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The effect of different light wavelengths and lighting duration on the yield and quality of *Pleurotus ostreatus* mushroom

Farklı ışık dalga boyları ve aydınlatma süresinin *Pleurotus ostreatus* mantarının verim ve kalitesine etkisi

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ABSTRACT

Objective: The study investigated the effect of period of lighting or lighting duration at different wavelengths on the yield and quality of *Pleurotus ostreatus* mushroom.

Materials and Methods: In order to realise this objective, four light colours representing different wavelengths during the production process were applied to the mushrooms using a microcontroller-based automation system with determined time intervals.

Results: Different wavelengths of visible light had no significant effect on the yield and earliness of *Pleurotus ostreatus* mushrooms, but blue light affected fruiting body size.

Conclusion: Mushroom quality can be improved by lighting duration of appropriate colour. More detailed studies are needed to determine the effects of different wavelengths on mushroom nutrients and bioactive content.

Keywords: Light dosing control, mushroom growth, oyster mushroom, visible lights

ÖZ

Amaç: Çalışmanın amacı, farklı dalga boyları ve ışıklanma süresinin (veya aydınlatma süresinin) *Pleurotus ostreatus* mantarının verim ve kalitesi üzerine etkisini araştırmaktır.

Materyal ve Yöntem: Bu amacı gerçekleştirmek için üretim sürecinde farklı dalga boylarını temsil eden dört farklı ışık rengi, belirlenen zaman aralıkları ile mikrodenetleyici tabanlı otomasyon sistemi kullanılarak mantarlara uygulanmıştır.

Araştırma Bulguları: Görünür ışıkların farklı dalga boyları, *Pleurotus ostreatus* mantarının verim ve erkenciliği üzerine belirgin bir etkisi olmasa da mavi ışığın şapka boyutları üzerinde etkiye sahip olduğu belirlenmiştir.

Sonuç: Mantar kalitesi uygun renkte ışıklanma süresi ile artırılabilir. Farklı dalga boylarının mantar besin içeriği ve biyoaktif içeriğine etkilerinin de belirleneceği daha ayrıntılı çalışmalara ihtiyaç vardır.

Anahtar sözcükler: Işık dozaj kontrolü, istiridye mantarı, görünür ışıklar, mantar gelişimi

INTRODUCTION

Mushrooms are one of the most important option in human dietary diversity. The fact that mushrooms can be grown quickly and are easily available, which important reasons for their preference, as well as their nutritional values are similar to other animal foods. As mushrooms are rich in vitamin D and this is particularly important for bone and muscle structure, it is recommended to consume a certain amount (Taofiq et al., 2017).

Many studies have been carried out to determine the parameters on which this significant food source depends in mushroom production. Studies have revealed that some mushrooms are sensitive to light and that yield and quality increase in direct proportion to the light (Roshita & Goh, 2018; Zhang et al., 2021). The formation of fruiting bodies of edible mushrooms is closely related to light. Light plays an important role in the growth and metabolism of edible mushrooms; It effects the mycelium growth, primordium formation, morphology of fruiting bodies (cap and color formation), and also regulates the physiological and biochemical process and nutrient metabolism of edible mushrooms (Roshita & Goh, 2018; Marim et al., 2020; Ye et al., 2021). Effecting of photosensitive proteins by light sometimes reveals wide effects on gene structure (Fuller et al., 2015). There are many effects of light, including the impact of different wavelengths on mushrooms, the behavior of light on various fungal species (Poyedinok et al., 2015), the effects of varying light duration on the product, and the developmental stage of the fungus (Nakano et al., 2010). The light effects not only the yield or physical but also on the content of bioactive components according to the study conducted by Zawadzka et al. (2022). Especially the duration of the light given to the product is also important.

Pleurotus species are highly valued as edible mushrooms with significant commercial importance worldwide. In addition to their high nutritional value, *Pleurotus* spp. have an important place in nutraceutical science with their medical uses as anticancer, anti-cardiovascular diseases, antidiabetes, antioxidant and hepatoprotective (Khan & Tania, 2012). This group comprises various species such as *Pleurotus ostreatus, P. sajor*-caju, *P. cystidiosus, P. cornucopiae, P. pulmonarius, P. tuberregium, P. sapidus, P. citrinopileatus*, and *P. flabellatus*, which are cultivated in temperate and subtropical regions globally. The cultivation of *Pleurotus* species offers numerous benefits, including fast mycelial growth, strong saprophytic colonization capabilities, easy and cost-effective cultivation methods, and a variety of species that can thrive in different climates. Recently, the commercial value of *Pleurotus* species has significantly increased due to these advantages (Zervakis & Balis, 1996). The mycelium of mushrooms from the *Pleurotus* genus does not require light for its growth (Sharma, 2004), nevertheless, light is necessary for the proper development of carpophores (Royse, 1991). Trukhonovets (1991) maintains that during the period of carpophore development and growth, light is an important factor in deciding about yielding and morphological characteristics of fruiting bodies.

Visible lights are located in the electromagnetic radiation spectrum, between infrared and ultraviolet lights (Anonymous, 2024). Visible light bands from red to violet are the colours seen by human beings (Figure 1). These light bands are also effective in the growth of plants. Similarly, the effects of light on mushroom quality have also been proven by some studies in the literature (Kap-Duk, 2000; Wu et al., 2013; Wang et al., 2020; Ryu et al., 2023). Different types of light likely have effects on the yield as well as the quality of *P. ostreatus.* Within the scope of this research, it was aimed to determine the effect of different light types on the yield and physical characteristics of *P. ostreatus* such as fruit body colour and size by using a computer-controlled automation system designed to physically operate the light sources.

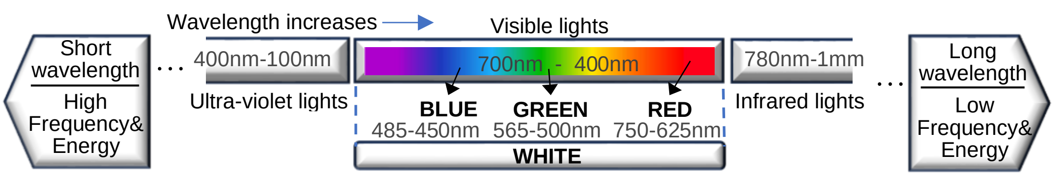

Figure 1. The light bands in electromagnetic spectrum.

Şekil 1. *Elektromanyetik spektrumdaki ışık bantları.*

MATERIALS and METHODS

Materials

The mushroom growing substrate used in the experiment was obtained from Asva Agriculture Ltd. Co. (Kemalpasa, İzmir). The mushroom strain used in the experiment was the "3002" strain of the commercial "Amycel" company related to *Pleurotus ostreatus* species.

The electronic automation system in the study was used for the timing of colour lights at the desired time interval and duration. It drives two 16-channel relay card modules to control direct current (DC) LED strips installed on up to 32 different lighting zones. The automation system has a microcontroller board, real-time-clock (RTC) module, parameter storage electrically-erasable programmable read only memory (EEPROM) chip, microSD card module for data logging, RS485 module (MAXIM, 2003) for MODBUS communication for remote control, an operator panel as human machine interface (HMI), a personal computer (PC) power supply, and two 16 channel relay module boards.

The microcontroller board was selected as Arduino Mega 2560 R3 because it has plenty of digital input output ports and four RS232 channels (ARDUINO, 2024). For timing the current date and time data was acquired from DS3231 RTC module (Anonymous, 2015). The RTC module has also AT24C32 EEPROM chip (MICROCHIP, 2003) and it is used to store and retrieve of zone active lighting time and the time period data. The micro-SD card module [ref] was also connected to the Arduino Mega 2560 R3 board for data logging. RS485 module was used to convert Arduino mega RS232 serial channel to RS485 MODBUS communication protocol (Yue, 2020) using a Weintek Easyview Operator panel as a remote terminal unit (RTU) (WEINTEK, 2017). 16 channel relay card (Anonymous, 2018) was an optically isolated digital 5V input controlled module and was usually used for automation for Arduino boards, Raspberry Pi boards and programmable logic controllers (PLCs) (Anonymous, 2011). SMD5050 is an LED chip that it can create light in different colours with 3 different RGB colour inputs (Anonymous, 2023). SMD 5050 contains three LEDs in a 5.0mm x 5.0mm area. Thus, an SMD5050 LED produces three times more light than a single-diode SMD3528 chip. Therefore, it is mainly used as "area lighting" and can replace lamps or LEDs used for room or indoor lighting. Figure 2 shows SMD 5050 RGB LED chip and RGB LED module.

Figure 2. SMD 5050 RGB LED chip (left) and RGB LED module (right).

Şekil 2. *SMD 5050 RGB LED çipi (solda) ve RGB LED modülü (sağda).*

The electronic system hardware schematic was given in Figure 3. The schematic shows the necessary electronic components and their connections.The control software initialized RTC3231 module, AT24C32 EEPROM chip, microSD card module, RS485 module, and 32 channel relay with initial values. Then, RTC date and time values were read from RTC module, and the zone relays timings and activation time parameters were read from EEPROM chip. RS485 operator panel poll operation was performed to change zone time values and update the EEPROM values. Finally, relays were controlled one by one to light colour LED strips because their pre-determined times. That control loop continued to the point that the operator stops the automation.

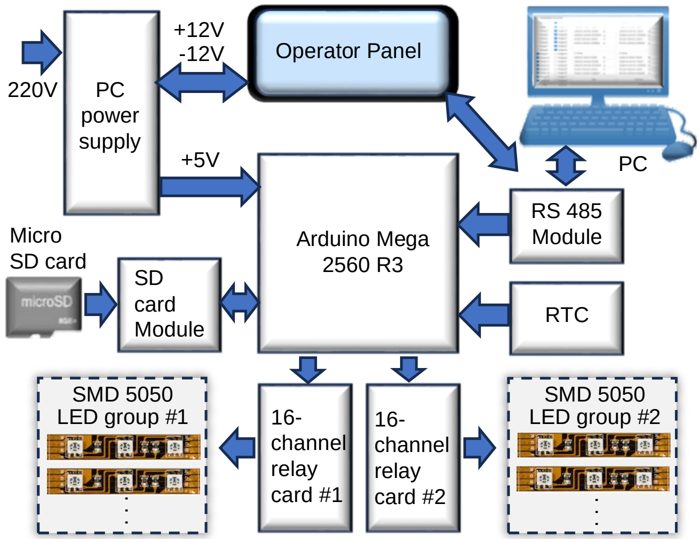

***Figure 3**. The electronic system hardware schematic.*

***Şekil 3.** Elektronik sistem donanım şeması.*

Method

The general algorithm of the control software was given in Figure 4.

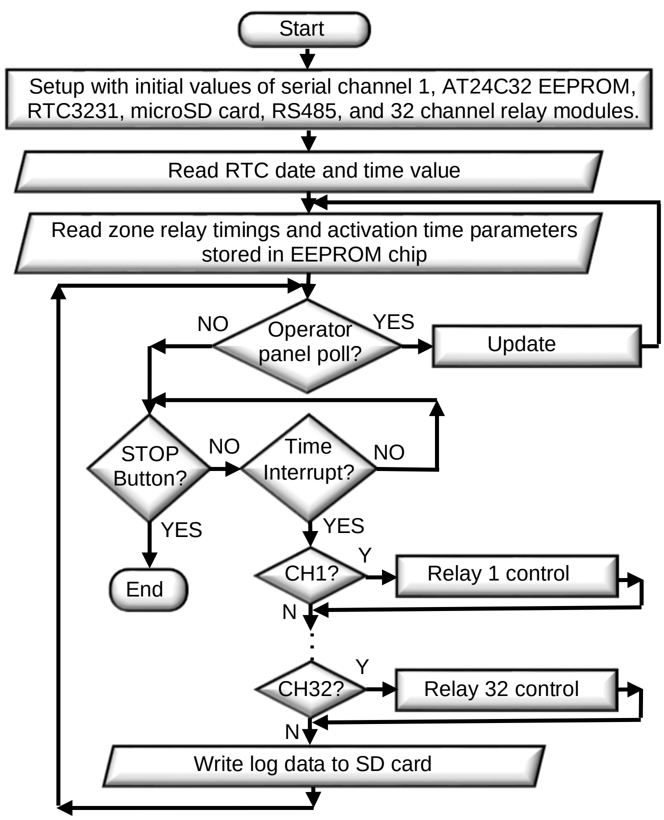

Figure 4. The algorithm of the control software.

***Şekil 4**. Kontrol yazılımının algoritması.*

The cultivation studies were carried out in the mushroom production rooms of Ege University Bergama Vocational School, which have computer-controlled automation systems. The spawn inoculated growing substrates were placed on the shelves in the production rooms depending on the light colour and lighting duration according to the random blocks experimental design with 8 replications for each application. In the study, each compost bag weight was prepared as 4 kg and the bags were inoculated with 3% (w:w) spawn. During the mycelial development period, the temperature of the production rooms was set at 25±2°C, humidity was kept at 85-90%, and fresh air was not supplied during this period (Figure 5).

Figure 5. A photo from the production room.

Şekil 5. *Üretim odasından bir fotoğraf.*

After the completion of mycelial development, the lightening was applied for 8 and 12 hours with white, red, blue, and green coloured LED lamps depending on the application to support the formation of outline and caps (Table 1). The application areas were surrounded with black bags to not be affected by each other. Furthermore, a control application using a fluorescent lamp was conducted for a duration of 8 hours (Atila, 2017). During this period, the room temperature was adjusted to 16-18°C, and the humidity was maintained at 85-90%. Maintenance procedures such as ventilation were carried out (Stamets, 1993). In this research, the total amount of the product obtained from each unit in a production period was calculated over 4 kg substrates and determined as total yield (g). The number of days until pinhead initiation, the number of days until the first harvest and the total number of mushrooms were determined. Average mushroom weight, cap diameter, stem diameter and stem length were determined.

***Table* 1**. Light colours and duration of lighting used in the experiment

Çizelge 1. *Denemede kullanılan ışık renkleri ve aydınlatma süreleri*

Application code	Duration of lighting (hours)	Colour
Control	8	Fluorescent
W:8	8	White
R:8	8	Red
B:8	8	Blue
G:8	8	Green
W:12	12	White
R:12	12	Red
B:12	12	Blue
G:12	12	Green

Statistical analysis

All statistical analyses were carried out with SPSS (version 16). One–way ANOVA was used to assess the statistical significance of the results between groups. The means were compared using Duncan multiple range test ($p<0.05$).

RESULTS AND DISCUSSION

Effect of light colour and lighting duration on the production process and yield of *Pleurotus ostreatus*

A significant difference between applications ($p<0.01$) was found when evaluating the effect of different light colours and durations on the mushroom pinhead initiation time of *P. ostreatus*. Depending on the light colour and duration, pinhead initiation times were 23.38-26.25 days. In all applications, *P. ostreatus* fruiting bodies were harvested between 34.25-36.25 days of production, approximately 9-11 days after pinhead initiation. While R:8 treatment was the latest to pinhead initiation with 26.25 days, R:12 treatment was the latest to harvest mushrooms with 36.25 days. Girmay et al. (2016), reported that pinhead initiation occurred on the 17th day and harvesting of mature mushrooms occurred on the 27th day in the study they conducted in compost prepared using cotton seeds. In the studies, it is generally reported that the time taken for pinhead initiation in *P. ostreatus* mushrooms varies between 20-27th day depending on the medium used (Fan et al., 2000). At the end of the production period was analyzed, 851.88 to 970.50 g/4 kg substrates was harvested and the difference between the applications was not statistically significant ($p>0.05$) (Table 2). In a study using cotton seed substrate, the mushroom yield was reported to be 277.30 g/kg (Girmay et al., 2016), while in another study it was reported as 312.4 g/kg (Atila, 2017). The data obtained in the study were found similar to the previous studies. Siwulski et al. (2013) investigated the effects of fluorescent lamps on different *P. ostreatus* strains depending on different light intensity and illumination times and reported that the mushroom yields obtained with 6 h/day illumination were lower than 10-14 h/day, and the highest mushroom yield was obtained with 14 h/day illumination at 500 and 700 lx illumination intensity. Jang et al. (2014) reported that the highest product amount in *P. ostreatus* was obtained in blue+white light. In studies with other mushroom species, it has been reported that blue light induces pigmentation during shiitake protoplast oogenesis (Leatham & Stahmann, 1987), and blue light affects pinhead initiation and basidiocarp growth in *Coprinus stercorarius* (Ellis et al., 1999). It was also reported that higher mycelial biomass was formed in the liquid culture of reishi mushrooms under blue light (425-475 nm) (Zapata et al., 2009). However, no significant effect of blue light on yield and earliness of mushrooms was observed in our study. The difference between the applications in terms of the number of mushrooms was found to be significant and the highest number of mushrooms was obtained from W:8 (65.50) and G:8 (64.00).

Table 2. The effect of light colour and lighting duration on the production process and the yield of Pleurotus ostreatus

Çizelge 2. *Işık rengi ve ışıklanma süresinin Pleurotus ostreatus'un üretim süreci ve verimine etkisi*

Application	Number of days until pinhead initiation (days)	Number of days until the first harvest (days)	Total yield (g/4 kg growing substrate)	Number of fruit bodies (mushroom/4 kg growing substrate)
Control	24,25±0,37 ab	35,13±0,13 ab	868.88	54,00±3,09 abc
W:8	25,50±0,38 bc	34,63±0,38 a	970.50	65,50±5,49 a
R:8	26,25±0,41 c	35,25±0,16 ab	893.25	59,50±4,65 ab
B:8	24,63±0,32 abc	34,25±0,37 a	970.38	59,38±2,15 ab
G:8	24,63±0,56 abc	34,63±0,38 a	851.88	64,00±4,99 a
W:12	25,25±0,37 bc	34,50±0,33 a	942.50	45,88±2,55 c
R:12	25,50±0,63 bc	36,25±0,82 b	873.63	50,88±3,94 bc
B:12	25,00±0,19 abc	34,75±0,25 a	903.50	47,13±1,69 c
G:12	23,38±0,38 a	34,50±0,33 a	896.25	49,25±2,70 bc
p value	<0.001	<0.029	0.190	<0.001

According to Duncan test, there is no significant difference between the applications in the same column and indicated by the same letter.

Effect of light colour and lighting duration on average mushroom weight and fruitbody size of *Pleurotus ostreatus*

The average mushroom weight, fruitbody diameter, stalk diameter and stalk length were determined for different colour and lightening periods and significant differences were found between applications ($p<0.01$). The average mushroom weight varied between 13.44 and 20.93 g. In terms of fruitbody diameter, the highest value was obtained in B:12 with 9.59 cm, while the lowest values were measured in R:8 and R:12 with 5.97 and 5.92 cm, respectively. Stem diameter varied between 1.37-1.98 cm and the highest value was obtained from B:8 (1.98 cm) and B:12 (1.93 cm). Similarly, the highest values were determined from B:12 and B:8 in terms of stem length (Table 3).

Girmay et al. (2016) investigated the effects of different substrates contents on *P. ostreatus* mushrooms and reported that the diameter of the cap was 6.95 cm, and the stem diameter was 3.11 cm and the stem length was 2.95 cm with cotton seed substrate. In the study researching the effects of light intensity and illumination duration on *P. ostreatus*, the highest cap diameter, stem diameter and length were obtained at 500 and 700 lx illumination intensity and 14 h/day illumination (Siwulski et al., 2013). Jang et al. (2014) investigated the effects of different coloured LED light mixtures on the quality of *P. ostreatus* mushrooms. In the study, the lowest fruitbody diameter value was obtained with green+red light, while mushrooms illuminated with blue+green, green+white, blue+white and fluorescent lamps displayed the same characteristics. In addition, it was reported that the highest value of cap diameter/stem length was found in blue+white colour application, while the highest value of stem length was obtained from green+red colour light application. Blue light appears to be beneficial for mushroom cultivation, other mushrooms reported to increase fruitbody size in blue light include shiitake (Namba et al., 2002) and maitake (Sakamoto et al., 2005).

Table 3. Effect of light colour and lighting duration on average mushroom weight and fruit bodies size of Pleurotus ostreatus

Çizelge 3. *Işık rengi ve ışıklanma süresinin Pleurotus ostreatus'un ortalama mantar ağırlığı ve meyve gövdesi büyüklüğü üzerine etkisi*

Application	Average mushroom weight (g)	Cap diameter (cm)	Stem diameter (cm)	Stem length (cm)
Control	16,23±0,86 [cde]	6,23±0,46 [ef]	1,15±0,07 [cd]	1,59±0,07 [cd]
W:8	15,48±1,16 [de]	9,21±0,51 [ab]	1,83±0,08 [ab]	1,77±0,06 [bc]
R:8	15,46±0,83 [de]	5,97±0,19 [f]	1,40±0,02 [d]	1,46±0,03 [d]
B:8	16,46±0,48 [bcde]	8,42±0,22 [abc]	1,98±0,06 [a]	2,02±0,06 [a]
G:8	13,44±0,63 [e]	6,76±0,53 [def]	1,67±0,07 [bc]	1,73±0,07 [bc]
W:12	20,93±1,18 [a]	7,98±0,38 [bcd]	1,86±0,09 [ab]	1,91±0,13 [ab]
R:12	17,72±1,06 [bcd]	5,92±0,55 [f]	1,47±0,07 [cd]	1,53±0,05 [cd]
B:12	19,30±0,64 [ab]	9,59±0,34 [a]	1,93±0,05 [a]	2,03±0,05 [a]
G:12	18,56±1,44 [abc]	7,50±0,53 [cde]	1,70±0,06 [bc]	1,76±0,10 [bc]
p value	**<**0.000	**<**0.000	**<**0.000	**<**0.000

According to Duncan test, there is no significant difference between the applications in the same column and indicated by the same letter.

Figure 6 shows the photographs from *Pleurotus ostreatus* production under different light colour and duration.

Figure 6. *Pleurotus ostreatus production under different light colour and lighting duration.*

Şekil 6. Farklı ışık rengi ve aydınlanma sürelerinde Pleurotus ostreatus üretimi.

CONCLUSION

According to the results obtained in the study, wavelength and duration of light do not affect yield and earliness of *Pleurotus ostreatus* mushroom. However, it was observed that blue light had positive effects on fruitbody size which were among the quality criteria. However, the effects of light wavelength and duration on the storage process and bioactive content of the mushroom should be investigated in detail in further studies.

Data Availability

The data is kept confidential for further study reason.

Author Contributions

Conception and design of the study: TA, MÇ, LÖA; sample collection: TA, MÇ, LÖA; analysis and interpretation of data: TA, MÇ, LÖA; statistical analysis: TA, MÇ, LÖA; visualization: TA, MÇ, LÖA; writing manuscript: TA, MÇ, LÖA.

Conflict of Interest

There is no conflict of interest between the authors in this study.

Ethical Statement

We declare that there is no need for an ethics committee for this research.

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Article Description

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