

In this equation, $T_{wb,i}$ represents the wet-bulb temperature, while $T_{db,i}$ and $T_{db,o}$ indicate the temperatures of the dry bulb inside and outside the air, respectively. The cooling pad, with a thickness of 150 mm, demonstrated a maximum effectiveness of 99% (as depicted in Figure 4), indicating successful temperature control and maintenance within the mushroom chamber. This outstanding level of efficiency signifies the successful temperature control and maintenance achieved within the confines of the mushroom chamber, showcasing the synergy between the cooling system and the chamber's environmental parameters.

DOI: https://doi.org/10.11113/jm.v46.496

The close integration of the cooling system with the mushroom chamber has yielded impressive results, ensuring that the chamber's interior environment remains consistently conducive to white oyster mushroom cultivation. This level of precision is essential, as even slight deviations in temperature and humidity can significantly impact mushroom growth and overall yield. Hence, the demonstrated 99% effectiveness underscores the practicality and robustness of this integrated cooling system, affirming its suitability for supporting optimal mushroom cultivation conditions.

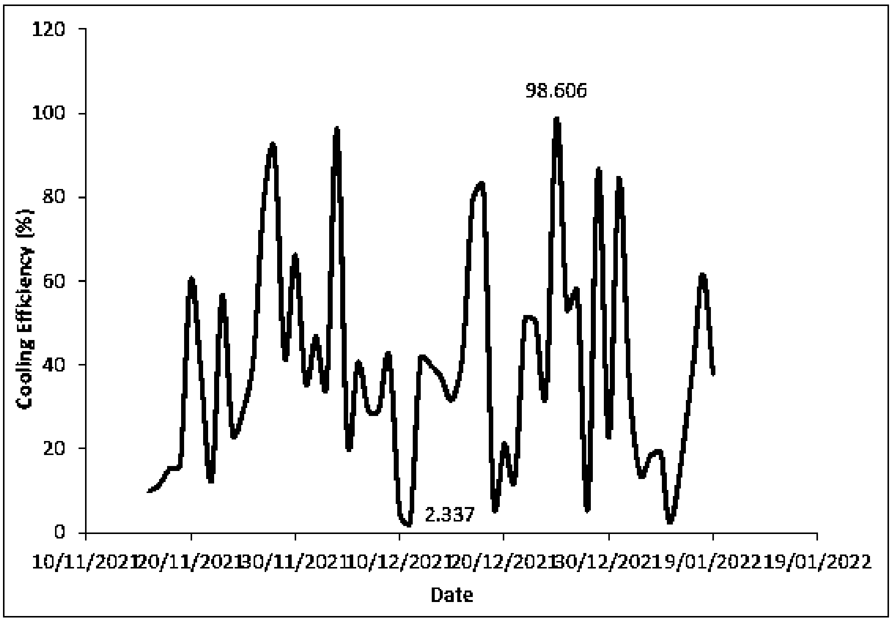

Figure 4: Graph of cooling efficiency for the mushroom chamber

2.2 Parameters Setup and Procedures

Six T5 LED tube lights (Table 2) with a white colour output of 1400 lm were installed in the mushroom chamber to provide appropriate lighting for mushroom growth (Figure 5). The fluorescent light (12-Hour) served as the control group in the experiment. Each of the ten fully-mycelial mushroom blocks was placed in separate partitions and exposed to different durations of light per day (3, 6, 9, 12, 15, and 24 hours). A digital timer was used to regulate the duration, and the light source was positioned at a distance of 15 cm from the front of the mushroom blocks.

Table 2: Specification of T5 white LED tube light

Specification	Value (unit)
Voltage	240 V
Power	14 W
Lumen	1400 lm
Intensity	700 lux

DOI: https://doi.org/10.11113/jm.v46.496

Figure 5: The mushroom chamber with samples

Upon complete colonization of the blocks by mycelium, the caps of the white oyster mushroom blocks were opened to allow for exposure to the LED light, promoting pin-head emergence and fruiting induction. After the growth period, the harvesting process involved removing fully developed fruiting bodies from the substrate blocks. The blocks were then sealed with a cap and left for the next fruiting cycle, allowing a seven-day interval. The total fresh weight of the harvested fruiting bodies from the two cycles was measured using a digital scale and recorded in grams (g).

Furthermore, to assess the physical characteristics of the mushrooms, such as pileus diameter, stipe diameter, and stipe length, the largest and smallest fruiting bodies were selected. Figure 6 depicts the flush from a mushroom block. The data obtained from each test were analysed using the mean and standard deviation (n=10). The statistical significance between the means of different groups was determined to allowing for the evaluation of the effects of different duration time exposures of LED lightings on the growth of white oyster mushrooms.

 DOI: https://doi.org/10.11113/jm.v46.496

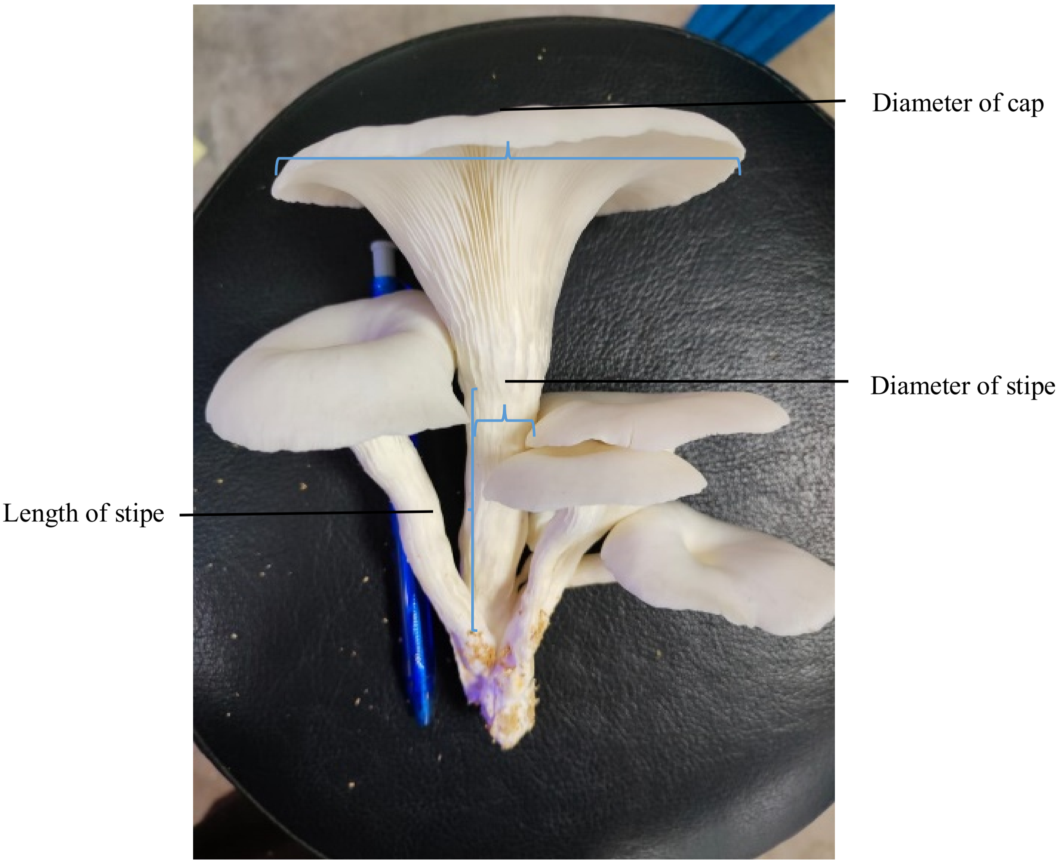

Figure 6: Anatomy of mushroom flush

3.0 RESULTS AND DISCUSSION

3.1 Yield Assessment

The production of white oyster mushrooms was collected for two harvesting cycles to assess the yield. In this experiment, different durations of light exposure were tested to assess their impact on yield, the number of fruiting bodies, and biological efficiency. The results indicate variations in these parameters among the samples. Among the examined samples, the 3-Hour sample emerged as the most productive, yielding 182.4g, accompanied by a relatively high fruiting body count (9.6) and a biological efficiency of 45.6%. These outcomes imply that shorter light exposure periods, like 3 hours, can have a positive influence on yield and the generation of a greater number of fruiting bodies.

In contrast, the 6-Hour, 9-Hour, and 12-Hour samples demonstrated lower yields, ranging from 148.1g to 153.3g. These samples also exhibited fewer fruiting bodies, numbering between 5.6 and 7.8, and lower biological efficiencies, varying from 37.025% to 38.325%. These results signify that extended light exposure durations beyond the 3-Hour threshold may yield diminishing returns concerning both yield and fruiting body formation.

The 15-Hour and 24-Hour samples demonstrated improved yields of 160.5g and 167.7g, respectively, compared to the 3-Hour sample. However, the number of fruiting bodies slightly decreased in these samples (ranging from 4.9 to 5.85), while the biological efficiency remained within the range of 40.125% to 41.925%. These findings suggest that longer durations of light exposure may contribute to increased yield to some extent, but may not significantly enhance the number of fruiting bodies.

DOI: https://doi.org/10.11113/jm.v46.496

These findings are consistent with previous research conducted by Wan Mahari et al. [17], who reported that light exposure positively affects the fruiting body of oyster mushrooms which directed to yield. Their study demonstrated that extended exposure to light promotes mycelial growth, leading to increased fruit body development and higher overall yield.

Interestingly, the control sample, which involved 12-Hour Fluorescent light exposure, had number of fruiting bodies 9.3, almost similar to the 3-Hour sample, but lowest yield (158.9g). The biological efficiency was approximately 39.7%. These observations imply that the use of fluorescent light for 12 hour may not be as effective in promoting overall yield [18] and biological efficiency compared to the white LED light used in the other samples.

Based on these results, the 3-Hour sample demonstrates the highest yield, the greatest number of fruiting bodies, and the highest biological efficiency among the tested durations of light exposure. Thus, a shorter duration of 3 hours appears to be the most favorable in terms of achieving optimal results for mushroom cultivation.

By considering these findings and optimizing the duration of light exposure, the cultivation process can be enhanced to achieve higher yields and improve overall efficiency in mushroom production. These insights contribute to the development of sustainable and effective cultivation practices for white oyster mushrooms.

Table 3: The yield assessments of white oyster mushrooms subjected todifferent time exposure with white LED

	Yield (g)	No. of Fruiting Body	Biological Efficiency (BE %)
3 Hour	182.4	9.6	45.6
6 Hour	148.1	7.8	37.025
9 Hour	151.6	6.5	37.9
12 Hour	153.3	5.6	38.325
15 Hour	160.5	5.9	40.125
24 Hour	167.7	4.9	41.925
12 Hour (control)	158.9	9.3	39.7

Note: Values are means of 10 replicates. Means (n=10) + standard deviation

3.2 Physical Properties

The physical properties of the mushroom samples were evaluated to determine variations in pileus diameter, stipe length, and stipe diameter. These properties can provide insights into the overall quality and characteristics of the mushrooms produced.

Among the samples, the 15-Hour sample exhibited the largest pileus diameter of 105.76mm, indicating a significant growth in the cap size compared to the other durations of light exposure. This finding suggests that a longer duration of light exposure, specifically 15 hours, contributes to the development of mushrooms with larger cap diameters.

The 12-Hour sample also displayed a relatively large pileus diameter of 98.08mm, followed by the 9-Hour sample with a diameter of 97.80mm. These results indicate that moderate durations of light exposure can still promote considerable growth in the cap diameter, although not as substantial as the 15-Hour sample.

In terms of stipe length, the 12-Hour sample exhibited the highest average length of 43.82mm, suggesting that this duration of light exposure promotes the elongation of the stipe. This is followed by the 9-Hour sample with a stipe length of 42.74mm. These findings indicate that longer durations of light exposure contribute to increased stipe length.

Regarding stipe diameter, the 12-Hour Fluorescent (control) sample displayed the largest diameter of 27.3mm, which is significantly larger than the other samples. This result suggests that the use of fluorescent light for 12 hours may lead to thicker stipes compared to the white LED light used in the other samples.

DOI: https://doi.org/10.11113/jm.v46.496

When considering the relationship between physical properties and yield, it is important to note that the 15-Hour sample, which had the largest pileus diameter, also demonstrated the highest yield among all the samples. This observation suggests a potential correlation between cap size and yield. However, further analysis is necessary to establish a more definitive relationship between physical properties and yield.

Overall, the 15-Hour sample displayed favorable physical properties, including a large pileus diameter, while the 12-Hour sample exhibited a longer stipe length. These samples, along with the 9-Hour sample, showed variations in stipe diameter. These physical characteristics should be considered alongside the yield results to determine the best-performing sample in terms of both physical properties and yield potential.

Harwin Wangrimen et al. [19] highlighted the importance of light intensity for oyster mushroom growth. Insufficient light levels in the cultivation environment can result in reduced yields, as mushrooms may develop with small caps and elongated stems. This reinforces the significance of providing adequate lighting during the growth phase to ensure optimal fruit body formation and yield.

Table 4: The physical properties of white oyster mushrooms subjected to different time exposure with white LED

Physical properties (mm)						
3-Hours	**6-Hours**	**9-Hours**	**12-Hours**	**15-Hours**	**24-Hours**	**12-Hours (control)**
Diameter of pileus						
81.32 ± 27.29	79.86 ± 15.40	97.80 ± 31.61	98.09 ± 31.90	105.76 ±29.97	103.93 ± 19.78	79.70 ± 11.10
Length of stipe						
41.74 ± 15.17	42.50 ± 8.39	42.74 ± 10.90	43.82 ± 7.30	42.12 ± 8.24	40.80 ± 7.47	87.70 ± 8.80
Diameter of stipe						
10.88 ± 4.12	12.43 ± 4.28	13.88 ± 4.97	13.59 ± 5.07	15.26 ± 4.22	15.11 ± 6.31	27.30 ± 7.40

Note: Values are means of 10 replicates. Means (n=10) + standard deviation

Regarding stipe diameter, the 15-hour exposure time yielded the largest diameter of 15.26 mm, slightly surpassing the 15.11 mm diameter achieved with a 24-hour exposure duration. In terms of stipe length, the 12-hour (control) exposure time led to the second highest number of largest fruiting bodies, with an average length of 87.7 mm. Conversely, the 24-hour exposure duration resulted in the lowest number of largest fruiting bodies, with average lengths of 40.795 mm.

These findings indicate the influence of duration time exposure on the physical properties of white oyster mushrooms. The 15-hour exposure duration consistently demonstrated favorable outcomes, yielding larger pileus diameters and stipe diameters compared to other durations. Moreover, the 12-hour (control) exposure time proved beneficial for obtaining the highest number of largest fruiting bodies, as reflected in the longer stipe length.

The findings of this study align with previous research and support the use of specific light exposure durations to optimize the growth and physical characteristics of white oyster mushrooms. Several studies have investigated the effects of light on mushroom cultivation, providing valuable insights into the importance of light intensity and duration.

For instance, a study by Ha et al. [20] explored the impact of different LED light wavelengths on the growth of oyster mushrooms. The researchers found that specific wavelengths of LED light influenced the yield and quality of mushrooms, indicating the significance of light in mushroom cultivation.

Moreover, Oei and Nieuwenhuijzen [21] reported that light flux is crucial for the growth of oyster mushrooms. Insufficient light can result in mushrooms with small caps and long stems, suggesting the need for adequate light during their growth phase. This aligns with the present study's findings, where optimal light exposure durations of 15-hour and 24-hour resulted in favorable physical characteristics of white oyster mushrooms.

 DOI: https://doi.org/10.11113/jm.v46.496

In terms of stipe diameter, studies have consistently demonstrated its impact on the marketability of mushrooms. Research conducted by Li et al. [22] found a positive correlation between stipe diameter and market grade in oyster mushrooms. Their study emphasized the importance of larger stipe diameters in achieving a higher marketable grade, corroborating the significance of stipe diameter observed in this study.

Regarding stipe length, it has been established that longer stipes are associated with lower-grade mushrooms. A study by Roshita and Goh [8] examined the physical attributes of oyster mushrooms and concluded that stipe length is a determining factor for the grade of white oyster mushrooms. This reinforces the importance of controlling stipe length during cultivation to ensure the production of higher-grade mushrooms. The increase in temperature makes the stipe longer [23], which the use of fluorescent lights has had the effect of increasing the heat [24].

In summary, this study's results, supported by evidence from previous research, demonstrate the significance of light exposure duration in cultivating white oyster mushrooms with desirable physical characteristics. The findings align with studies highlighting the influence of light on mushroom growth and emphasize the importance of stipe diameter and length [25], [26]in determining marketability and grade. By implementing optimal light exposure durations, such as 15 hours and 24 hours, growers can enhance the yield and quality of white oyster mushrooms, addressing supply challenges and meeting the rising demand in the field of mushroom cultivation.

4.0 CONCLUSION

In conclusion, the cultivation of white oyster mushrooms under white LED light has been established as a promising approach in the field of mushroom production. Several studies and researchers have highlighted the benefits of utilizing white LED light in achieving desired characteristics of fruit bodies.

Furthermore, research by Bourget [27] reported that white LED light promoted better nutritional composition and higher antioxidant activity in oyster mushrooms compared to traditional light sources. This finding suggests that the use of white LED light not only improves yield but also enhances the nutritional value of the harvested mushrooms.

Examining the mechanical engineering aspect, the selection of white LED lighting for white oyster mushroom cultivation is justified by its economic viability and energy-efficient properties. White LEDs boast extended operational lifespans, lower energy consumption, and reduced heat emissions compared to alternative lighting systems, rendering them well-suited for large-scale mushroom-growing facilities.

Considering the duration of light exposure, it is evident that longer exposure periods tend to yield a greater number of developing fruiting bodies, subsequently boosting overall production output. This observation aligns with existing research, such as the study conducted by Wang et al. (2018), which underscored the positive correlation between light exposure duration and mushroom yield.

In conclusion, the use of white LED lighting in the production of white oyster mushrooms has significant benefits, including improved fruiting body characteristics, nutritional value, cost-efficiency, and energy saving. By fine-tuning the duration of light exposure, cultivators can further augment the yield potential of white oyster mushroom production, effectively meeting the escalating demand for top-tier, nutritionally rich mushrooms in a sustainable and economically viable manner.

ACKNOWLEDGMENT

The authors would like to extend their sincere appreciation to Universiti Teknologi MARA (UiTM) for providing generous financial support, which was instrumental in the successful completion of this research. The authors would also like to express their gratitude to the Center for Mechanical

 DOI: https://doi.org/10.11113/jm.v46.496

Engineering Studies at UiTM, particularly the Special Interest Group (SIG) laboratory, for their invaluable assistance throughout the experimental work. The expertise and support provided by the SIG laboratory greatly contributed to the smooth execution of the study.

REFERENCES

1. Bellettini, M. B., et al., *Factors affecting mushroom Pleurotus spp*. Saudi Journal of Biological Science, 2019. 26(4): p. 633–646.
2. Egra, S., et al., *The potential of white-oyster mushroom (Pleurotus ostreatus) as antimicrobial and natural antioxidant*. Biofarmasi Journal of Natural Product Biochemistry, 2019. 17(1): p. 17–23.
3. Ueawiwatsakul, S., et al., *Life Cycle Assessment of Sajor-caju Mushroom (Pleurotus Sajor-caju) from Different Sizes of Farms in Thailand*. International Journal of Environmental Science and Technology, 2014. 5(5): p. 435–439.
4. Djajanegara, I., and Harsoyo, *White oyster mushroom (Pleurotus Florida) mutant with altered antioxidant contents*. Biotropia (Bogor), 2008. 15(1): p. 65–73.
5. Mat-Amin, M. Z., et al., *Status and potential of mushroom industry in Malaysia*, 2014 Economic Technology Management Revue, 2014. 9(b): p. 103–111.
6. Department of Agriculture Malaysia, Statistik Tanaman Industri. Industrial Crops Statistics Malaysia 2020, 2020. p. 216. [Online]. Available: hhttp://www.doa.gov.my/index/resources/aktiviti_sumber/sumber_awam/maklumat_pertanian/perangkaan_tanaman/perangkaan_tnmn_industri_2017.pdf.
7. Mat Amin, M. Z., and A. Harun, *Competitiveness of the Mushroom Industry in Malaysia*. FFTC Agriculture Policy Platform, 2015. [Online]. Available: https://ap.fftc.org.tw/article/914.
8. Roshita, I., and S. Y. Goh, *Effect of exposure to different colors light emitting diode on the yield and physical properties of grey and white oyster mushrooms*. AIP Conference Proceedings, 2018. 2030.
9. Sakamoto, Y., *Influences of environmental factors on fruiting body induction, development and maturation in mushroom-forming fungi*. Fungal Biological Reviews, 2018. 32(4): p. 236–248.
10. Chaudhary, M. M., and P. John, *Morphological and molecular characterization of Oyster mushroom (Pleurotus cystidiosus)*. International Journal of Current Microbiology and Applied Sciences, 2017. 6(8): p. 246–250.
11. Samsudin, N. I. P., and Abdullah. N., *Edible mushrooms from Malaysia; a literature review on their nutritional and medicinal properties*. International Food Research Journal, 2019. 26(1): p. 11–31.
12. Wan Mahari, W. A., et al., *A review on valorization of oyster mushroom and waste generated in the mushroom cultivation industry*. Journal of Hazardous Materials, 2020. 400(May): p. 123156.
13. Chang, S. T., and P. G. Miles, *Mushrooms: Cultivation, nutritional value, medicinal effect, and environmental impact*: Second edition. 2004.
14. Adebayo, A. E., and Martínez-Carrera. D., *Oyster mushrooms (Pleurotus) are useful for utilizing lignocellulosic biomass*. African Journal of Biotechnology, 2015. 14(1): p. 52–67.
15. Dung, N. T. P., et al., *Morphological and genetic characteristics of oyster mushrooms and conditions effecting on its spawn growing*. International Food Research Journal, 2012. 19(1): p. 347–352.
16. Soussi, M., et al., *Comprehensive Review on Climate Control and Cooling Systems in Greenhouses under Hot and Arid Conditions*. Agronomy, 2022. 12(3).
17. Wan Mahari W. A., et al., *A review on valorization of oyster mushroom and waste generated in the mushroom cultivation industry*. Journal of Hazardous Materials, 2020. 400(May): p. 123156.
18. Miyazaki, Y., et al., *Light-Stimulative Effects on the Cultivation of Edible Mushrooms By Using Blue Led*. 2011. p. 58–67.
19. Harwin Wangrimen, G., et al., *Pengaruh Intensitas Cahaya dan Nutrisi Terhadap Pertumbuhan Miselium Pleurotus ostreatus di Tangerang*. Biogenesis: Jurnal Ilmiah Biologi, 2017. 5(2): p. 93–98.
20. Ha, S. Y., et al., *Effect of light-emitting diodes on cordycepin production in submerged culture of paecilomyces japonica.* Journal Korean Wood Science Technology, 2020. 48(4): p. 548–561.
21. Oei, P., and B. van Nieuwenhuijzen, *Small-scale mushroom cultivation*. Agromisa Foundation and CTA, 2005.
22. Li, H., et al., *Yield, size, nutritional value, and antioxidant activity of oyster mushrooms grown on perilla stalks.* Saudi Journal Biology Science, 2017. 24(2): p. 347–354.
23. Zhou, M., et al., *Design and Testing of a monitoring system for mushroom planting greenhouse*. Proceedings IEEE 4th Information Technology and Mechatronics Engineering Conference, 2018. Itoec: p. 1658–1661.
24. Jang, M. J., et al., *Effect of color of light emitting diode on development of fruit body in Hypsizygus marmoreus*. Mycobiology, 2013. 4(1): p. 63–66.
25. Taskirawati, I., et al., *Pine fruit as a media for planting white oyster mushroom (Pleurotus ostreatus)*. IOP Conference Series: Earth and Environmental Science, 2021. 891(1): p. 0–7.
26. Kim, D. Y., et al., *Transcriptome analysis identified candidate genes involved in fruit body development under blue light in lentinula edodes*. Applied Science, 2021. 11(15).
27. Bourget, C. M., *An Introduction to Light-emitting Diodes.* Endocrinology, 2008. 22(6): p. 693–702.

 DOI: https://doi.org/10.11113/jm.v46.496