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Study on Changes of Microclimate in Greenhouse of *Pleurotus nebrodensis* in Jizhou, Tianjin

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Abstract

Based on the air temperature (1.0 m and 1.5 m) every 10 minutes, ground temperature (0 cm, 10 cm and 20 cm) and air relative humidity (1.5 m) from the stations in the greenhouse, and the air temperature (1.5 m) every 10 minutes and air relative humidity (1.5 m) from the regional stations in Chutouling Town, Jizhou district of Tianjin from April 2019 to November 2020, the changes of the microclimate in the greenhouse of *Pleurotus nebrodensis* were studied. The results explained that 1) the heat preservation effect of the greenhouse was the best in spring, the effective accumulative temperature and active accumulated temperature in the greenhouse had increased by 203.7˚C and 233.7˚C, respectively, compared with that outside the greenhouse. In the sunny or cloudy days of summer, the range of temperature difference (TD) between inside and outside the greenhouse was wider, more than 90% of the TD ranged from −6.0˚C to 2.9˚C; 2) the minimum temperature occurred later because of heat preservation effect of the greenhouse, the delay time can reach about 30 minutes in spring, it was about 20 minutes in summer and autumn, and 10 minutes in winter, however, the maximum temperature appeared earlier, it occurred 50 minutes ahead of time in spring, and it has been advanced by 20 minutes in summer and 10 minutes in autumn and winter; 3) the greenhouse mainly played a role of increasing humidity, the humidity in the greenhouse basically was larger than that outside the greenhouse, except the periods of 03:10-07:20 in spring, 0:00-08:50 and 23:10-23:50 in winter; 4) the temperature in the greenhouse significantly positively correlated with the temperature outside the greenhouse, the stronger correlation also appeared between the ground temperature (at the depth of 0 cm and 10 cm) in the greenhouse and the temperature inside and outside the greenhouse, however, there was a weak correlation between the ground temperature (20 cm) and the temperature inside and outside the greenhouse, this implies that the change of temperature had less impact on the ground temperature at deeper soil layers. This paper is of significance in identifying the microclimate in the *Pleurotus nebrodensis* greenhouse.

Keywords

Pleurotus Ostreatusin Greenhouse, Microclimate, Variation Law

1. Introduction

Pleurotus nebrodensis meat is tender, it has high edible and medicinal value. With a short fruiting time, it can be planted all year round (Cao, 2017), and the market demand is great. Jizhou district (39˚45'N - 40˚15'N, 117˚05'E - 117˚47'E) in Tianjin city is in a warm temperate semi-humid continental monsoon climate zone, it has four distinct seasons, and it is suitable for the *Pleurotus nebrodensis* growth. The largest edible mushroom planting base in North China is in the Chutouling town of Jizhou, which is located in the hearts of Beijing, Tianjin, Tangshan and Chengde, the developed traffic makes it easy to transport *Pleurotus nebrodensis* (Cao et al., 2019). The growth and development of *Pleurotus nebrodensis* is greatly affected by the microclimate in the greenhouse (Xue & Zhao, 2006), especially the changes of temperature and ground temperature have a great influence on the yield of *Pleurotus nebrodensis*.

Study on the change characteristic of microclimate in the greenhouse is the key of meteorological disaster monitoring (Huang et al., 2011; Hou et al., 2015; Zhang et al., 2015) and early warning in greenhouse (Zhang et al., 2015; He et al., 2018). Recently, temperature difference (TD) between the inside and outside the greenhouse have been researched. For example, Wang and Liu (1986) suggested that the TD in January in fir greenhouse in Gansu forest areas increased to 14.1˚C, Ji and Cui (1997) found that the TD in the vegetable greenhouse of Shanxi Province ranged from 0.7˚C to 3.0˚C at 6:00 o'clock on April 21, 1995. The TD in the vegetable greenhouse in Xinxiang city of Henan province was 11.5˚C in winter (Gao et al., 2003). In the recent 20 years, Liu et al. (2008) indicated that the maximum TD was about 20˚C in sunny days in Wuhan vegetable greenhouse from December 2006 to March 2007, and the maximum TD of strawberry greenhouse in Cixi City, Zhejiang Province in February was about 12˚C (Fu et al., 2011). However, the minimum TD in Xingyang City, Henan Province in January was 12.34˚C (Wang et al., 2013). Microclimate changes can be studied by simulating indoor climate parameters (Nebbali et al., 2012). The characteristics of microclimate can also be studied by the heat change of crops in the greenhouse (Kichan et al., 2012). The temperature inside the plastic shed in Xiaokunshan Town of Shanghai during the daytime is higher 1.2˚C - 4.9˚C than that outside the shed from May to June in 2015 (Gu et al., 2017). The vegetable greenhouses in Jiangsu Province increased by 3.5˚C in sunny days from February to November in 2015 (Wang et al., 2017). Analysis of hourly temperature inside and outside the shed from January to May in 2016 showed that the average temperature inside the shed in March was 2.9˚C higher than that outside the shed (Yan et al., 2017). The average temperature of tomato greenhouse in January increased by 8.5˚C compared with that outside the greenhouse (Dong et al., 2020). The warming range of vegetable greenhouses in Taiyuan, Shanxi was −2.4˚C - 1.3˚C in sunny days (Meng et al., 2020). Nutrients in different soil layers in cucumber greenhouse had a great impact on cucumber growth (Lian et al., 2020). The high and low temperature disaster of kiwifruit occurred at different times, and the low temperature freezing injury mainly happened in January (Zhang et al., 2021).

With the progress of society and the improvement of people's living standards, greenhouse cultivation has attracted wide attention. The microclimate of greenhouse is the key to maintain greenhouse cultivation. Previous studies have been carried out on the microclimate variation in greenhouse, but they mainly used the daily or hourly data with short observed period, and they also mainly concentrated on the vegetable crops. At present, because of the growing demand for fungus food, and minute-level meteorological observation can be provided, the microclimate change in the greenhouse of *Pleurotus nebrodensis* will be researched in this paper.

2. Data and Methods

2.1. Observation Sites

The observing site is located in Zhongyijianliang edible mushroom cooperative (117˚41'E, 40˚04'N) planting demonstration base of Chutouling Town, Jizhou District of Tianjin City. There is a microclimate observation station (CAWS2000) in the greenhouse, which is produced by the Beijing Huayun Shangtong Technology Co., Ltd.

2.2. Data

The data used in this paper are from observation stations in the greenhouses of *Pleurotus nebrodensis* and regional observation stations. Observation stations in the greenhouse provide air temperature every ten minutes (1.0 m and 1.5 m), ground temperature (at the depth of 0 cm, 10 cm and 20 cm), and air relative humidity (1.5 m) from April in 2019 to November in 2020. Regional observation stations provide air temperature every ten minutes (1.5 m) and air relative humidity (1.5 m).

2.3. Methods

2.3.1. Classification Standard of Seasons and Weather Types

The variation of microclimate in the greenhouse is closely related to seasons and weather types. In order to accurately analyze the relationship between microclimate in greenhouse and seasons and weather types, according to the climatology method, there are four seasons, including spring (March-May), summer (June-August), autumn (September-November) and winter (december-February in the next year). Based on the sunshine percentage (S), four weather types are defined: sunny (S ≥ 80%), cloudy (60% ≤ S < 80%), cloudy (20% ≤ S < 60%) and overcast sky (0 ≤ S < 20%).

2.3.2. Frequency of Regulation Effect on Temperature in the Greenhouse

In order to quantitatively study the regulation effect on temperature of *Pleurotus nebrodensis* greenhouse, the temperature outside the greenhouse can be divided, with intervals of 5˚C, and the TD between the inside and outside of the greenhouse also was divided in a 3˚C interval, then the frequency of regulation effect on temperature can be calculated. For example, if the total observation number was N, the number that the temperature outside the greenhouse was between 0.0 and 5.0˚C, and the TD was about 0.0˚C - 3.0˚C, was M_1, then the frequency of regulation effect on temperature (F_1) can be calculated by the Formula (1):

$$F_1 = \frac{M_1}{N} \times 100\% \quad (1)$$

2.3.3. Accumulated Temperature

Accumulated temperature can reflect the demand of crops for heat, which is divided into active accumulated temperature and effective accumulated temperature. Active accumulated temperature refers to the sum of active temperatures which is higher than or equal to the biological zero temperature during crop growth period, effective accumulated temperature refers to the sum of the difference between active temperature and crop biological zero temperature during the growth period of crops, which is the main index reflecting the influence of temperature on crop growth (Su et al., 2020).

2.3.4. Correlation Analysis

Correlation analysis is a statistical method which can reflect the relationship between two or more variables, the larger correlation coefficient indicates the stronger relationship. In this paper, the correlation between the temperature inside and outside the greenhouse, as well as the temperature and ground temperature, were analyzed, which can help to realize the variation curve of the temperature and ground temperature.

2.3.5. Regression Analysis

Regression analysis is a statistical regression method that can determine the quantitative relationship between two or more variables. The regression equation is obtained through regression analysis, and the independent variable factor can be used to predict the dependent variable. In this paper, the temperature outside the shed (1.5 m) and time were taken as independent variables, and the temperature inside the shed (1.5 m) was taken as the dependent variable. The regression equations were established respectively to analyze the variation law of temperature inside the shed, and the main meteorological factor affecting the growth of

Pleurotus nebrodensis.

3. Results

3.1. Accumulated Temperature Inside and Outside the Pleurotus Nebrodensis Greenhouse

The biological zero temperature of *Pleurotus nebrodensis* was 5˚C. Compared the effective accumulated temperature and active accumulated in *Pleurotus nebrodensis* greenhouse with that outside the *Pleurotus nebrodensis* from April 2019 to November 2020, they both increased 243.1˚C and 393.1˚C, respectively. Accumulated temperature behaved differently in different seasons, the warming effect in spring and winter was significant. The regulation effect of greenhouse on temperature (warming and cooling effect) was very important for the cultivation of *Pleurotus nebrodensis*, which weakened the influence of drastic changes in ambient temperature on hypha growth and effectively avoided the sharp decline in yield caused by high and low temperature disasters.

3.2. Characteristic of Temperature Inside and Outside the *Pleurotus nebrodensis* Greenhouse

3.2.1. Diurnal Variation Characteristics of Temperature

The temperature inside and outside the greenhouse is greatly affected by the seasonal change. Figure 1 displayed the diurnal variation of temperature at 1.5 m inside and outside the greenhouse in four seasons. It can be seen that in spring and winter, the greenhouse represented warming effect, especially in winter.

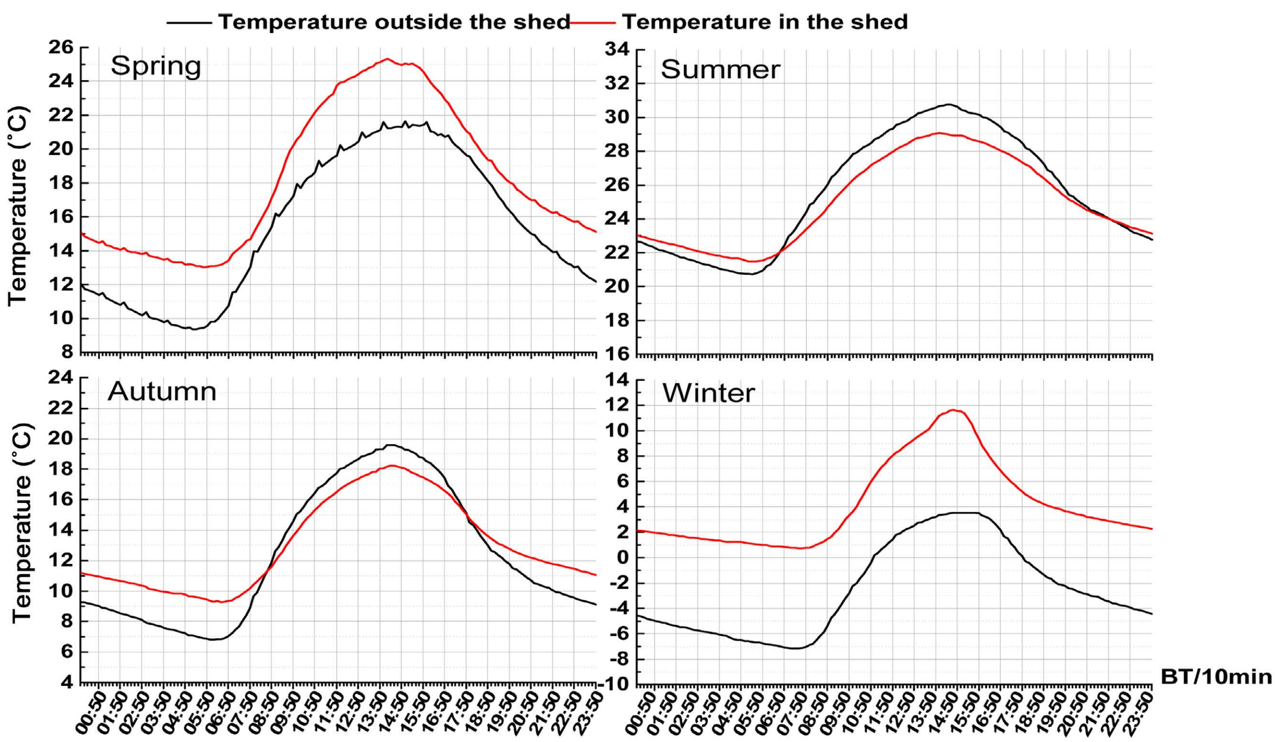

Figure 1. Diurnal variation of 1.5 m temperature inside and outside the greenhouse in four seasons.

While in summer and autumn, it had cooling effect in the daytime, and warming effect in the night and morning. The minimum (maximum) temperature inside and outside the greenhouse in spring appeared at 5:50 (14:10) and 5:20 (15:00), respectively, it occurred at 5:30 (14:00) and 5:10 (14:20) in summer, at 6:30 (14:30) and 6:10 (14:20) in autumn, and at 7:30 (14:40) and 7:20 (14:50) in winter. Overall, due to the heat preservation effect of greenhouse, the occurrence time of daily minimum temperature in the greenhouse was later than that outside the greenhouse. The delay effect in spring was the most significant, it can reach about 30 minutes, and then in summer and autumn it was about 20 minutes, while in winter it was only 10 minutes. The daily maximum temperature in the greenhouse appeared earlier than that outside the greenhouse, the early effect in spring was remarkable, it achieved about 50 min, then it can reach about 20 minutes in summer, 10 minutes in autumn and winter. In summer, the temperature outside the greenhouse was hot, although the temperature in the greenhouse declined by 0˚C - 1.7˚C, it was still higher. The temperature for the *Pleurotus nebrodensis* mycelium growth should be controlled below 28˚C, therefore, greenhouse ventilation from 11:50-16:50 in summer is necessary to reduce the temperature inside the greenhouse (Xue & Zhao, 2006).

The temperature in the greenhouse also had obvious temporal variation characteristics. At dawn, it reached the lowest value, then after sunrise in the morning, it increased rapidly, and it can reach the peak value around 14:00 pm. After 15:00 pm, it displayed a declined trend, and it decreased slowly until the night. The rate of temperature change in greenhouse not only had to do with time, but also was related to human regulation, for example, if the plastic sheeting is opened in the morning, the increasing rate of the temperature will become quickly. Table 1 displayed the relationship between temperature and time. It can be seen that the change characteristic of temperature can be fitted by the quadratic curve in four seasons ($p < 0.05$), based on these regression equations, the temperature in the greenhouse at any time can be forecasted.

3.2.2. Correlation Analysis of Temperature Inside and Outside the Greenhouse

Table 2 indicated the relationship between the inside and outside temperature of the greenhouse. It suggested that they had strong positive correlation ($p < 0.01$)

Table 1. Regression analysis between air temperature in the greenhouses and time.

	equation	r	r^2	r0.01
Spring	$y = 7.849 + 0.71x - 0.02x^2$	0.852**	0.7295	0.826
Summer	$y = 4.589 + 0852x - 0.02x^2$	0.9278**	0.8609	0.852
Autumn	$y = 3.773 + 0.622x - 0.007x^2$	0.9665**	0.934	0.826
Winter	$y = 5.275 + 0.947x - 0.04x^2$	0.8202*	0.6727	0.826

Note : * and ** denote the regression analysis pass 95% and 99% significance level, respectively.

Table 2. The relationship between the temperature inside and outside of the greenhouses (x and y are the outside and inside temperature of the greenhouses).

	Time	equation	r
Spring	00:00-23:50	y = 0.656x + 8.141	0.8516**
Summer	00:00-06:40	y = 0.823x + 4.398	0.8971**
	06:40-21:50	y = 0.758x + 5.578	0.8943**
	21:50-23:50	y = 0.720x + 6.722	0.8357**
Autumn	00:00-08:40	y = 0.820x + 3.482	0.9558**
	08:40-17:40	y = 0.833x + 1.833	0.9646**
	17:40-23:50	y = 0.833x + 3.165	0.9645**
Winter	00:00-23:50	y = 0.790x + 6.183	0.7809**

Note: ** denotes the correlation coefficient passes 99% significance level.

at some time periods in all four seasons, and the regression equation was also established. Base on the linear regression equation, the temperature in the greenhouse can be estimated.

3.2.3. Regulation Effect of Greenhouse on Temperature

The greenhouse can help the temperature increasing or decreasing, the temperature adjustment effect from greenhouse is linked to the seasons and weather types. For example, the weather types in summer can be divided into four types, such as sunny, partly cloudy, cloudy and overcast sky. Figure 2 illustrated the temperature adjustment effect under different weather types in summer.

In sunny days, when the temperature outside the greenhouse ranged from 15.1˚C to 35.0˚C, and the TD was about −6.0˚C - 2.9˚C, the frequency of temperature control effect of greenhouses (FTCE) was 93.6%. While the TD range was between −6.0˚C and −0.1˚C, the greenhouse had a cooling effect, and the FTCE was 57.6%, furthermore, when the TD changed from 0˚C to 11.9˚C, the greenhouse had a warming effect, and the FTCE was 36%. In partly cloudy days, when the temperature outside the greenhouse range was between 15.1 and 35.0˚C, and the TD was between −3.0 and 2.9, the FTCE can reach 94.0%. If the TD concentrated upon a range of −3.0˚C - −0.1˚C (0˚C - 2.9˚C), the greenhouse represented cooling (warming) effect, and the FTCE was 65.8% (28.2%). In cloudy days, when the temperature outside the greenhouse changed from 15.1 to 35.0˚C, and the TD range was between −6.0˚C and 2.9˚C, the FTCE was 94.6%, if the TD concentrated upon a range of −6.0 - −0.1 (0˚C - 2.9˚C), the greenhouse represented cooling (warming) effect, and the FTCE was 66.0% (28.62%). In overcast days, when the temperature outside the greenhouse ranged from 15.1˚C to 35˚C, and the TD was between −3.0˚C and 2.9˚C, the FTCE was 91.9%. If the TD concentrated upon a range of −3.0˚C - −0.1˚C (0˚C - 2.9˚C), the greenhouse had cooling (warming) effect, and the FTCE was 43.28% (48.27%).

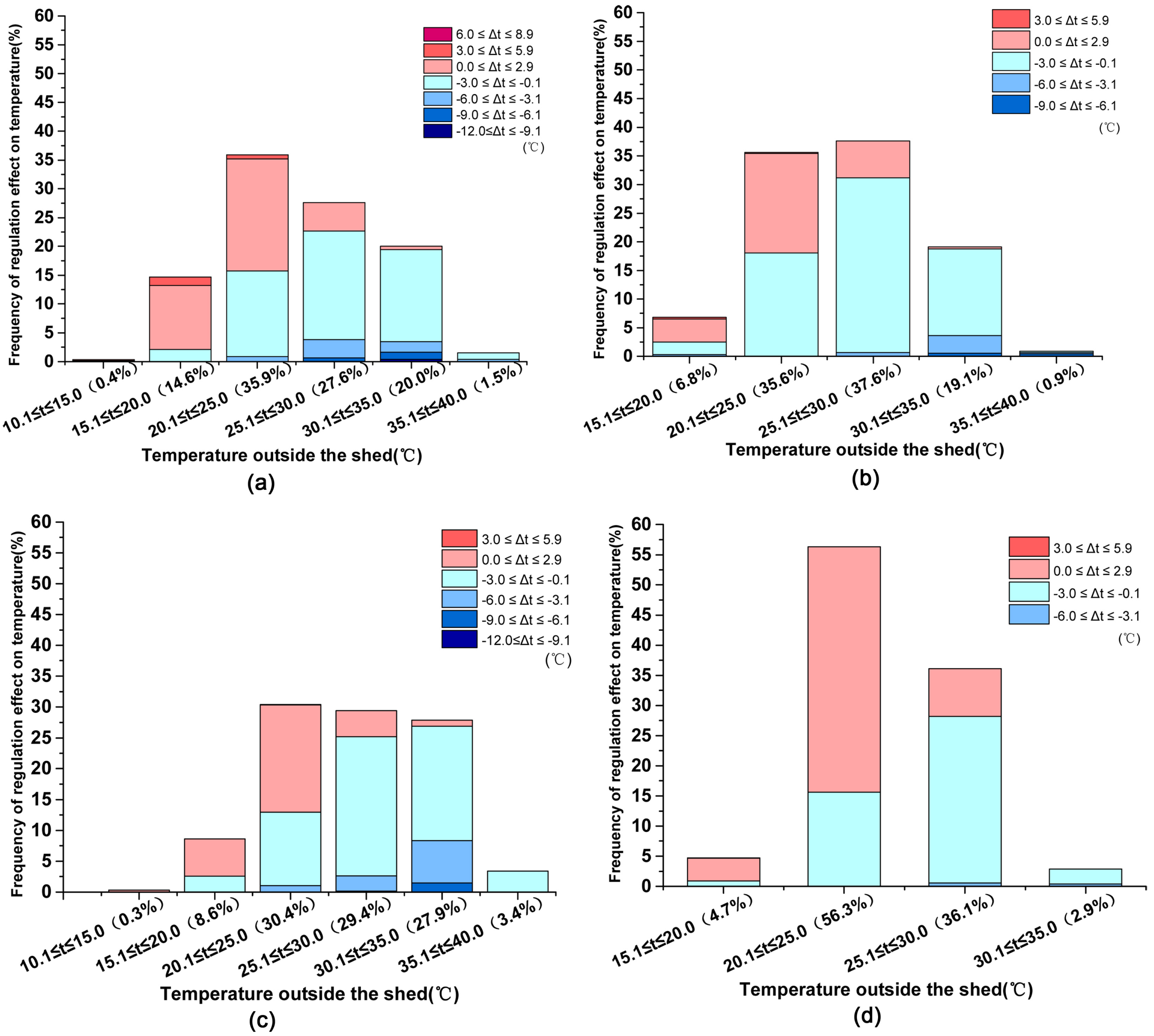

Figure 2. Frequency distribution of summer greenhouse temperature regulation effect. (a) Clear day; (b) partly cloudy; (c) cloudy; (d) overcast sky.

To sum up, in the sunny, partly cloudy and cloudy days, more than 90% of temperature outside the greenhouse was between 15.1˚C and 35˚C, however, in overcast days, temperature outside the greenhouse ranged from 20.1˚C to 35.0˚C, these features were similar to that in spring, in sunny and cloudy days, the TD ranges was wide, more than 90% of which was between −6.0˚C and 2.9˚C.

3.3. Temporal Variation of Relative Humidity Inside and Outside the Greenhouse

Figure 3 represented the daily variation of relative humidity inside and outside the greenhouse in the four seasons. The relative humidity outside the greenhouse reached the peak value before and after sunrise, and the minimum value

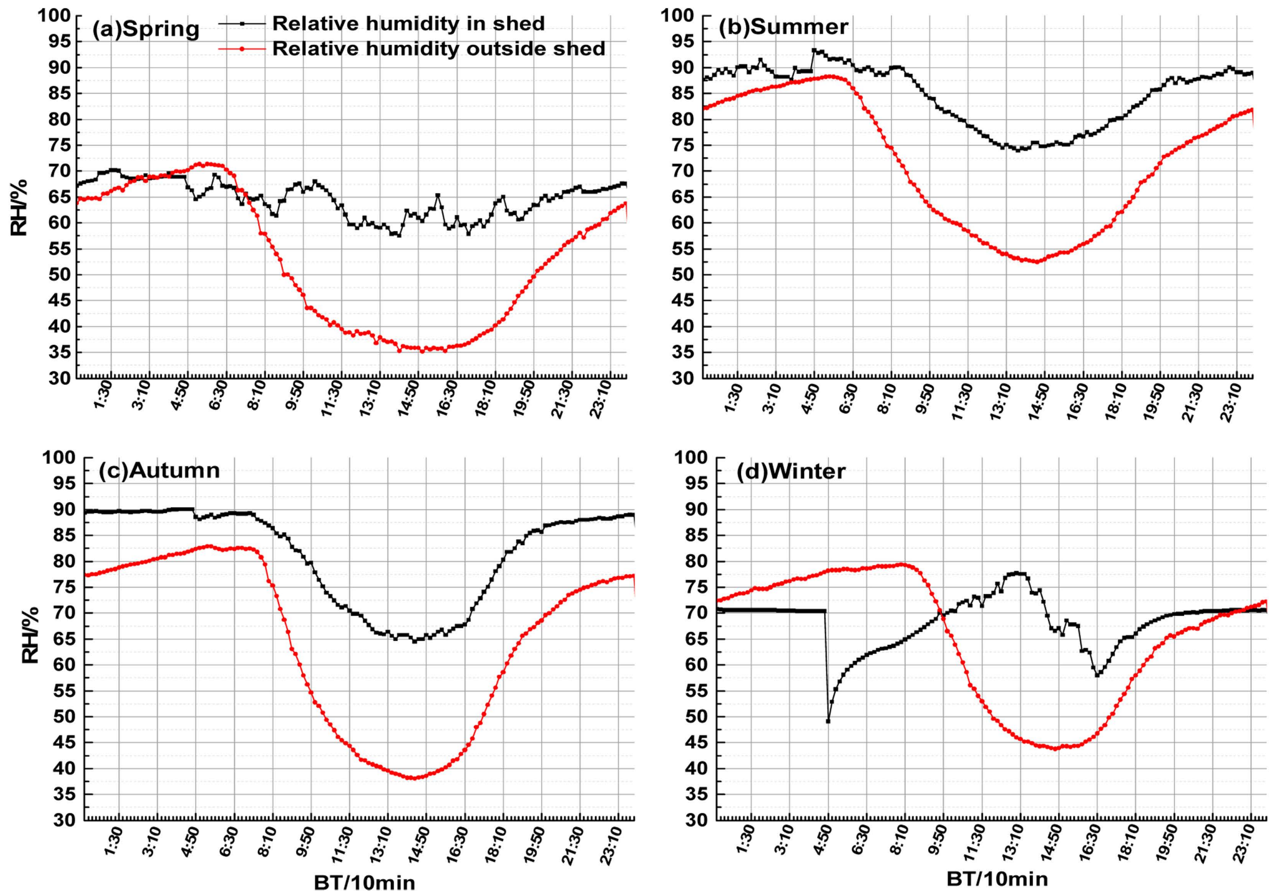

Figure 3. Diurnal variation of relative humidity of 1.5 m air inside and outside greenhouse in four seasons.

occurred in the afternoon, these features were consistent in all the seasons, but they were opposite, compared with the daily change of temperature at 1.5 m outside the greenhouse. In summer and autumn, the humidity in the greenhouse was significantly higher than that outside the greenhouse, which represented humidifying effect, especially during the day. In spring, the greenhouse mainly played the role of humidification, but from 03:10 to 07:20 in the morning, the humidity in the greenhouse was less than that outside the greenhouse. In winter, except the two periods of 0.00-08.50 in the morning and 23.10-23.50 at night, the greenhouse mainly had a humidifying effect at all other times. In summer and autumn, the daily changes of humidity was consistent with that outside the greenhouse, while in spring and winter, there were larger difference between the humidity inside and outside the greenhouse, which is related to the too low humidity during the day outside the greenhouse. The most suitable humidity for the growth of mycelial and fruiting body of *Pleurotus nebrodensis* was about 60% - 62%, too low or high humidity are both bad news for *Pleurotus nebrodensis* growth, therefore, artificial humidifying was necessary in spring and winter. In winter, the humidity in the greenhouses can reach 70% before sunrise, this may affect the feeding speed of *Pleurotus nebrodensis*, so the humidity in the greenhouse needed to be reduced sharply by opening the greenhouses manually.

It is needed high humidity when *Pleurotus nebrodensis* begins fruiting, and the most suitable humidity is about 90%, so artificial humidifying is needful for promoting fruiting in spring and winter, while in summer and autumn, in order to protected phage from spoiling, it is needed to open and ventilate the greenhouse at night, and artificially humidifying from 10:00 to 20:00 in summer and from 08:00 to 20:00 in autumn.

3.4. Correlation Analysis of Temperature and Ground Temperature in Greenhouse

There is a complex correlation between the temperature of different heights and ground temperature at different depth in the *Pleurotus nebrodensis* greenhouse. As shown in **Table 3**, there were significantly positive correlation between the temperature (1.0 m and 1.5 m) inside the greenhouse and the temperature (1.5 m) outside the greenhouse, meanwhile, both the temperature at 1.0 m and 1.5 m were positively correlated in the greenhouse. The ground temperature at 0cm and 10 cm depth had significantly positive correlation with the temperature inside and outside the greenhouse, while the correlation between the ground temperature at the depth of 20 cm with the temperature was weak. In general, the ground temperature interacted with the air temperature in the greenhouse, and the temperature increasing had significantly impact on the ground temperature, especially at the shallow depth.

3.5. Comparative Analysis of Temperature and Ground Temperature in the Greenhouse

Table 3 illustrated the interactions between temperature and ground temperature in the greenhouse, however, both the temperature and ground temperature displayed the different characteristics in the four seasons. Moreover, **Figure 4** indicated the daily variation of the temperature and ground temperature in all four seasons. In spring and summer, the ground temperature at the depth of 0 cm was basically lower than that at the depth of 10 cm within a day, however, the

Table 3. Correlation between air temperature and ground temperature in greenhouse.

		temperature outside the shed/m	the shed temperature/m		ground temperature/cm	
		1.5	1.5	1.0	0	10
the shed temperature/m	1.5	0.96**				
	1.0	0.90*	0.94**			
soil depth/cm	0	0.89*	0.88*	0.80*		
	10	0.90*	0.91*	0.83*	0.99**	
	20	0.29	0.24	0.30	0.38	0.34

Note: * and ** denote the correlation coefficients pass the 95% and 99% significant level.

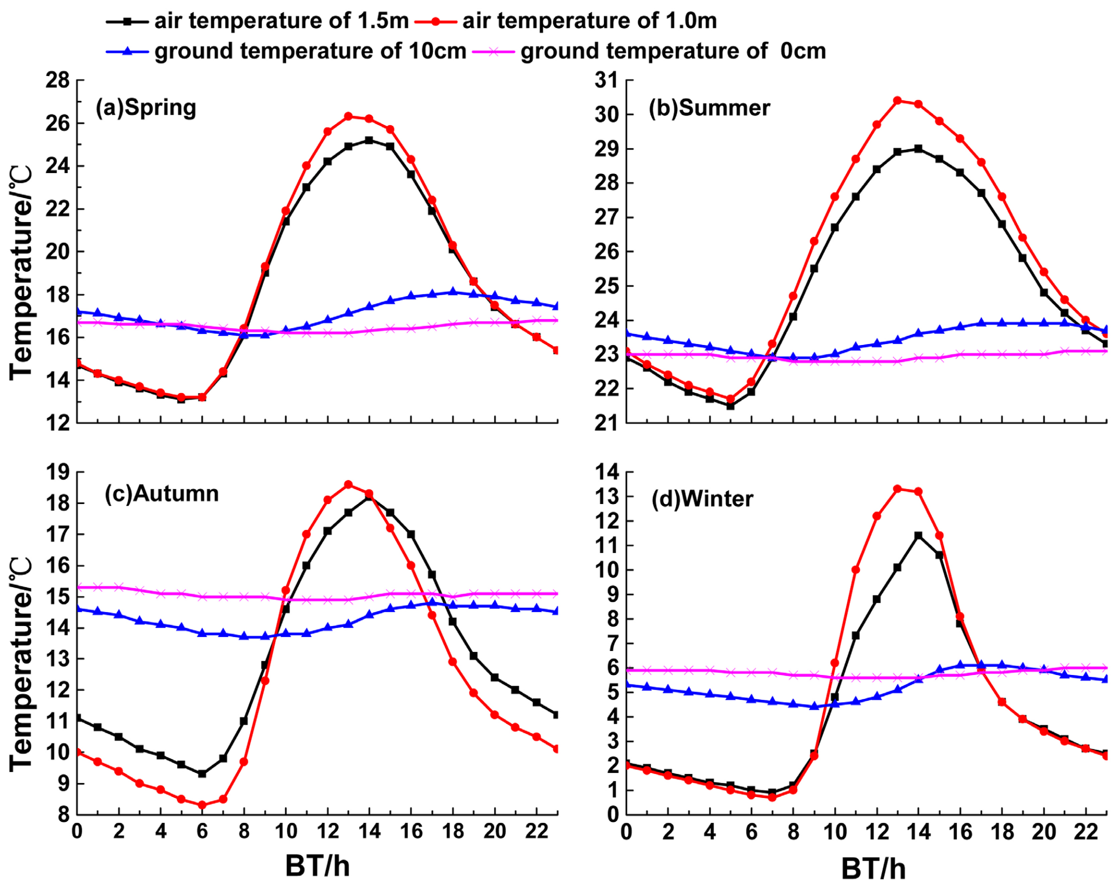

Figure 4. Diurnal variation of temperature and ground temperature in greenhouse.

opposite characteristics were occurred in autumn and winter. The air temperature at 1.0 m was higher than that at 1.5 m, but air temperature at 1.0 m was lower than that at 1.5 m before 09:00 in autumn and winter, this feature also occurred after 14:00 in autumn. In general, temperature had greater impact on the ground temperature with a certain lag. This means the ground temperature will also increase or decrease, when temperature increased or decreased over a period of time.

4. Conclusions

1) The accumulated temperature in the greenhouse increased in all seasons, except in summer. The effective accumulated temperature and active accumulated temperature in the greenhouse were higher than that outside the greenhouse all year round, the best heat preservation effect of the greenhouse was in spring. The effective accumulated temperature and active accumulated temperature increased 203.7˚C and 233.7˚C, compared with that outside the greenhouse, which can provide guarantee for realizing more than one crop a year.

2) Greenhouse made the minimum temperature occur later than that outside the greenhouse, especially in spring, the delay effect was the best, it can delay 30 minutes, in summer and autumn the delay time reached about 20 minutes, while

in winter, the delay time was only about 10 minutes. The maximum temperature occurred earlier than that outside the greenhouse, especially in spring, it appeared 50 minutes in advance, then in summer it can occur 20 minutes early, in autumn and winter it was about 10 minutes early. Furthermore, according to the regression equations between temperature at 1.5 m inside and outside the greenhouse and time, the temperature at all times can be predicted in the greenhouse.

3) The temperature control effect of *Pleurotus eryngii* greenhouse varies under different weather types. In summer sunny and cloudy days, the TD range is between −6.0 and 2.9, which accounts for around 90%.

4) The greenhouse may play a role of humidification, especially during the day. The humidity inside the greenhouse was less than that outside the greenhouse from 03:10 to 07:20 in spring, meanwhile, the humidity inside the greenhouse was also less than that outside the greenhouse during the two periods of 0.00-08:50 and 23:10-23:50 in winter. Except for the greenhouse control, the artificial regulation also had a greater impact on the humidity in the greenhouse.

5) The temperature inside the greenhouse had significant relationship with the temperature outside the greenhouse, the obvious relationship also occurred between the ground temperature (at the depth of 0 cm and 10 cm) and the temperature both inside and outside the greenhouse. However, the relationship between the ground temperature at the depth of 20 cm and temperature inside and outside the temperature was weak. This implied that the temperature had a little effect on ground temperature at deeper layer.

In spring and summer, because of the strong solar radiation and long sunshine time, both the air temperature and ground temperature in the greenhouse are high, meanwhile, soil has an insulating effect on ground temperature, and insulating effect is more obvious at the deep soil layer, therefore, the surface ground temperature was basically lower than that at the depth of 10 cm throughout the day. However, in autumn and winter the solar radiation is weaker and sunshine time is fewer than that in spring and summer, so the ground temperature presented an opposite feature in autumn and winter.

The temperature at 1.0 m was lower than that at 1.5 m before 09:00 in autumn and winter, the temperature after 14:00 in autumn also displayed the same feature. In general, the change of temperature had a greater impact on the ground temperature, which displays the hysteresis effect, it means the ground temperature will increase or decrease after the temperature increasing or decreasing during a period of time.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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