# Research and Preparation of Mycelium-Soybean Straw Composite Materials

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**Abstract.** Non-sterilized substrates mainly composed of soybean straw were used to cultivate *Ceriporia lacerata* for preparing mycelium-soybean straw composite materials (MSCM) in this research. The effect of the particle sizes of soybean straw on preparing MSCM was evaluated. Compression properties, thermal conductivity and sound absorption properties of MSCM were tested. The results showed that cultivation of *C. lacerata* with non-sterilized substrates could be applied to prepare MSCM. It was conducive to mycelium growth and molding of MSCM while the particle sizes of soybean straw were bigger within a certain range. And the results of the tests showed that MSCM had properties of high compressive strength, good thermal insulation and good sound absorption.

## Introduction

Foamed plastics, with properties of thermal insulation, sound absorption and cushioning, have been widely used in construction, packaging, filling, and other fields. However, this traditional petroleum-based foamed plastic is non-degradable and consumes a large amount of oil resources. Therefore, the research and development of biodegradable plastics for substituting petroleum-based plastics have become a hotspot in the world.

In 2007, Bayer and McIntyre [1] invented a novel kind of biodegradable materials prepared by fungi, which was called Mushroom Materials. This kind of materials was prepared by cultivation of mushrooms with plant-based agricultural wastes. The mushroom digested plant-based substrates to grow mycelium which would intertwine and bond the discrete plant-based particles together to form a solid. After being dried, the mycelium was inactivated and Mushroom Materials were obtained. As a novel kind of natural composite materials, Mushroom Materials have acceptable mechanical properties and can be used to replace a portion of traditional petroleum-based plastics. And the applications include thermal insulation materials, cushioning materials for packaging, sound absorption materials, and sandwich panels [2–4].

When preparing Mushroom Materials by cultivation of mushrooms, the culture substrates generally need to be sterilized by high temperature [2–6] and the culture environment for preparing Mushroom Materials should be relatively sterile. It not only consumes a large amount of energy, but also restricts the mass production of Mushroom Materials.

Therefore, in this research, non-sterilized substrates mainly composed of soybean straw were used to cultivate *Ceriporia lacerata* for preparing mycelium-soybean straw composite materials (MSCM), which would greatly reduce energy consumption for sterilization and lower production cost of Mushroom Materials. And no antibacterial/bacteriostatic agents were added in the non-sterilized substrates. The effect of the particle sizes of soybean straw on preparing MSCM was evaluated. In addition, compression properties, thermal conductivity and sound absorption properties of MSCM were tested.

## Materials and Methods

### Strain

*Ceriporia lacerata* (TIB.BPE.11002), was provided by Tianjin Institute of Industrial Biotechnology, Chinese Academy of Sciences.

### Culture Media

Agar slant culture medium: PDA (Potato Dextrose Agar, BD), sterilized at 121$^o$C for 20 min.

First order seed culture medium: soluble starch (Tianjin Guangfu Fine Chemical Research Institute) 20 g/L, dried corn steep liquor powder (Shandong Shengtai Biotechnology Co., Ltd.) 6 g/L, $KH_2PO_4$ (analytically pure, Sinopharm Chemical Reagent Co., Ltd.) 1 g/L, sterilized at 121$^o$C for 20 min.

Second order seed culture medium: corn starch (Tianjin Zhongying Health Food Co., Ltd.) 60 g/L, dried corn steep liquor powder 8 g/L, $KH_2PO_4$ 5 g/L, α-amylase (3700 U/g, Beijing Solarbio Science & Technology Co., Ltd.) 0.198 g/L, sterilized at 121$^o$C for 20 min.

Culture substrate (percentages by dry weight): soybean straw (Xingming Corncob Fabrication Plant of Changtu County) 79%, wheat bran (Shandong Ensign Industry Co., Ltd.) 20%, gypsum (Tianjin Guangfu Fine Chemical Research Institute) 1%, not sterilized.

### Methods

#### Preparation of Liquid Seed

The strain of *C. lacerata* was initially grown on PDA medium for 7 days at 25$^o$C and then stored at 4$^o$C. Approximately 3 cm$^2$ of the slant culture was inoculated to each 500-mL buffled shake flask containing 150 mL first order seed culture medium. Then it was cultivated in a rotary incubator shaker at 150 r/min and 25$^o$C for 3.5 days.

7.5 mL of the first order seed was inoculated to each 500-mL flask containing 150 mL second order seed culture medium. Then it was cultivated in a rotary incubator shaker at 150 r/min and 25$^o$C for 3 days.

#### Cultivation of *C. lacerata* With Non-sterilized Substrates

A stainless steel tub (Φ58 cm×18 cm) with a cover was used as the culture container. 1 kg of dry culture substrate was put into each tub. Without sterilization or adding any antibacterial/bacteriostatic agents, 375 mL of second order seed was inoculated to each tub. The moisture content of the culture substrate was adjusted to about 65%. It was cultivated at 25$^o$C for 5 days and the culture substrate was turned over and mixed one time per day. The colonization by mycelium was recorded every day.

#### Preparation of MSCM

The inoculated culture substrate was cultivated at 25$^o$C for 5 days to make mycelium fully colonize the culture substrate. After 5 days, the culture was broken up into small particles and then they were placed into a mold. In the next 4 days, the mold was cultivated at 25$^o$C to grow mycelium for intertwining and bonding the discrete particles into a solid. After cultivated in the mold for 4 days, the culture was popped out of the mold and cultivated at 25$^o$C and over 85% relative humidity for 3 days. Finally, the culture was dried at 60$^o$C and the dried culture was prepared MSCM.

#### The Effect of the Size of Soybean Straw on Preparation of MSCM

Soybean straw with the sizes of less than 2 mm, 2–8 mm, 50% less than 2 mm coupled with 50% 2–8 mm and 3–8 mm were used to prepare MSCM. The culture mold was a polypropylene plastic box (15 cm×15 cm×7.8 cm).

#### Test of Compression Properties

According to standard GB/T 8813–2008 (Rigid cellular plastics—Determination of compression properties) [7], compression properties of MSCM prepared by using different sizes of soybean straw were tested. The compressive speed was 3 mm/min and the sizes of the specimens were 110 mm×110 mm×30 mm.

**Test of Thermal Conductivity**

According to standard GB/T 10294–2008 (Thermal insulation—Determination of steady-state thermal resistance and related properties—Guarded hot plate apparatus) [8], thermal conductivity of MSCM prepared by soybean straw of 2–8 mm was tested. The size of the specimen was 300 mm×300 mm×30 mm.

**Test of Sound Absorption Properties**

According to standard GB/T 18696.1–2010 (Acoustics—Determination of sound absorption coefficient and impedance in impedance tubes—Part 1: Method using standing wave ratio) [9], sound absorption properties of MSCM prepared by soybean straw of 2–8 mm were tested. The size of the specimen was 300 mm×300 mm×30 mm.

## Results and Discussion

### Cultivation of *C. lacerata* With Non-Sterilized Substrates

Cultivation of edible mushrooms with raw substrates generally refers to inoculating the culture substrate without being sterilized, but the culture substrate usually contains some carbendazim or other antibacterial/bacteriostatic agents. In this research, the culture substrate for cultivation of *C. lacerata* was non-sterilized and no antibacterial/bacteriostatic agents were added.

Non-sterilized substrates mainly composed of soybean straw were inoculated second order seed. The mycelium germinated in 24 h. A few mold spores spawned on the substrates in the second day. In the third day, the mycelium of *C. lacerata* grew rapidly that there were a large number of mycelium balls appeared, while the growth of the mold was restrained. In the fourth day, the mycelium of *C. lacerata* colonized most of the substrate. In the fifth day, the mycelium of *C. lacerata* fully colonized the substrate, as shown in Fig. 1.

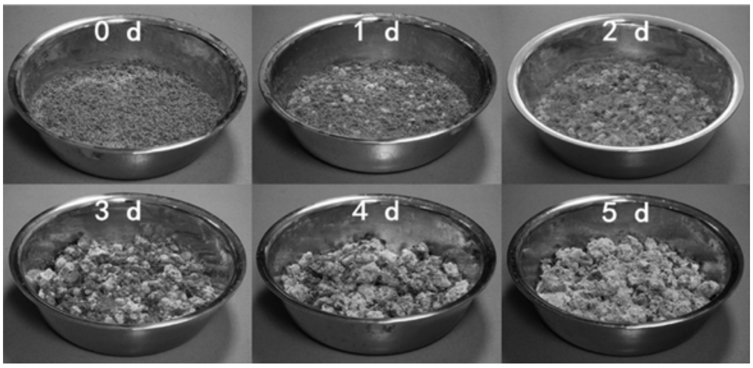


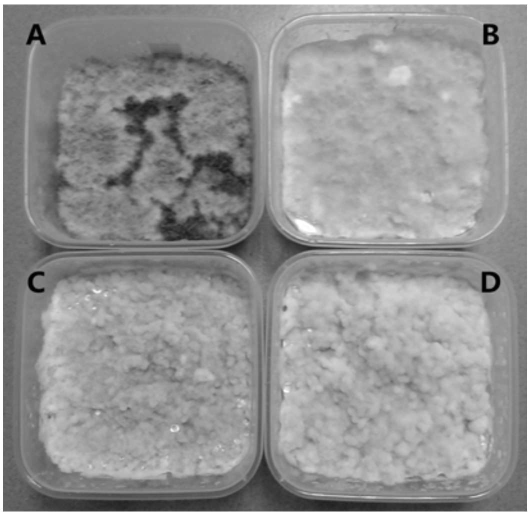

Fig. 1 The colonization by mycelium of *C. lacerata* in 5 days

The mycelium of *C. lacerata* could grow rapidly and became the dominant microorganism in non-sterilized substrates. This property of *C. lacerata* provided a basis for preparing MSCM with non-sterilized substrates.

### The Effect of the Particle Size of Soybean Straw on Preparing MSCM

Different sizes of soybean straw were used for preparing MSCM in this research. After cultivated with non-sterilized substrates for 5 days, the colonization of the substrates by mycelium of *C. lacerata* was shown in Fig. 2.

When the size of soybean straw was less than 2 mm, the rate of mycelium growth was relatively slow, and the mycelium failed to fully colonize the substrates in 5 days. When the size of soybean straw was 3–8 mm, the rate of mycelium growth was the fastest and the mycelium was the densest after cultivated for 5 days.

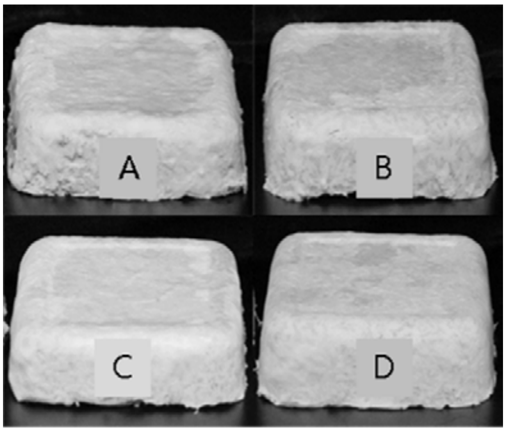



A: less than 2 mm; B: 2–8 mm; C: 50% less than 2 mm and 50% 2–8 mm; D: 3–8 mm

Fig. 2 The colonization by mycelium of *C. lacerata* in the substrates composed of different sizes of soybean straw after cultivated for 5 days

After cultivated for 12 days, the molded cultures were shown in Fig. 3. After being dried, the density test showed that the densities of MSCM were 160±10 kg/$m^3$. With a simple destructive test, it was revealed that the MSCM prepared by using soybean straw of less than 2 mm were apparently more brittle than the others. And the strength of the MSCM prepared by using soybean straw of 3–8 mm were the highest.

The results demonstrated that it was in favor of mycelium growth and molding of MSCM while the particle sizes of soybean straw were bigger within a certain range.




A: less than 2 mm; B: 2–8 mm; C: 50% less than 2 mm and 50% 2–8 mm; D: 3–8 mm

Fig. 3 MSCM prepared by using different sizes of soybean straw

## Compression Properties

According to standard GB/T 18696.1–2010, sound absorption properties of MSCM prepared by using different sizes of soybean straw were tested and the stress-strain curves of MSCM were shown in Fig. 4 (MSCM prepared by using soybean straw of less than 2 mm were not tested due to fragile). The stress-strain curves of MSCM prepared by soybean straw of 2–8 mm, 50% less than 2 mm coupled with 50% 2–8 mm and 3–8 mm were relatively smooth and had similar trends. When the strain reached about 50%, the stress started to rise sharply. All the tested MSCM had quite high compressive strength and the compressive strength was above 0.6 MPa when the strain reached 50%. The MSCM prepared by using soybean straw of 3–8 mm had the highest compressive strength and the compressive strength is above 0.8 MPa when the strain reached 50%.

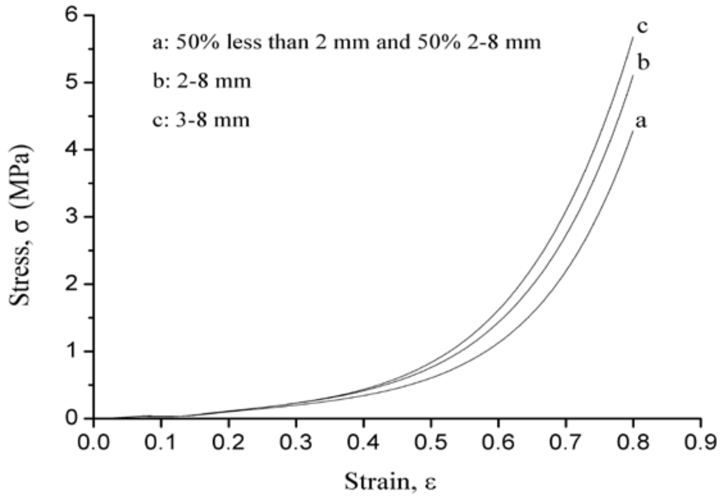



Fig. 4 The stress-strain curves of MSCM prepared by using different sizes of soybean straw

**Thermal Conductivity**

According to standard GB/T 10294–2008, thermal conductivity of MSCM prepared by using soybean straw of 2–8 mm was tested. The results showed that thermal conductivity of the MSCM was 0.054 W/(m·K) at 25$^{o}$C. In general, materials with less than 0.25 W/(m·K) of thermal conductivities were defined as thermal insulation materials and materials with less than 0.05 W/(m·K) of thermal conductivities were defined as highly efficient thermal insulation materials [10]. The thermal conductivity of MSCM was 0.054 W/(m·K), close to 0.05 W/(m·K), thus MSCM had a good property of thermal insulation.

**Sound Absorption Properties**

According to standard GB/T 18696.1–2010, sound absorption properties of MSCM prepared by using soybean straw of 2–8 mm were measured, and the curve of sound absorption was shown in Fig. 5. As shown in Fig. 5, the sound absorption coefficients were very low at low frequencies while that were quite high at middle and high frequencies. The evaluation of sound absorption property is generally represented by noise reduction coefficient (NRC), which is determined by the arithmetic average of the sound absorption coefficients at the frequencies of 250, 500, 1000, and 2000 Hz. In this way, NRC of MSCM was 0.55. According to standard GB/T 16731–1997 (The gradation of sound absorption property for absorbent products) [11], the gradation of MSCM was III ($0.60 > NRC \geq 0.40$) in sound absorption materials.

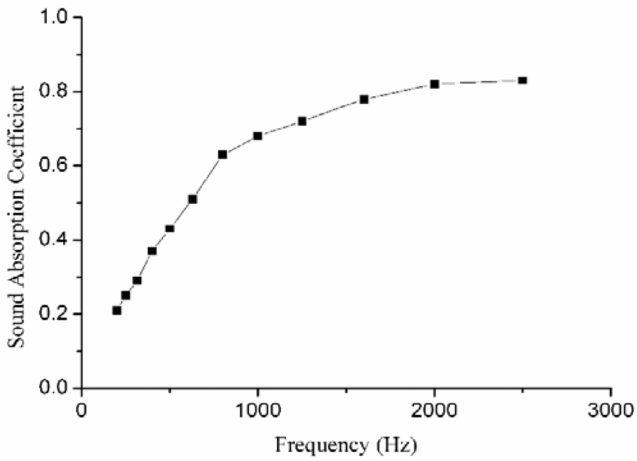



Fig. 5 The curve of sound absorption of MSCM

## Conclusions

In this research, mycelium-soybean straw composite materials (MSCM), a kind of Mushroom Materials, were prepared by cultivation of *C. lacerata* with non-sterilized substrates mainly composed of soybean straw. And the results of the tests showed that MSCM had properties of high compressive strength, good thermal insulation and good sound absorption.

This research also established a process of preparing Mushroom Materials by cultivation of *C. lacerata* with non-sterilized substrates. With this process, it will not only greatly reduce the energy consumption used for sterilization and the cost of production, but also lower the requirements for the culture environment in the process of preparing Mushroom Materials. Furthermore, it will promote Mushroom Materials to form a large-scale production for replacing traditional petroleum-based plastics.

## Acknowledgement

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