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Research Article

Antimildew Treatment and Control Effect of Citral on Bamboo

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Presently, chemical agents remain the main antimildew agents for bamboo, which has a certain negative impact on the environment and human health. Therefore, it is urgent to develop new environment-friendly antimildew agents for bamboo. Here, citral, an environment-friendly natural antibacterial agent, was used as an antimildew agent for bamboo. The orthogonal test was used to explore the effects of citral concentration, impregnation pressure, and pressurization time on the drug loading capacity of treated bamboo strips. The effect of antimildew-treated bamboo strips on bamboo mold was also discussed. Furthermore, the Fourier transform infrared spectroscopy and ultraviolet spectrophotometer were used to investigate the distribution of citral in bamboo strips. Results showed that the optimum technological parameters of citral mildew-proof treatment of bamboo were as follows: citral concentration: 0.795 mg/ml, impregnation pressure: 0.3 MPa, and pressurization time: 90 min. Also, citral was easy to volatilize, which decreased the citral content of bamboo strips after vacuum drying and showed the trend of a lower surface layer and a higher inner layer. The concentration of citral therefore had a significant effect on the drug loading of the antimildew-treated bamboo strips. Thus, it was difficult to achieve effective prevention and control of bamboo mold when bamboo strips were impregnated with a lower concentration of citral solution. When the concentration of citral reached 200 mg/ml, the prevention and antimold efficiency of antimildew bamboo strips reached over 100%. This study will provide references for the development and application of environment-friendly natural antibacterial agents in the field of bamboo mildew prevention.

1. Introduction

Bamboo is one of the fastest growing natural plants in the world, which has the advantage of tensile strength comparable to low carbon steel, good toughness, degradability, and regeneration. Compared with many natural materials, bamboo also has clear advantages in structure, cost, and the environment [1, 2]. Bamboo and its products have been widely used in decoration, architecture, furniture, gardens, and other fields [3–6]. However, they are susceptible to infection by mold, which not only affects the appearance and reduces the useful value but also results in allergies, asthma, and other diseases because of the large number of spores in the mold [7]. So, it is of great significance to conduct research on bamboo mildew prevention. At present, scholars at home and abroad have conducted many studies on bamboo mildew prevention [8–11]. However, most of these studies are chemical mildew prevention methods, and the antifungal agents used are mainly synthetic chemical agents, which have certain adverse effects on the environment and human health. Therefore, there is an urgent need to develop environment-friendly new bamboo mildew agents. Recently, the research and application of natural antibacterial agents derived from plants have been widely concerned. Citral mainly comes from Litsea cubeba essential oil [12], which has the characteristics of good antibacterial effects, wide antibacterial spectrum, and strong lemon flavor [13–16]. The European Commission and the US Food and Drug Administration have also recognized this compound as a safe food additive and perfume in cosmetics [17–19].

Therefore, using citral as a mildew agent for bamboo is not only green and safe but also expected to achieve better mildew-proof effect. Interestingly, there are few research reports on the mildew-proof treatment of bamboo with citral. Of interest in this study is to investigate what the inhibition performance of citral on bamboo mold would be. Also, because citral is easy to oxidize and volatilize, does it have a better control effect after it is used to treat bamboo? These problems are still unknown and need to be studied and discussed systematically. For this reason, the author took the lead on the research of citral's antimildew treatment technology and its control effect on bamboo mold. This study can lay the foundation and provide a theoretical reference for the popularization and application of citral in the field of bamboo antimildew.

2. Materials and Methods

2.1. Materials. Moso bamboo was processed into bamboo strips (length 50 mm × width 20 mm × thickness 5 mm). The bamboo strips did not contain bamboo nodes, and the moisture content was about 10%. Bamboo strips were purchased from Xizhuyuan Bamboo Products Factory in Zhenghe County, Fujian Province. Citral (97%), sodium dihydrogen phosphate and disodium hydrogen phosphate were purchased from Sinopharm Chemical Reagent Co., Ltd. Tween 80 was obtained from Shanghai Lingfeng Chemical Reagent Co., Ltd. The test strains are as follows: *Penicillium citrinum* (PC), *Trichoderma viride* (TV), *Aspergillus niger* (AN), and a mixed mold (Hun, which is mixed by PC, TV, and AN in equal proportions).

2.2. Methods

2.2.1. Experimental Design of Citral Mildew-Proof Treatment of Bamboo Strips. When the concentration of citral reached 100 mg/ml, the bacteriostatic rates of citral against PC, TV, AN, and Hun exceeded 100% [20]. On this basis, the concentration of citral was gradually diluted from 100 mg/ml to 0 mg/ml by the multiple dilution method. The minimum inhibitory concentration (MIC) of TV among the 4 molds was the highest, reaching 0.265 mg/ml [20]. Therefore, to make citral inhibit the growth of 4 kinds of molds, the experimental concentration of citral in this study was set at 1 time (0.265 mg/ml), 2 times (0.530 mg/ml), and 3 times (0.795 mg/ml) the MIC, pressurization time, and impregnation pressure of the 3 levels. These experimental conditions were set with reference to the research of Yu et al. [9]. The experiment of bamboo strips impregnated with citral was carried out by the L_9 (3^3) orthogonal test method [21]. The test scheme is shown in Table 1. Then, the same test number was treated twice, and the results were averaged. Furthermore, the SPSS v.11.0 software was used to perform range analysis and variance analysis on the orthogonal test data. The significance level was set at $P < 0.05$. During the test, a certain amount of citral was weighed and placed in a beaker. Then, Tween 80 accounting for 2% of the total volume and a proper amount of deionized water were added and mixed evenly to prepare citral solutions with different concentrations. After that, bamboo strips were placed in a sealed treatment tank, pressurized, and soaked in citral solution. Subsequently, they were taken out of the treatment tank, and absorption of the excess citral solution on the surface of bamboo strips was done. The resultant weight was also taken. Calculation of the drug loading capacity was then done according to formula (1). Similarly, based on drug loading, orthogonal test results and analysis were obtained, and the better parameters of citral mildew-proof treatment of bamboo were selected.

Table 1: Scheme of orthogonal test L_9 (3^3).

Test number	Citral concentration (mg/ml)	Pressurization time (min)	Impregnation pressure (MPa)
1	0.265	30	0.1
2	0.265	60	0.3
3	0.265	90	0.5
4	0.530	30	0.3
5	0.530	60	0.5
6	0.530	90	0.1
7	0.795	30	0.5
8	0.795	60	0.1
9	0.795	90	0.3

Table 2: Classification standard of surface infection levels of samples.

Infection value	Infected area of sample
0	No hyphae or mildew on the sample surface
1	Infected area of sample < 1/4
2	Infected area of sample 1/4–1/2
3	Infected area of sample 1/2–3/4
4	Infected area of sample > 3/4

$$R = \frac{(m_2 - m_1) \times C \times 10^6}{S}, \quad (1)$$

where R is the drug loading (g/m^2), m_2 is the mass of bamboo after treatment (g), m_1 is the mass of bamboo before treatment (g), C is the concentration of citral (mass fraction) (%), and S is the sum of 6 surface areas of bamboo (mm^2).

2.2.2. The Control Effect of Citral Mildew-Proof Treatment of Bamboo Strips. Following the optimal dipping process parameters obtained from the orthogonal test, bamboo strips were dipped into citral. Investigations were conducted according to the relevant regulations of national standard, "Test Method for Antimildew Agents in Controlling Wood Mould and Stain Fungi" (GB/T 18261-2013) [22]. Subsequently, the antimildew test on bamboo treated with citral solution was conducted. The infections of bamboo strips infected by PC, TV, AN, and Hun were observed every day to determine the infection values of the bamboo strips

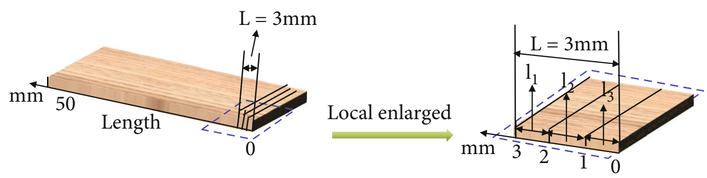

FIGURE 1: Schematic of the interception of l_1,l_2, andl_3.

TABLE 3: Orthogonal test results and range analysis.

Experiment number	Citral concentration (A) (mg/ml)	Pressurization time (B) (min)	Impregnation pressure (C) (MPa)	Drug loading (R) (g/m^2)
1	0.265	30	0.1	0.126
2	0.265	60	0.3	0.173
3	0.265	90	0.5	0.197
4	0.530	30	0.3	0.306
5	0.530	60	0.5	0.369
6	0.530	90	0.1	0.334
7	0.795	30	0.5	0.477
8	0.795	60	0.1	0.407
9	0.795	90	0.3	0.541
K_{1j}	0.497	0.91	0.868	
K_{2j}	1.009	0.949	1.020	
K_{3j}	1.425	1.072	1.043	
$\bar{K}_{1j}$	0.166	0.303	0.289	
$\bar{K}_{2j}$	0.336	0.316	0.340	
$\bar{K}_{3j}$	0.475	0.357	0.348	
R_j	0.309	0.054	0.058	
Excellent level	A_3	B_3	C_3	
The optimal combination	$A_3B_3C_2$ is citral concentration: 0.795 mg/ml, impregnation pressure: 0.5 MPa, pressurization time: 90 min			
Relationship	$A > C > B$			

(Table 2). Calculations to ascertain the antimold efficiency of the treated bamboo strips on bamboo mold according to equation (2) [22] were also conducted.

$$E = \left(\frac{1 - D_1}{D_0} \right) \times 100\%. \quad (2)$$

In the formula, E is the antimold efficiency (%), D_1 is the average infection value of the bamboo strips treated with citral solution, and D_0 is the average infection value of the bamboo strips in the control group.

2.2.3. The Control Effects of Bamboo Strips Treated with Different Concentrations of Citral. When the concentration of citral reached 100 mg/ml, the inhibition rates of citral on PC, TV, AN, and Hun were more than 100%. Based on this observation and volatile properties of citral, citral solutions with 6 concentrations of 75, 100, 125, 150, 175, and 200 mg/ml were prepared. Then, bamboo strips were treated with citral solution of these 6 concentrations under the conditions of better impregnation pressure and pressurization time. And the drug loading of bamboo strips was calculated according to Section 2.2.1. Finally, the control effects of bamboo strips treated with different concentrations of citral were discussed. From the results, analysis of the experimental operation processes and control effects was the same as Section 2.2.2.

2.2.4. Fourier Transform Infrared Spectroscopy (FT-IR) Analysis of Bamboo Strips Treated with Citral. After vacuum drying, a file was used to file the surface of the bamboo strips to get the bamboo powder and the powder was mixed with KBr according to the mass ratio of 1 : 100. Then, the powder was pressed into thin slices. After, the molecular structure was characterized and analyzed by the IR-Prestige-21 Fourier transform infrared spectrometer. Resolution of the FT-IR was at 4 cm^{-1}, and the wavelength range was set at 4000–500 cm^{-1}.

Table 4: Analysis of variance of orthogonal test results.

Source of difference	Type III sum of square	Degree of freedom	Mean square	*F* value	*P* value	Significance
Citral concentration	0.144	2	0.072	53.100	0.018	*
Pressurization time	0.005	2	0.020	1.757	0.363	
Impregnation pressure	0.006	2	0.030	2.222	0.310	
Error	0.003	2	0.020			

*Significant difference ($P < 0.05$).

2.2.5. Distribution of Citral in Mildew-Proof Bamboo Strips. Analysis of the distribution of citral in mildew-proof bamboo strips was qualitatively conducted by ultraviolet spectrophotometry. First, an equal mass of citral, Tween 80, and a mixture of citral and Tween 80 in equal masses was mixed with absolute ethanol to prepare a citral standard solution and Tween 80 standard solution, as well as the citral and Tween 80 mixed standard solutions which were then measured to check their absorbance at a wavelength range of 200–350 nm.

Second, we selected the mildew-proof bamboo strips (length 50 mm × width 20 mm × thickness 5 mm) with the best control effect in Section 2.2.3, and from the end to the middle along the length of the bamboo strips in the range of 0–1 mm (l_1), 1–2 mm (l_2), and 2–3 mm (l_3), it was cut into a thin layer of bamboo, respectively (see Figure 1 for the cutout diagram). Then, the bamboo powder was made using a crushing equipment. Subsequently, 0.05 g bamboo powder was diluted to 20 ml with absolute ethanol. After ultrasonication for 15 min, the mixture obtained was then placed in a centrifuge at 9000 r/min for 10 min. Then, the 0.1 ml supernatant was taken and diluted to 10 ml with absolute ethanol. Furthermore, the prepared citral ethanol solution, Tween 80 ethanol solution, and the antimold bamboo supernatant were then put into a quartz cuvette with an optical path length of 1 cm and scanned in a UV-1800 ultraviolet spectrophotometer to detect their absorbance at a wavelength range of 200–350 nm. Using absolute ethanol as a reference, the scanning step size was 1 nm.

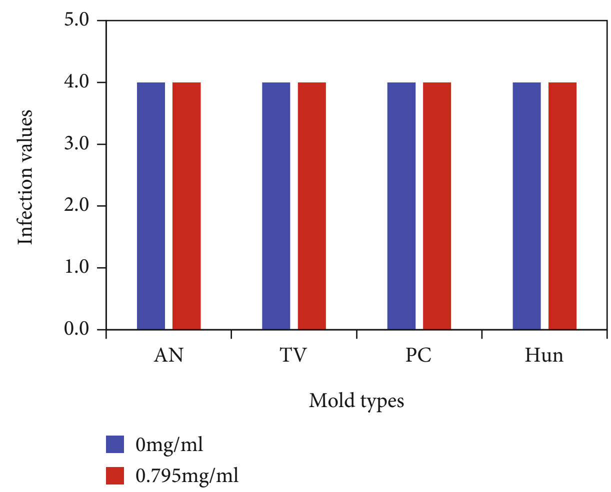

Figure 2: The mildew grade of untreated and treated bamboo strips on the 7th day.

3. Results and Discussion

3.1. Effect of Citral Antimold Treatment Process of Bamboo Strips on Drug Loading. The effects of the concentration of citral, pressurization time, and impregnation pressure on drug loading were studied by the orthogonal test. The results and range analysis are shown in Table 3.

According to the test results and range analysis in Table 3, when the concentration of citral reached 0.795 mg/ml, the drug loading of bamboo strips was 0.475 g/m^2, which was 2.86 times and 1.41 times that of the citral concentrations of 0.265 mg/ml and 0.530 mg/ml, respectively. Therefore, increasing the concentration of citral is the most effective way to increase the drug loading of the antimildew bamboo strips to enhance the antimildew performance of bamboo strips treated with citral. Similarly, in the effect of pressurization time on the drug loading of bamboo strips, with an increase in the pressurization time, the drug loading of bamboo strips was increased. In the effect of impregnation pressure on the drug loading of bamboo strips, also, with an increase in impregnation pressure, the drug loading of bamboo strips increased continuously. However, when the impregnation pressure reached 0.5 MPa, the drug loading of bamboo strips was 0.348 MPa, which was 1.02 times that of the impregnation pressure of 0.3 MPa. The drug loading of bamboo strips at 0.5 MPa was slightly different from that at 0.3 MPa. Therefore, when the impregnation pressure exceeded 0.3 MPa, it was of little significance to increase the impregnation pressure to increase the drug loading of bamboo strips.

In Table 3, the range values (R_j) of the citral concentration, impregnation pressure, and pressurization time were 0.309, 0.054, and 0.058, respectively. Among them, the range value (R_j) to the citral concentration was the largest, which was about 6 times the impregnation pressure and pressurization time. The concentration of citral had a great influence on the drug loading of bamboo strips, while the impregnation pressure and pressurization time had little effect. Therefore, the concentration of citral was the main factor affecting drug loading of bamboo strips, while the impregnation pressure and pressurization time were secondary factors. Therefore, the influence order of the factors was as follows: citral concentration > impregnation pressure > pressurization time. To further understand the significance of citral concentration, pressurization time, and impregnation pressure on the drug loading of citral antimold bamboo strips, variance analysis was conducted on the results of the orthogonal test. Results are shown in Table 4.

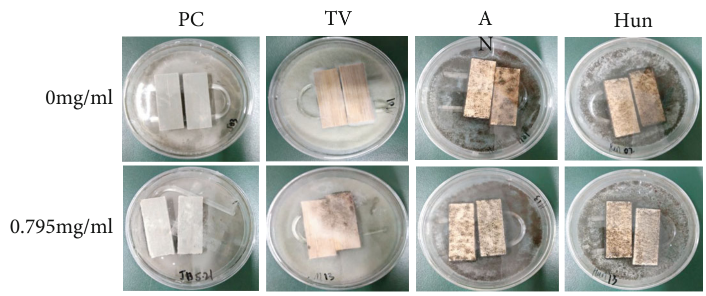

Figure 3: The mildew image of untreated and treated bamboo strips on the 7th day.

It can be seen from Table 4 that the P value corresponding to the citral concentration factor is 0.018 ($P < 0.05$). This result indicated which concentration of citral had a significant effect on the drug loading of bamboo strips. Also, the corresponding P values of the 2 factors were 0.363 and 0.310, respectively ($P > 0.05$), which indicated that the pressurization time and impregnation pressure had no significant effect on the drug loading of bamboo strips. The results of variance and range analysis also showed that the concentration of citral was the main factor affecting the drug loading of bamboo strips, while the pressurization time and impregnation pressure were secondary factors.

In summary, the concentration of citral had a significant effect on the drug loading of bamboo strips, and the impact of pressurization time and impregnation pressure was not significant. Therefore, better impregnation process parameters for citral antimold treatment of bamboo were citral concentration: 0.795 mg/ml, pressurization time: 90 min, and an impregnation pressure: 0.3 MPa.

3.2. Antimold Efficiency of Citral Mildew-Proof Treatment of Bamboo Strips. The antimildew treatment of bamboo strips was conducted with the optimum process of citral concentration set at 0.795 mg/ml (3 times of MIC), pressurization time at 90 min, and impregnation pressure at 0.3 MPa. Then, the antimildew test of bamboo was conducted. Results of the antimildew test on the 7th day are shown in Figures 2 and 3.

Figure 2 shows that on the 7th day of the antimildew experiment, the mildew grade of untreated and treated bamboo strips reached 4.0, while the antimold efficiency of citral was 0. Additionally, it can be seen from Figure 3 that the surfaces of the untreated and treated bamboo strips were covered with mold. Therefore, there was no significant difference in the degree of infection and the amount of surface mold growth between the untreated and treated bamboo strips within 7 days. Similarly, compared with citral directly acting on mold, the bacteriostatic rate of bamboo strips impregnated with citral was greatly reduced. Also, even if citral with 3 MIC was used for mildew prevention treatment of bamboo strips, it was impossible to realize the mildew prevention of bamboo. It was even more impossible to meet the 28-day mildew prevention test requirements specified in the national standard "Test Method for Antimildew Agents in Controlling Wood Mould and Stain Fungi" (GB/T 18261-2013) [21]. The main reason was that the drug loading of bamboo strips treated using this method was only

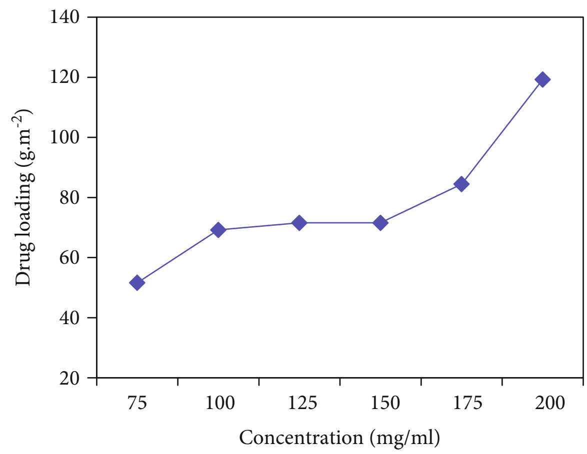

Figure 4: Drug loading of bamboo strips treated with citral at different concentrations.

0.472 g/m^2, which cannot meet the demand of common mold control of bamboo. Furthermore, as citral concentration was the main factor affecting the drug loading of bamboo strips, only by increasing the citral concentration greatly was the drug loading of bamboo strips greatly improved, and the requirements for bamboo mildew prevention were met.

3.3. Effect of Citral Concentration on Drug Loading of Treated Bamboo Strips. The effect of citral concentration on the drug loads of treated bamboo strips is shown in Figure 4.

It can be seen from Figure 4 that, with the increase of citral concentration, the drug loading of bamboo strips with different concentrations of citral was gradually increased. The drug loading of bamboo strips with six concentrations of citral was 51.620 g/m^2, 69.204 g/m^2, 71.566 g/m^2, 71.574 g/m^2, 84.457 g/m^2, and 119.250 g/m^2, respectively. So, increasing citral concentration is the most effective method to increase the drug loading of bamboo strips.

3.4. Effect of Citral Concentration on the Antimold Efficiency of Treated Bamboo Strips

3.4.1. Effect of Citral Concentration on Mildew Grade of Bamboo Strips. Bamboo strips impregnated with different concentrations of citral should be dried to a suitable moisture content before they can be applied. The bamboo strips

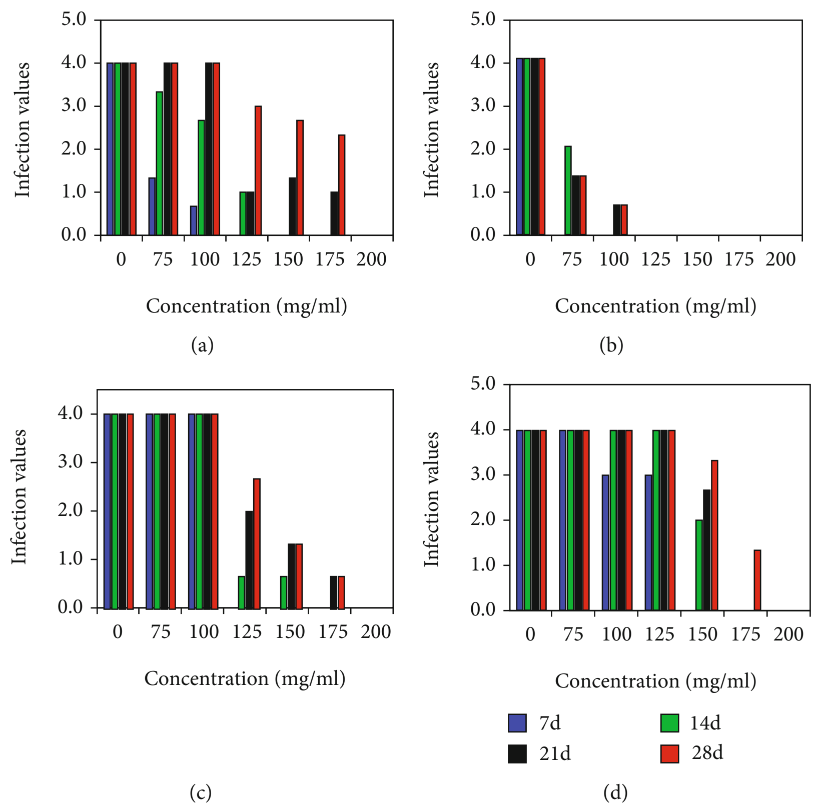

Figure 5: Molding grade of bamboo strips treated with different concentrations of citral within 28 days:(a) PC; (b) TV; (c) AN; (d) Hun.

impregnated with citral were, therefore, dried in a vacuum, and then, the antimildew experiment was conducted. The mildew grades of bamboo strips treated with citral with different concentrations within 28 days are shown in Figure 5.

It can be seen from Figure 5 that on the 7th day of the antimildew experiment, the infection values of PC, TV, AN, and Hun on the surfaces of bamboo strips (0 mg/ml) in the control group were 4.0, which indicated that untreated bamboo strips had no antimold efficiency on the 4 common molds in bamboo. It can also be seen from Figure 5(a) that on the 7th day of the antimildew experiment, the infection values of PC on the surfaces of bamboo strips treated with the 6 concentrations of the citral solution were 1.33, 0.67, 0, 0, 0, and 0, respectively. Similarly, on the 28th day, the infection values of bamboo strips treated with 6 kinds of citral solutions were 4.0, 4.0, 3.0, 2.67, 2.33, and 0, respectively, which indicated that bamboo strips treated with citral had no or low prevention and control effect on PC, whereas bamboo strips treated with 200 mg/ml citral still had good prevention and control effect on PC.

It can also be seen from Figure 5(b) that on the 7th day of the antimildew experiment, the infection values of bamboo strips treated with the 6 concentrations of the citral solution were zero, which indicated that treated bamboo strips had good prevention and control effect on TV. Similarly on the 28th day, the infection values of TV infection on bamboo strips treated with the 6 concentrations of the citral solution were 1.33, 0.67, 0, 0, 0, and 0, respectively. These results indicate that the bamboo strips treated with citral solutions of 75 mg/ml and 100 mg/ml had a lower effect on the prevention and treatment of TV, whereas the bamboo strips treated with citral solutions of 125 mg/ml, 150 mg/ml, 175 mg/ml, and 200 mg/ml still had a good preventive effect on TV.

Table 5: Antimold efficiency of bamboo strips treated with different concentrations of citral on the 28th day.

Concentration (mg/ml)	Antimold efficiency (%)			
	PC	TV	AN	Hun
0	0	0	0	0
75	0	66.75	0	0
100	0	83.25	0	0
125	25	100	33.25	0
150	33.25	100	66.75	16.75
175	41.75	100	83.25	66.75
200	100	100	100	100

It can also be seen from Figure 5(c) that on the 7th day of the antimildew experiment, the infection values of bamboo strips treated with citral solution at 6 citral concentrations of 75 mg/ml, 100 mg/ml, 125 mg/ml, 150 mg/ml, 175 mg/ml, and 200 mg/ml were 4.0, 4.0, 0, 0, 0, and 0, respectively. Similarly, on the 28th day, the infection values of AN infection on bamboo strips treated with the 6 kinds of citral solutions were 4.0, 4.0, 2.67, 1.33, 0.67, and 0, respectively. This result indicated that bamboo strips treated with citral had no or low prevention and control effect on AN, but bamboo strips treated with 200 mg/ml citral had good prevention and control effects on AN.

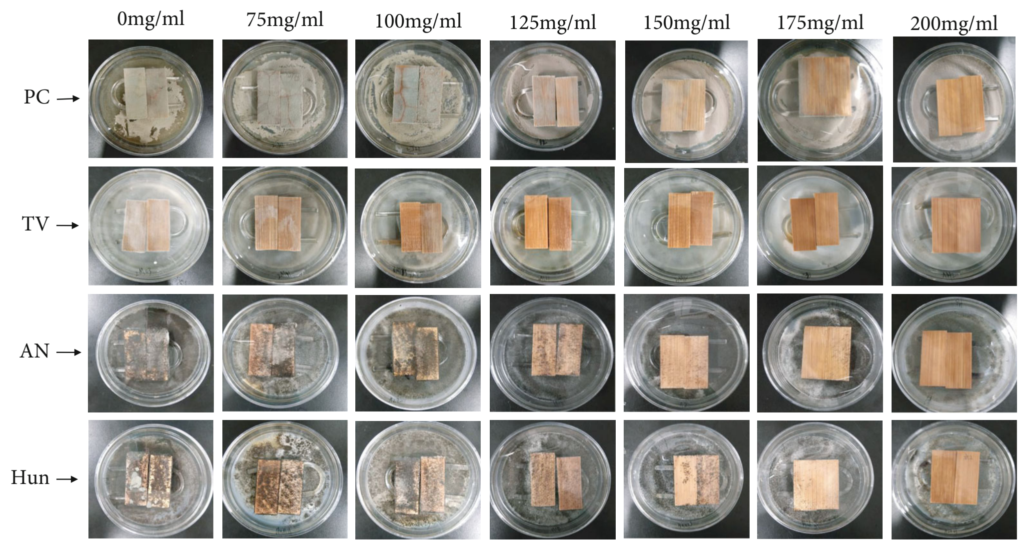

Figure 6: Mildew prevention of bamboo strips treated with different concentrations of citral on the 28th day.

It can be seen from Figure 5(d) that on the 7th day of the antimildew experiment, the infection values of Hun on the surfaces of the bamboo strips treated with the 6 concentrations of the citral solutions, 75 mg/ml, 100 mg/ml, 125 mg/ml, 150 mg/ml, 175 mg/ml, and 200 mg/ml, were 4.0, 3.0, 3.0, 0, 0, and 0, respectively. On the 28th day, the infection values of Hun on the surface of bamboo strips treated with 6 kinds of citral solutions were 4.0, 4.0, 4.0, 3.33, 1.33, and 0, respectively, which indicated that bamboo strips treated with citral had no or low prevention and control effect on Hun, but bamboo strips treated with 200 mg/ml citral still had good prevention and control effect on PC.

In summary, on the 28th day of the antimildew experiment, for the bamboo strips treated with citral solutions of 5 concentrations, including 75 mg/ml, 100 mg/ml, 125 mg/ml, 150 mg/ml, and 175 mg/ml, the mildew grades of 4 types of mold infections such as TV, AN, and Hun did not reach zero. Only when the concentration of citral reached 200 mg/ml did the mildew grades of the 4 types of mildew infections of the antimold bamboo strips reach zero. Therefore, 200 mg/ml can be used as the best concentration of citral for the antimildew treatment of bamboo.

3.4.2. Effect of Citral Concentration on the Antimold Efficiency of Bamboo Strips. After vacuum drying of bamboo strips treated with different concentrations of citral, the antimold efficiency and mildew resistance of bamboo strips on the 28th day are shown in Table 5 and Figure 6, respectively.

It can be seen from Table 5 that the antimold efficiency of untreated bamboo strips (0 mg/ml) against 4 kinds of molds were zero, which indicated that untreated bamboo strips had no antimold efficiency against bamboo molds. Similarly, when citral solutions with concentrations of 75 mg/ml and 100 mg/ml were used to treat bamboo strips, only a preventive effect on TV was observed, with no control effect on other molds.

Treating bamboo strips with citral solutions at concentrations of 125 mg/ml, 150 mg/ml, 175 mg/ml, and 200 mg/ml, the antimold efficiency of TV was 100%. Also, for the other 3 kinds of molds, the antimold efficiency reached 100% only when the concentration of citral was 200 mg/ml, which indicated that the bamboo strips treated with citral had the best control effect on TV. It can be seen from Figure 6 as well that the surfaces of the bamboo strips in the control group were covered with 4 kinds of molds. However, even if the surfaces of bamboo strips treated with citral at 5 concentrations of 75 mg/ml, 100 mg/ml, 125 mg/ml, 150 mg/ml, and 175 mg/ml were covered with mold, as the concentration of citral increased, the amount of mold infection decreased. Furthermore, when the concentration was 200 mg/ml, the surfaces of the treated bamboo strips had no effect on PC, TV, AN, and Hun, and the antimold efficiency reached 100%, which further proved that the best concentration of citral for mildew-proof treatment of bamboo was 200 mg/ml.

3.5. FT-IR Analysis of Citral Mildew-Proof Bamboo Strips. The untreated bamboo strips and those treated with citral solution at the 200 mg/ml concentration were dried in a vacuum, after which FT-IR analysis was conducted. Its infrared spectrum is shown in Figure 7.

It can be seen from Figure 7 that 2923 cm^{-1} was the absorption peak of saturated $-CH_2$, while 2862 cm^{-1} was the absorption peak of $-CH_3$. Also, the absorption peaks of mildew-proof bamboo strips were enhanced at these 2 points, mainly due to the absorption of $-CH_2$ and $-CH_3$ on citral. Alternatively, 1600 cm^{-1} and 1506 cm^{-1} were the C=C skeleton stretching vibration points of the mononuclear aromatic hydrocarbons, as the absorption peaks of the mildew-proof bamboo strips were enhanced at these 2 points, which is proposed to be due to the oxidative degradation of citral to produce p-cymene, which contains a single benzene ring. Furthermore, the absorption peak at 1732 cm^{-1} was C=O, while the absorption peak at 1732 cm^{-1} was enhanced, which is proposed to be due to the absorbance of C=O of citral. Finally, after vacuum drying, the citral in the bamboo strips was either oxidized or volatilized,

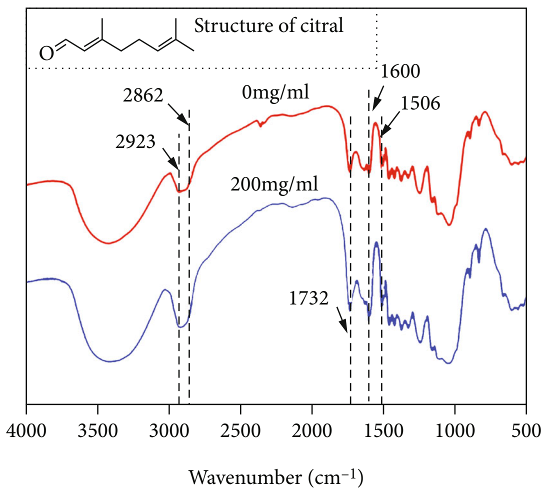

FIGURE 7: Infrared spectrum of citral mildew-proof bamboo strips.

which was also the reason why the antimold efficiency of the bamboo strips was reduced.

3.6. Distribution of Citral in the Mildew-Proof Bamboo Strips. After vacuum drying, the distribution of citral in treated bamboo strips was an important factor affecting the antimildew effect of treated bamboo strips. The distribution of citral in treated bamboo strips was therefore qualitatively analyzed by ultraviolet spectrophotometry. The absorption spectra of the citral and Tween 80 standard solutions, as well as the mixed standard solution of citral and Tween 80 with equal mass in the wavelength range of 200–350 nm, are shown in Figure 8. The ultraviolet absorption spectrum of bamboo strips treated with citral at a concentration of 200 mg/ml is also shown in Figure 9.

It can be seen from Figure 8 that the wavelengths of the maximum absorption peaks of citral and Tween 80 were 238 nm and 233 nm, respectively, and the absorption peak of Tween 80 in the wavelength range of 200–350 nm was lower than that of citral. Figure 8 also shows that the wavelength of the maximum absorption peak of the mixed citral and Tween 80 standard solutions with equal mass was 233 nm. Also, the absorbance at 233 nm was higher than that of Tween 80 at the same concentration and lower than that of citral with the same concentration. The reason for this phenomenon is proposed to be that the polarity of Tween 80 was greater than that of citral and that the blue shift of citral occurred after mixing at the same concentration. Additionally, it is possible that a part of citral was embedded between the Tween 80 micelles, which decreased citral absorption. Therefore, the distribution of citral in the treated bamboo strips was qualitatively analyzed by comparing the intensity of the absorption peak at 233 nm. Furthermore, it can be seen from Figure 9 that the content of citral at 0–3 mm along the length direction of the bamboo strips from the end to the middle increased with an increase in the depth of sampling.

The content of citral was the lowest at a length direction of 0–1 mm (l_1) and most at a position of 2–3 mm (l_2). After drying, the content of citral on the surface of bamboo strips

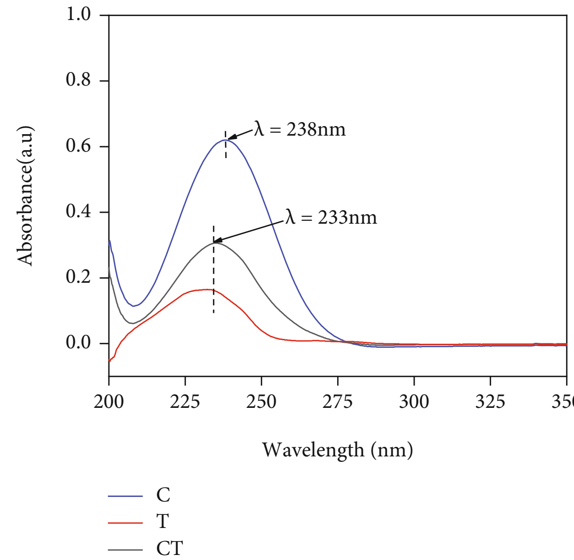

FIGURE 8: UV absorption spectrum of the standard solutions (C: citral standard solution; T: Tween 80 standard solution; CT: mixed standard solution of citral and Tween 80).

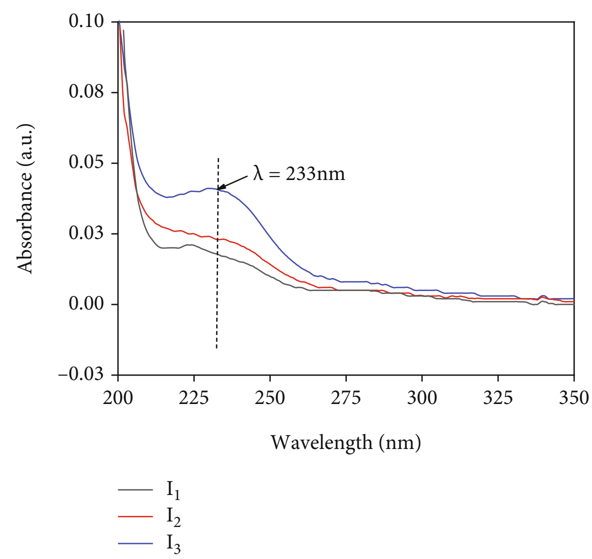

FIGURE 9: UV absorption spectra of bamboo strips treated with citral (l_1: supernatant at 0–1 mm of bamboo length direction; l_2: the supernatant at 1–2 mm along the length direction of bamboo strips; l_3: the supernatant at 2–3 mm along the length direction of bamboo strips).

was first lost and the amount of loss was the most. However, in the mold-proof test of bamboo strips, the mold first infects the surface of bamboo strips. According to the results of bamboo mold prevention experiments in Section 3.4.2, the mold of bamboo did not infect the surfaces of bamboo strips treated with citral at a 200 mg/ml concentration. It can therefore be inferred that the mold of bamboo will not infect the interior of the mold-proof bamboo strips with citral at this concentration. It was further proven in this study that the optimum concentration of citral was 200 mg/ml.

4. Conclusions

The results showed that the concentration of citral had a significant effect on drug loading, but the pressure and time had no significant effect on drug loading. The results also showed that the optimum impregnation process parameters were as follows: citral concentration: 0.795 mg/ml, pressurization time: 90 min, and impregnation pressure: 0.3 MPa.

Citral was volatile. This property led to the loss of citral in bamboo strips after vacuum drying. On the basis of this fact, the content of citral in bamboo strips was greatly reduced, thus causing a gradual increase from the surface layer to the inner layer.

The higher the concentration of citral, the higher the drug loading of the antimold treatment on bamboo strips, and the higher the control effect of the mold on bamboo. Therefore, only when the concentration of citral reached 200 mg/ml did the control effect of the 4 kinds of common mold in bamboo all reach 100%. Thus, the optimal concentration of citral from this study was 200 mg/ml.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

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

Authors' Contributions

Jingjing Zhang and Chungui Du contributed equally to this work.

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