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Effects of Various LED Light Colours on Yield and Physical Characteristics of White Oyster Mushrooms

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ABSTRACT

Commercial mushroom farming in Malaysia predominantly focuses on grey oyster mushrooms, while white oyster mushrooms are comparatively less popular due to their slower growth rate. Previous studies have explored the effects of natural light on mushroom growth, but there is limited research on the use of artificial light in mushroom production. Therefore, this study investigated the influence of different LED light colours on the growth performance, yield and physical properties of white oyster mushrooms in a controlled mushroom chamber. The objective was to identify the optimum LED light colour to enhance yield and physical characteristics. In the experiment, mushroom blocks were exposed to various LED light colours, including white, warm white, blue, red, and green. The results indicated that exposure to blue light significantly increased both the yield and physical quality of white oyster mushrooms. In conclusion, blue LED light proved to be the most effective treatment for promoting the development of white oyster mushrooms.

Keywords: *LED light colours, physical properties, white oyster mushrooms, yield*

1. INTRODUCTION

Mushrooms, renowned for their nutritional value and potential health benefits, are cultivated worldwide, including in Malaysia, where the mushroom industry occupies about 340 hectares of land and involves a limited number of farmers and entrepreneurs [1]. Notably, Selangor emerged as the prominent region with high mushroom yields [2]. Despite the increasing popularity and demand for mushrooms, the country is struggling to meet the local market's needs due to inadequate mushroom supply [3].

One particular variety, the white oyster mushroom, encounters additional challenges in terms of its slower growth rate [4]. To address this issue, innovative methods have been developed to enhance white oyster mushroom production, such as leveraging specific types of lighting. Light has been found to play a crucial role in triggering the growth and development of mushroom fruiting bodies [5].

In this context, the use of LED lighting is significant as a potential solution for promoting the growth of white oyster mushrooms in Malaysia. LED lighting offers several advantages, including energy efficiency, longer lifespan, and the ability to emit specific light wavelengths that can be tailored to meet the unique requirements of mushroom cultivation [6]. By utilising LED lighting, mushroom growers in Malaysia can potentially overcome the challenges

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associated with the slow growth of white oyster mushrooms [4], thereby increasing their productivity and meeting the rising demand in the market.

Furthermore, the adoption of LED lighting technology has significant benefits for mushroom users and consumers. White oyster mushrooms cultivated under optimised LED lighting conditions are likely to exhibit improved quality in terms of enhanced texture, colour, taste, and nutritional composition [7]. It enhances the overall consumer experience as well as promotes a healthier life by providing a nutrient-rich dietary option.

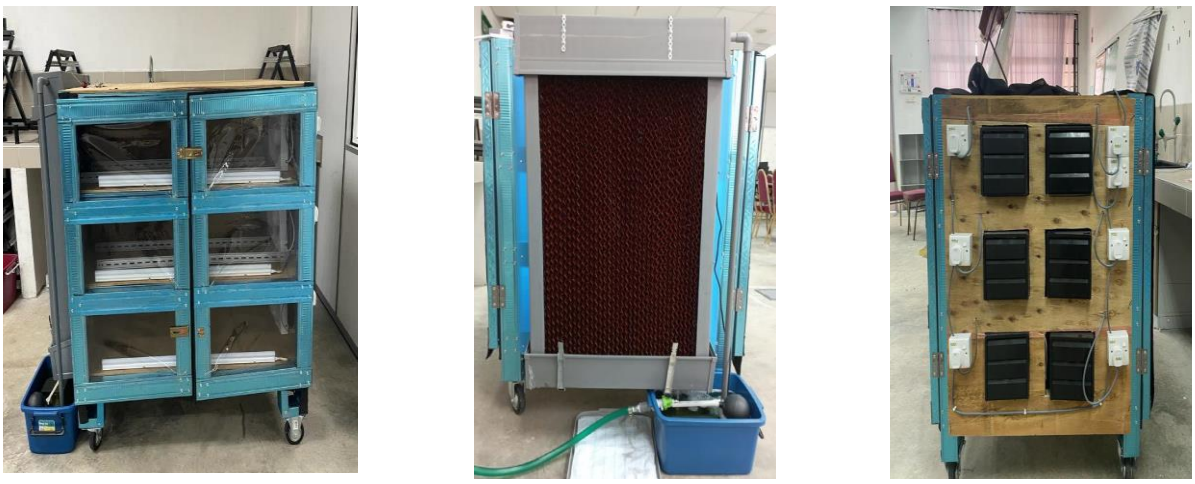
Moreover, the application of LED lighting in mushroom cultivation has broader implications for the industry as reported by previous research [4], [8–11]. By improving the growth efficiency and yield of white oyster mushrooms, the industry can meet the growing demand, reduce dependence on imports, and contribute to the country's economic growth. Additionally, the adoption of sustainable and energy-efficient LED lighting systems is aligned with the industry's efforts to enhance resource management and minimise environmental impact.

Therefore, this study aimed to investigate the effect of different LED light colours on the yield and physical properties of white oyster mushrooms in Malaysia. The findings have the potential to revolutionise mushroom cultivation practices and offer valuable insights to mushroom growers, users, and the industry at large. It can further lead to enhanced productivity, improved product quality, and sustainable growth.

2. MATERIALS AND METHODS

2.1 Experimental setup

The experimental setup involved the cultivation of white oyster mushrooms in a meticulously designed mushroom chamber equipped with an evaporative cooling pad system. Figure 1 depicts the side and front views of the mushroom chamber, showcasing the position of the cooling pad and exhaust fans. This system operated based on the principles of heat and mass transfer, employing evaporative cooling to regulate the temperature in the chamber.



(a) (b) (c)

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

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The cellulose pad, manufactured by the CELdek brand, served as the main component of the cooling system, with its structure and dimensions measuring 150 mm in thickness and occupying an area of 1.0 m x 0.6 m. It was strategically positioned close to the exhaust fans to maximise its effectiveness. The pad was designed to absorb water from the irrigation pipe, which sprayed water uniformly over its surface. The water, which came in contact with the air passing through the chamber, underwent evaporation, extracting heat from the surrounding air and lowering the temperature [12] in the chamber.

A 6-inch exhaust fan was strategically placed opposite the cooling pad in each treatment partition of the mushroom chamber to ensure efficient air circulation. The fan facilitated the movement of air, drawing it through the wet cooling pad and exhausting it out of the chamber. This created a continuous flow of air, promoting the evaporation process and maintaining a controlled temperature environment [13] for mushroom growth.

Air velocity in the chamber was carefully controlled at 0.3 m/s to optimise the distribution of cool air and ensure uniform cooling across the mushroom cultivation area. The calculated air volume of 0.0683 m^3/s allowed for an adequate flow rate to effectively dissipate heat and maintain optimum conditions. The air velocity of the mushroom chamber was determined as Equation 1.

$$\text{The volume of air} = \text{cross-sectional area} \times \text{air velocity} \tag{1}$$

Wet and dry bulb temperatures were measured using a Benetech GM1365 digital humidity and temperature data logger with an accuracy of 2 °C to monitor the effectiveness of the cooling system. These data loggers were carefully placed in specific areas inside and outside the chamber, away from the cooling pad, to obtain accurate temperature and humidity readings. Before the experiments, temperature and humidity readings were taken to establish baseline conditions and ensure the system was functioning properly.

The cellulose pad was thoroughly soaked in water for 24 hours before the experiment was conducted to initiate the cooling process, ensuring its complete saturation. The purpose was to ensure that when the air passes through the wet pad, maximum evaporation and heat extraction occur, effectively lowering the temperature in the chamber [13].

A waiting period of at least 10 minutes was observed before placing the mushroom block samples in the chamber to establish an equilibrium between the air conditions of the room and the pad. This allowed the stabilisation of temperature and humidity levels, ensuring consistent and controlled conditions for mushroom growth experiments.

Continuous monitoring of temperature and humidity at the inlet and outlet of the cooling pads was performed once a steady state was achieved, guaranteeing accurate measurements of cooling efficiency. The environmental conditions in the mushroom chamber were carefully maintained at an average temperature of 21 ± 4 ℃ and relative humidity of 92.5 ± 2.5%, as depicted in Figure 2, to provide optimum growth conditions for white oyster mushrooms [14].

A schematic diagram of the experimental setup, as shown in Figure 3, provides an overview of the mushroom chamber and the position of the cooling pad, exhaust fans, and measurement

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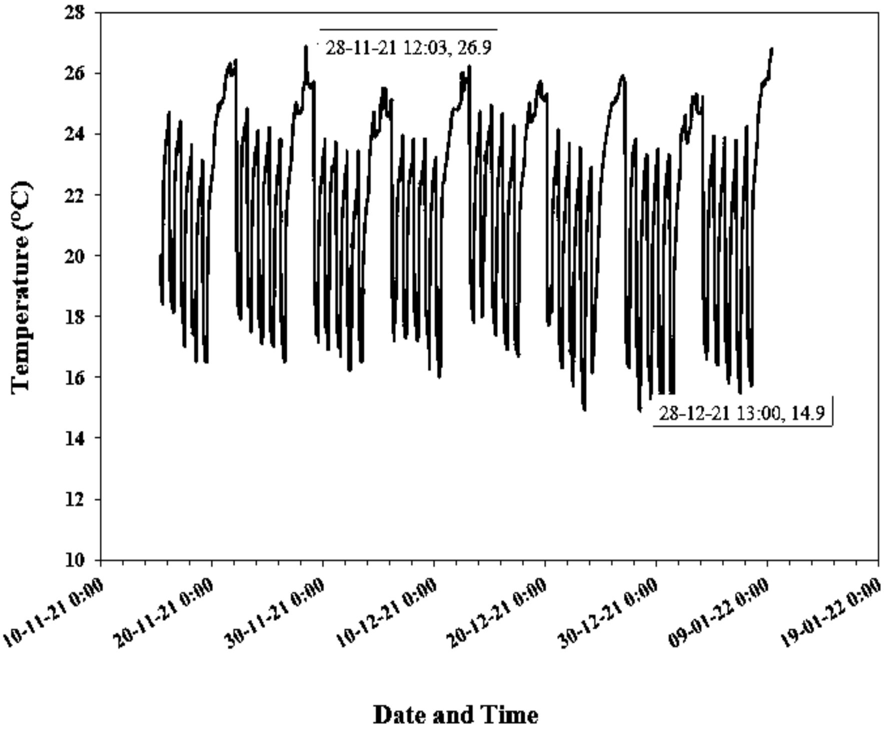
points. Furthermore, Figure 4 depicts an actual image of the mushroom chamber, showcasing the LED lights employed in conjunction with the cooling system.

(a)



(b)

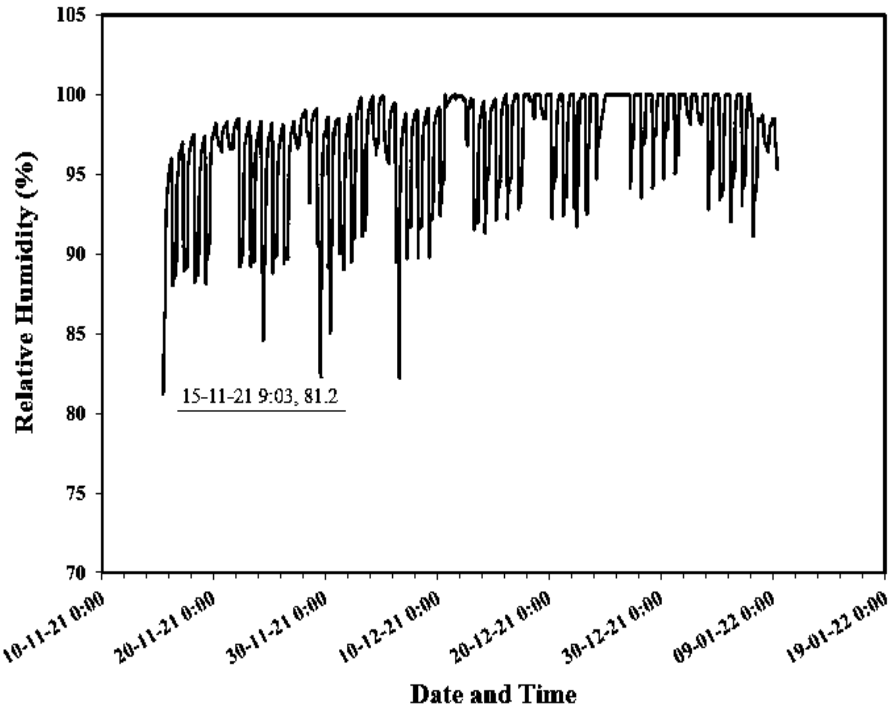


Figure 2: (a) Temperature and (b) relative humidity of the mushroom chamber

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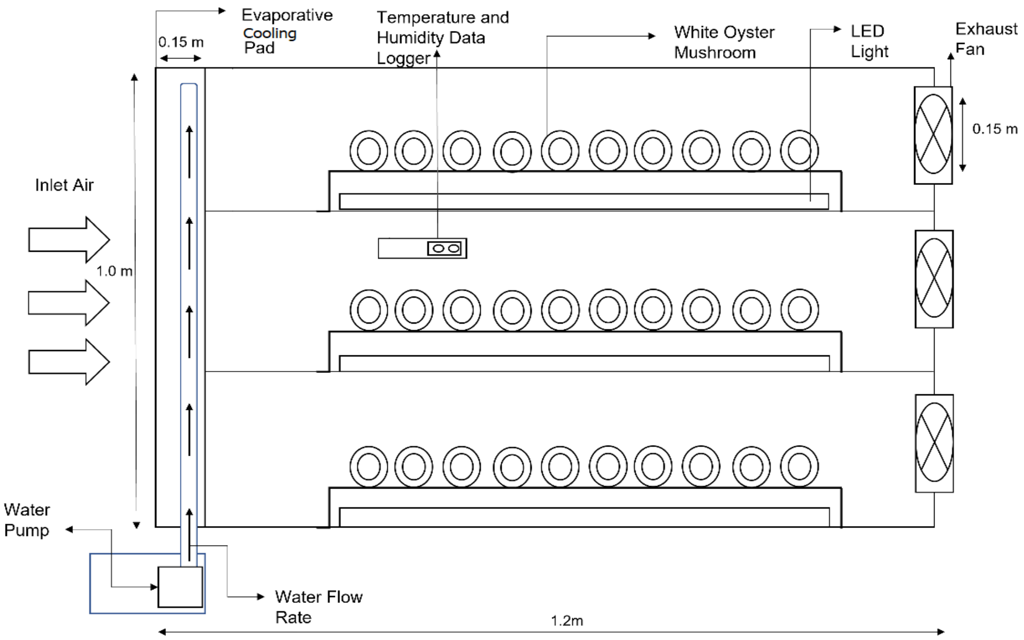
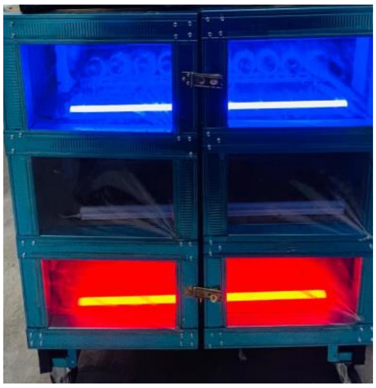


Figure 3: Schematic diagram of mushroom chamber

(a)



(b)

Figure 4: (a) Mushroom chamber with warm white, white, and green LED lights, and (b) mushroom chamber with blue and red LED lights

The cooling efficiency (η) of the pad, estimated using Equation 2, quantifies the effectiveness of the evaporative cooling process in reducing the temperature in the chamber. The wet-bulb temperature (T_{wb}), dry bulb temperature (T_{db}), and the calculated difference between them are used to assess the cooling performance. $T_{db,i}$ is the initial air temperature, $T_{db,o}$ is the air temperature after cooling, $T_{\omega,i}$ is the initial wet-bulb temperature, andT_{wb_l} is the wet-bulb temperature after cooling. The equation shows the amount of heat removed by the cooling system from the air. A higher value indicates a good cooling system, while a lower value indicates less effective cooling.

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

With a pad thickness of 150 mm, the cooling efficiency could reach 100%, indicating the system's capability to effectively maintain and lower the temperature inside the mushroom chamber (Figure 5). This demonstrated the successful implementation of the evaporative cooling pad system in creating optimum growth conditions for white oyster mushrooms.

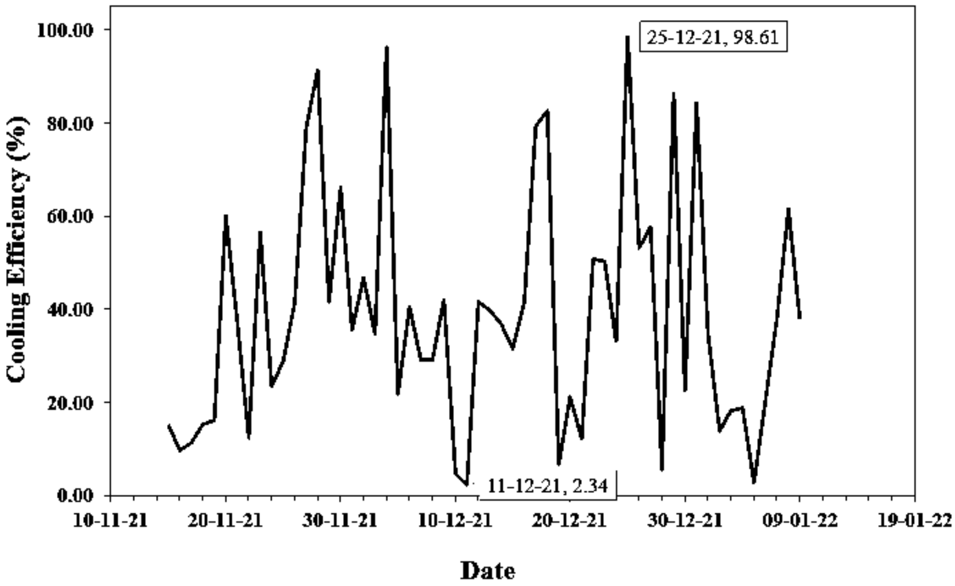

Figure 5: Cooling efficiency of the mushroom chamber

2.2 Parameter setup and procedures

The parameter setup involved the meticulous installation and configuration of five distinct T5 LED tube light colours (red, blue, green, white, and warm white; 1400 lm) in the mushroom chamber. The control group for the experiment was not exposed to lighting. Each LED light colour was carefully selected to explore its effect on the growth of white oyster mushrooms. The LED lights were positioned strategically at the front to ensure uniform illumination across the mushroom cultivation area.

A digital timer was employed to precisely regulate the duration of light exposure for the mushroom blocks to create controlled lighting conditions. Each day, the LED lights were programmed to illuminate the chamber for 12 hours, replicating a consistent light cycle. This controlled lighting regime aimed to simulate natural daylight conditions and provide the necessary light energy for photosynthesis and mushroom growth.

The LED lights were placed at a distance of 15 cm from the mouth of the mushroom blocks, allowing optimum light penetration and coverage. This position ensured that the mushrooms received sufficient light intensity for proper development and fruiting induction as the fruiting mushroom bodies emerged from the mouth of the mushroom block. The mycelium-filled blocks of white oyster mushrooms were closely monitored during the growth phase. Once the mycelium colonisation was complete, the caps of the mushroom blocks were opened, exposing

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them to the LED lights. This exposure stimulated pin-head emergence and initiated the fruiting process.

Upon reaching maturity, the fully developed fruiting bodies were harvested from the mushroom blocks. To maintain the integrity of the remaining mycelium, the blocks were closed with caps and left undisturbed for the subsequent fruiting cycle of seven days. This allowed the regeneration of new fruiting bodies for further harvests. For yield analysis, the total fresh weight of fruiting bodies harvested for three harvester cycles was weighed using digital balance and calculated based on the Equation 3 and Equation 4 below.

$$\text{Average yield per block} = (\text{Total harvested yield from 10 blocks}) / 10 \tag{3}$$

$$\text{Total Yield} = \text{Average Yield of Harvest Cycle 1} + \text{Average Yield of Harvest Cycle 2} + \text{Average Yield of Harvest Cycle 3} \tag{4}$$

Evaluation of mushroom growth and physical properties involved precise measurements of key parameters. Growth performances, pileus diameter, stipe diameter, and stipe length of the largest and smallest fruiting bodies were recorded. These measurements provided insights into the morphological characteristics and overall quality of the harvested mushrooms (Figure 6).

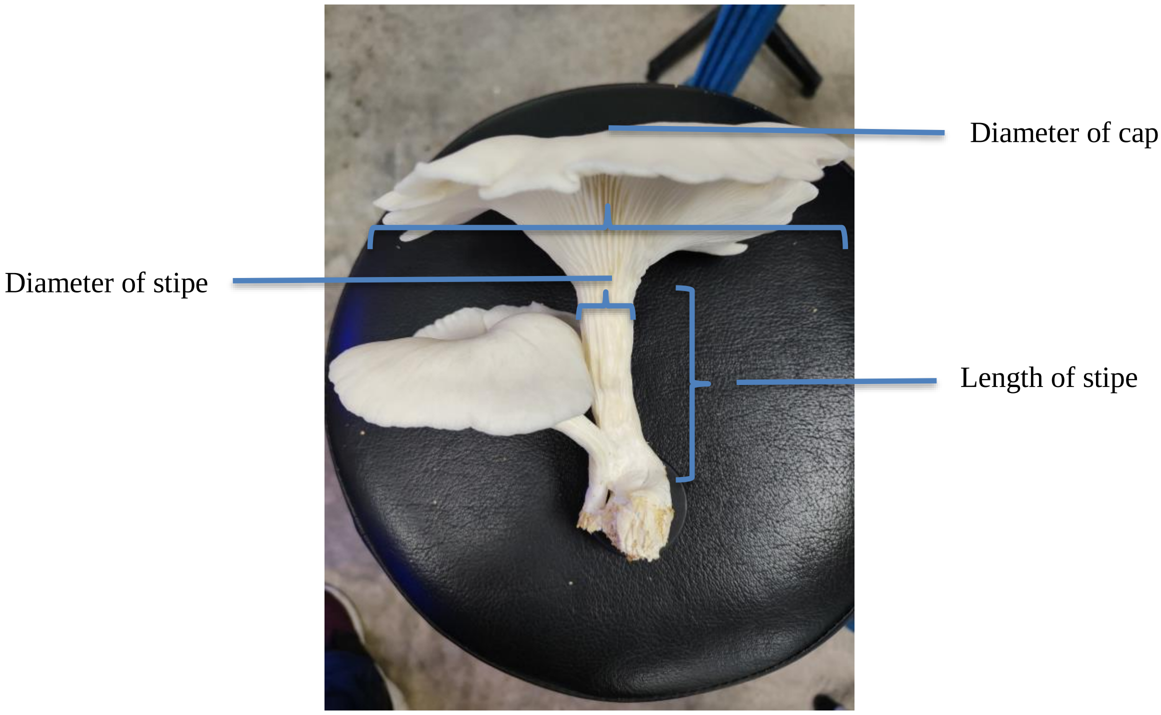

Figure 6: Anatomy of the mushroom

Various dimensions of the mushroom structure were examined to gain a deeper understanding of their attributes. For instance, the pileus diameter, indicating the cap's width, was measured. Similarly, the stipe diameter, representing stem width; and stipe length, reflecting stem height, were also quantified. These assessments were conducted for both the largest and smallest fruiting bodies.

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Referring to Figure 3, specific locations were selected for each measurement: the widest point of the cap for the pileus diameter, the thickest part of the stem for the stipe diameter, and from the stem base to the cap attachment point for the stipe length. These measurements collectively unveiled critical insights into the mushroom's physical characteristics and overall quality after harvesting.

Visual representation of mushroom morphology would enhance comprehension of where these measurements were taken. By delving into these structural dimensions, this study aimed to unveil the effects of distinct LED light colours on mushroom shape and quality.

Through this meticulously designed parameter setup, the influence of different LED light colours on the growth and physical properties of white oyster mushrooms could be precisely examined. Thus, it contributes valuable insights to the field of mushroom cultivation and guides future agricultural practices.

3. RESULTS AND DISCUSSION

3.1 Growth performances

The growth of white oyster mushrooms encompasses two distinct stages, namely pinhead emergence and fruiting body formation, which are crucial for successful cultivation. In this study, the effects of different LED light colours on the growth stages were investigated, considering their impact on pinhead emergence time and fruiting body development.

Significant variations in pinhead emergence time were observed among the different treatments (Figure 7). The LED light colour treatments exerted a more pronounced influence on accelerating pinhead emergence compared to the time-varying exposure treatments, resulting in differences ranging from 5.2 to 11.8 days. This finding is aligned with previous research by Roshita and Goh [5] that specific light colours can significantly affect the timing of pinhead emergence in oyster mushrooms. The utilisation of various LED light colours provides an efficient means of controlling and accelerating the growth process.

Contrary to the red LED treatment, which exhibited the longest time for pinhead formation and fruiting body maturation, the white LED treatment was the fastest. This finding is supported by the research of Jang and Lee [6] that white LED illumination enhances the growth and maturation of fruiting bodies in mushrooms. The white light spectrum encompasses a broad range of wavelengths, providing a balanced and optimum light environment for mushroom cultivation.

In the field of mechanical engineering, the selection and optimisation of LED lighting systems play a crucial role in agricultural applications, including mushroom cultivation. LED lights offer advantages such as energy efficiency, controllability, and the ability to tailor light spectra to specific plant requirements. The integration of LED technology in mushroom cultivation systems enables precise control over growth parameters, resulting in enhanced productivity and quality.

By understanding the effects of different LED light colours on the growth stages of white oyster mushrooms, this study contributes valuable insights to the fields of mechanical engineering and agricultural practice. The findings support the optimisation of LED lighting systems for

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efficient and sustainable mushroom cultivation, enabling increased yields, accelerated growth rates, and improved overall performance.

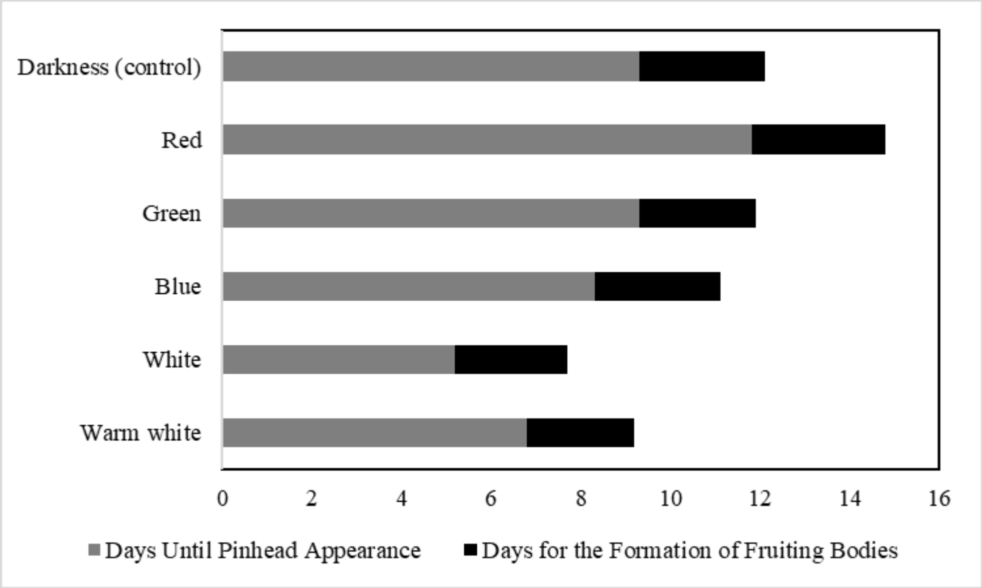

Figure 7: Total Days Taken

3.2 Yield assessments

Assessment of yield in white oyster mushroom cultivation is a crucial factor in determining the success and profitability of the production process. In this study, the yield was significantly influenced by different LED light colour treatments, highlighting the importance of the light spectrum in mushroom growth and productivity.

Among the LED light colour treatments, the blue LED light treatment yielded the highest white oyster mushroom production, with a total yield of 260.9 g (Figure 8). This result is consistent with previous research findings that suggest the positive effect of blue light on mushroom growth. For instance, Roshita and Goh [4] reported that blue light with a wavelength of 475 nm resulted in the highest total fresh weight of white oyster mushrooms. The blue light in the range of 340-520 nm enhanced fruit body output by activating adenosine triphosphate (ATP) synthase in mushrooms.

Similar to the blue LED light treatment, the green LED light treatment also demonstrated a significant effect on the yield of white oyster mushrooms, with a total production of 240.6 g. Green light has been reported to influence various physiological processes in plants and fungi, including photosynthesis and morphogenesis [16]. Although the specific mechanisms underlying the positive effect of green light on mushroom yield are still being studied, it is believed to contribute to the overall growth and development of fruiting bodies.

Moreover, the white LED light treatment resulted in a total yield of 233.8 g, showing comparable performance to those of blue and green LED light treatments. White light, consisting of a combination of different wavelengths, provides a broad spectrum that supports photosynthesis and general plant growth. The utilisation of white LED light in mushroom

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cultivation indicated promising results in promoting fruiting body formation and enhancing overall yield.

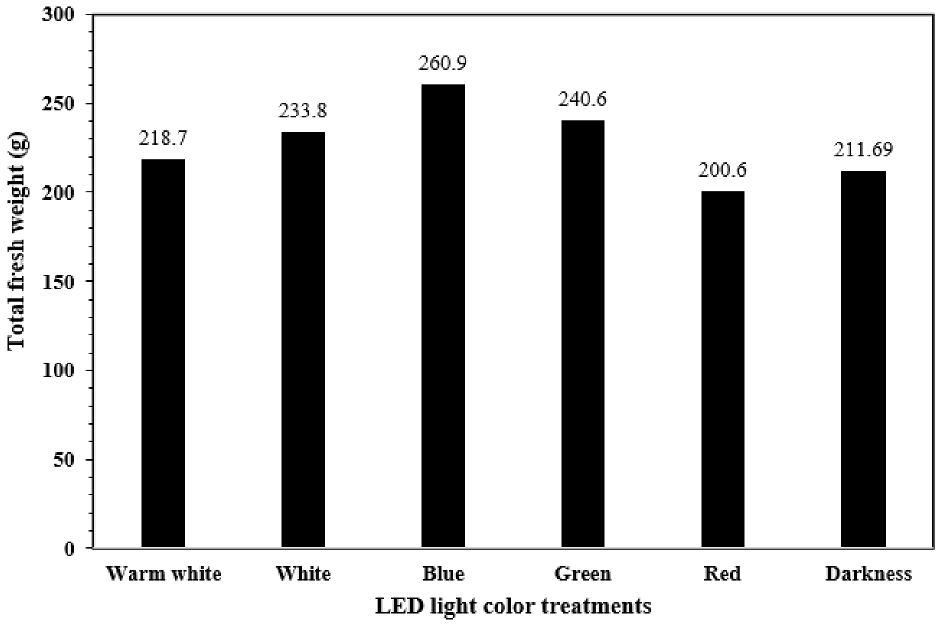

Figure 8: Yield of mushrooms cultivated under various LED light colour treatments

On the other hand, the red LED light treatment exhibited the lowest yield among other LED light colours tested, with a total production of 200.6 g. This finding is in line with previous studies indicating that red light may have a suppressive effect on mushroom growth and development. Red light, with its longer wavelength, is known to be less effective in driving photosynthesis and may not provide the optimum conditions for robust mushroom yields [9], [17].

The results highlighted the significance of LED light colour selection in maximising yield and productivity in white oyster mushroom cultivation. The finding is aligned with the principles of mechanical engineering, where the design and optimisation of lighting systems play a crucial role in achieving the desired outcomes in various agricultural applications. By harnessing the specific characteristics of different LED light colours, engineers can develop lighting systems tailored to the specific needs of mushroom cultivation, thereby optimising growth, yield, and commercial viability.

The observation of high fruiting body growth under blue LED light is in agreement with the findings of Roshita and Goh [4] that blue light with a wavelength of 475 nm recorded the highest total fresh weight of mushrooms. This could be attributed to the activation of ATP synthase, which is known to increase fruit body output in mushrooms cultivated under light within the range of 340-520 nm [4], [8], [18].

Statistical analysis of the data revealed significant differences in yield between LED light colour treatments, indicating the crucial role of light colour in influencing mushroom growth and productivity [19]. The results of this study provided valuable insights for mushroom growers and the agricultural industry in selecting the most effective LED light colour,

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particularly blue LED light, to optimise yield and improve production efficiency [10]. By harnessing knowledge from mechanical engineering and incorporating it into mushroom cultivation practices, advancements can be made to enhance the yield and sustainability of mushroom production.

3.3 Physical properties

Physical properties of mushrooms, including pileus diameter, stipe length, and stipe diameter, were measured for each LED light colour treatment as well as control samples. These physical properties provide valuable insights into the overall quality and characteristics of the mushrooms.

Among the LED light colour treatments, the blue LED samples exhibited the largest pileus diameter of 106.11 mm, indicating robust growth and a well-developed cap (Table 1). This finding suggested that the blue LED light provided optimum conditions for the expansion and development of the pileus. Synytsya et al. [20] asserted that mushrooms with larger pileus diameters and shorter stipes generally possess superior quality attributes. In contrast, the red LED samples exhibited the smallest pileus diameter of 73.42 mm, indicating relatively smaller caps and potentially inferior growth.

Table 1: Physical properties of white oyster mushrooms when exposed to various light colours.

	LED lights					
Physical properties (mm)	Warm white	White	Blue	Green	Red	No LED light (Dark condition)
Diameter of Pileus	87.42 ± 17.56	91.34 ± 20.07	106.11 ± 14.47	90.72 ± 22.12	73.42 ± 6.17	90.87 ± 14.23
Diameter of Stipe	12.52 ± 3.21	12.63 ± 2.76	15.02 ± 4.04	11.85 ± 2.29	10.77 ± 2.08	11.63 ± 2.81
Length of Stipe	48.08 ± 16.53	45.26 ± 8.64	42.84 ± 11.44	44.45 ± 9.61	48.51 ± 5.77	40.07 ± 8.97

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

This study demonstrated that white oyster mushrooms treated with blue LED light produced the largest fruiting bodies, indicating favourable mushroom quality as a result of increased pileus diameter. Conversely, the utilisation of red LED light led to a smaller pileus diameter, resulting in comparatively lower quality. These observations are consistent with the research conducted by Hoa et al. [21], which also reported the production of high-quality mushrooms under blue light conditions.

When considering stipe length, the warm white LED samples demonstrated the longest average stipe length of 48.08 mm. This indicated that the warm white LED light promoted elongation and growth of the stipe. On the other hand, the blue LED samples had the shortest average stipe length of 42.84 mm. Disparities in stipe length between different LED light colour treatments could be attributed to variations in light intensity, spectrum, and exposure duration, which directly affected the elongation of the stipe.

As an essential parameter influencing mushroom quality, it was found that the red LED light treatment resulted in the longest stipe length, indicating lower yield quality. Conversely,

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Mondal et al. [22] and Hoa et al. [21] highlighted that oyster mushrooms with larger stipe diameters exhibit exceptional commercial quality.

In terms of stipe diameter, the blue LED samples exhibited the largest average diameter of 15.02 mm, indicating robust and well-developed stipes. This finding suggested that the blue LED light treatment facilitated the thickening and strengthening of the stipe structure, potentially enhancing the overall stability and quality of the mushrooms. Meanwhile, the red LED samples had the smallest average stipe diameter of 10.77 mm, indicating relatively thinner and potentially weaker stipes.

Compared to the LED light colour treatments, the control samples showed average physical properties within a similar range: pileus diameter of 90.87 mm, stipe length of 40.07 mm, and stipe diameter of 11.63 mm. These results indicated that the control samples, which received no LED light treatment, exhibited average physical properties comparable to the other LED light colour treatments.

Based on the analysis of physical properties, the blue LED samples demonstrated the most favourable characteristics among the LED light colours tested, with larger pileus diameter, longer stipe length, and thicker stipe diameter. On the other hand, the red LED samples, with relatively smaller pileus diameter, longer stipe length, and thinner stipe diameter, indicated potentially inferior growth and lower quality.

In the context of mechanical engineering, these findings highlighted the importance of LED lighting systems in influencing the physical properties and overall quality of mushrooms. By meticulously selecting and optimising LED light colours, it is possible to enhance specific physical attributes of mushrooms, such as pileus diameter, stipe length, and stipe diameter. This knowledge can be applied to the design and development of controlled environment systems for mushroom cultivation, enabling improved yield, quality, and commercial viability.

4. CONCLUSION

In conclusion, the findings of this study demonstrated a significant effect of LED light colour on the growth and physical properties of white oyster mushrooms, specifically concerning pileus diameter and stipe length. The use of blue LED light facilitated the development of mushrooms with larger pileus diameters, while red LED light led to longer stipe lengths, both associated with lower quality. These results contribute to the body of knowledge in mushroom cultivation and emphasise the importance of selecting appropriate LED light colours to optimise mushroom production and enhance commercial viability.

In conclusion, the cultivation of white oyster mushrooms was significantly affected by blue LED light treatment. It resulted in the production of fruit bodies with desirable characteristics and high yields. The positive effect of blue LED light on mushroom growth is in line with the research conducted by Hoa et al. [12], where blue light exposure leads to the generation of numerous high-quality mushrooms. This evidence highlights the significance of LED light colour selection in optimising the mechanical aspects of mushroom cultivation.

Conversely, the use of red LED light was found to be inappropriate as it negatively affected the physical properties of the mushrooms and resulted in low yields. Mondal et al. [13] reported in their study that longer stipe lengths and smaller pileus diameters were associated with exposure

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to red light, which resulted in poor mushroom quality. Thus, it can be inferred that LED light colours are a critical factor in enhancing the overall performance and yield of white oyster mushroom cultivation.

The importance of blue LED lighting in this study relied on the effectiveness of its treatment for promoting the growth and development of white oyster mushrooms. It was also evident that the blue LED light significantly increased yield, accelerated growth rates, and enhanced physical characteristics, such as pileus diameter and stipe length. The distinct wavelength and attributes of blue LED light positively impact the mushrooms' biological processes, leading to improved overall performance and product quality.

The results of this study could guide mushroom growers and the agricultural industry to select the optimum LED light colours to achieve superior mushroom quality and maximise productivity. Continuous investigation in the domain of mushroom cultivation can delve into cutting-edge lighting technologies and optimisation strategies to elevate the growth, physical properties, and overall efficiency of mushroom production systems.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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