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Morphological Structure and Basic Characteristics of *Miscanthus floridulus* Fibers

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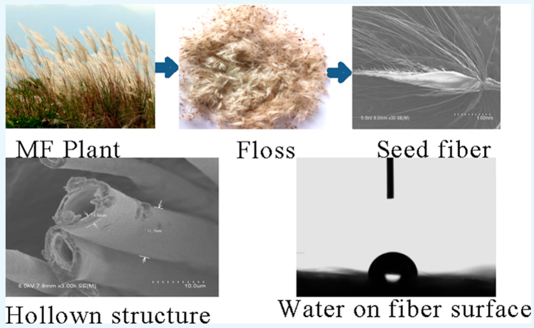
ABSTRACT: *Miscanthusfloridulus* fibers obtained from the seed floss of *M. floridulus* (a perinneal plant of Gramineae native to Africa and Asia and widely distributed in tropical and subtropical regions) have potential application value in textile and other fields. At present, the biological characteristics and ecological benefits of *Miscanthus floridus* have been extensively studied by researchers, but there have been no literature on *M. floridus* fibers. In order to make reasonable use of *M. floridus* fibers, their morphological structure, physical properties, chemical composition, thermal insulation properties, and surface absorption properties were explored in detail in this study. The results showed that the *M. floridus* fiber is fine and short and has a hollow structure with a density of 0.67 g cm^{-3}. Chemical analyses revealed that the main constituents of the fiber are cellulose (66.98%), hemicelluloses (13.86%), lignin (6.97%), pectin (1.99%), and wax (4.38%). The fill power and warmth retention performance of the fiber are similar to those of wool. In particular, the *M. floridus* fiber surface has hydrophobic and lipophilic properties with a static contact angle of 123.7° for water droplets in equilibrium. Therefore, the *M. floridus* fiber has a promising application prospect in bulk textile thermal insulation and oil−water separation fields.



1. INTRODUCTION

Biological fibers, a kind of abundant renewable fibers, are obtained from wild plants, agricultural and forestry resources, and animal and municipal wastes and have the characteristics of abundant resource, low cost, and environment-friendly.[1−5] Their special surface, structure, and natural chemical composition are in accord with the current concept of carbon neutral production and economic sustainable development, which have attracted more and more attention and exhibited great potential for application in many fields. In recent years, the *Calotropis gigantea* fiber, kapok, cattail fiber, straw and rice straw fiber, and floss obtained from poplar seeds have been used in many fields because of their unique morphological structures and biodegradability.[6−11] Take *C. gigantea* fibers, also called vegetable silk, for example, they are harvested from the seeds in the plant pods and have been successfully used in traditional textile and other fields, such as medical fabrics, flexible wearable electronics, oil-absorbing materials, and even in the reinforcement of lightweight composite materials due to their special cavity structure.[12−17]

Miscanthus floridulus is wild Miscanthus of Gramineae native to East Asia, also known as awn grass, thatch, and so forth, and it usually grows on roadsides, ramps, and lakes with developed roots and strong vitality. It is traditionally used for wind prevention, soil consolidation, paper-making, weaving, greening, and so on.[18] In the 1960s, in Europe and the United States, Miscanthus was studied as an energy plant and used as a biofuel for power generation or as solid and gas fuels. The power generation using Miscanthus in the EU 15 countries accounted for 20% of the total power generation at the beginning of the 20th century.[19−23] Due to its high contents of crude protein and cellulose, *M. floridulus* has become a good raw material for animal-feeding and paper-making.[24−26] It accounts for 42% of the paper-making raw materials in Hunan and Hubei Provinces of China.[27,28] The published papers revealed that *M. floridulus* can effectively remove the heavy metals and polycyclic aromatic hydrocarbon pollutants in soil for gradually improving the soil nutrient status. Therefore, it can be considered as an ecological restoration plant with a high development potential now.[29−31] In addition, it has been used for its medicinal value in traditional Chinese medicine, due to the effects of clearing heat and drenching, dispelling wind and dehumidification, diuresis, and detumescence. Recently, some researchers have made in-depth research on the medicinal value of *M. floridulus* and pointed out that the glycosides extracted from *M. floridulus* can significantly inhibit the NF-kB

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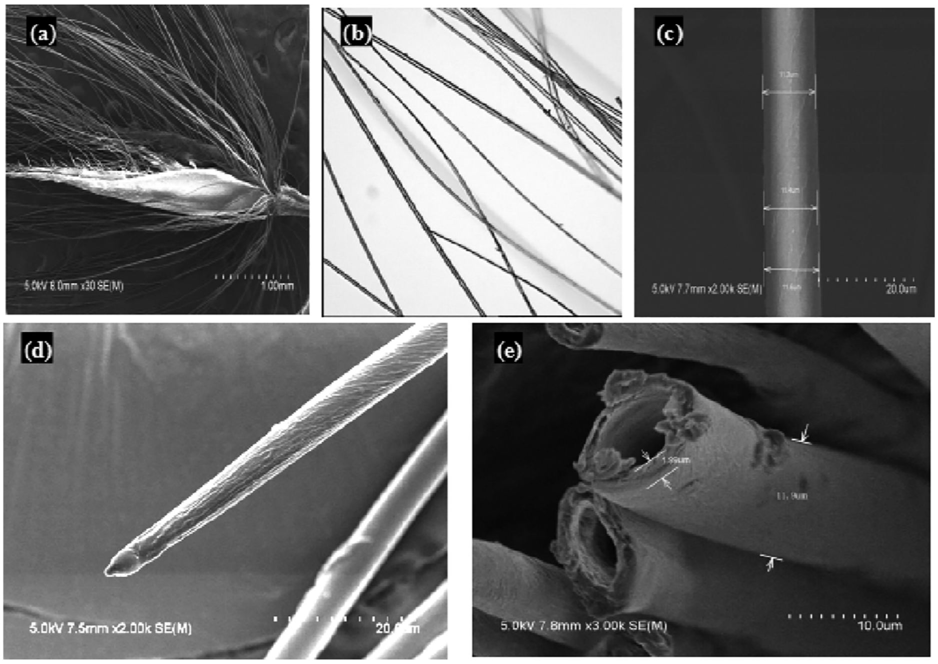

Figure 1. SEM images of the *M. floridulus* fibers: (a) single fiber velvet; (b) longitudinal direction of the fiber; (c) surface of the fiber; (d) fiber tip; and (e) fiber cross section.

activation induced by the lipopolysaccharide, thereby exhibiting anti-inflammatory and bactericidal effects and improving the antiviral protective ability of the human body.[32−35] Additionally, *M. floridulus* contains water-soluble glycoproteins and is therefore used for antiallergy treatment.[36] In summary, the present research on *M. floridulus* is mainly focused on its biological characteristics, biomass energy, ecological restoration, and medicinal values.

Due to its application as an ecological environmental restoration material and in paper-making, *M. floridulus* is widely planted in China with a huge output. As a byproduct, except for a very small amount of landscape decoration and broom binding, *M. floridulus* flower naturally falls off or landfills and burns after maturity, which not only severely pollutes the natural environment but also degrades natural organic resources. How to reasonably develop and utilize *M. floridulus* fibers is a problem to be solved by scientific researchers.

The M. floridulus fiber is a kind of renewable natural hollow plant fiber and also has the characteristics of low density and hydrophobic/lipophilic properties, which show that it has promising potential for application in the textile, thermal insulation, and oil−water separation fields.[37] However, to the best of our knowledge, no literature investigating the *M. floridulus* fiber has been published, and the fiber properties have not been rigorously assessed. Therefore, there is a need to analyze and evaluate properties of the *M. floridulus* fiber, using optical microscopy and scanning electron microscopy (SEM) methods, and the fiber morphological structure was probed in this paper. The chemical composition was determined and investigated according to the GB5889-86 standard.[38] The fiber samples were analyzed by Fourier transform infrared (FTIR) spectroscopy, SEM, and X-ray diffraction (XRD). The thermal insulation performance and fill power as well as surface absorption characteristics were also measured. The experimental and theoretical results provide a basis for the use of the *M. floridulus* fiber and indicate that the fiber has potential application value in the textile industry and other fields.

2. RESULTS AND DISCUSSION

2.1. Macrostructure. The macrostructure of *M. floridulus* fibers was analyzed and presented in Figure 1. Figure 1a shows that the *M. floridulus* fibers grow on seeds as cotton fibers do, and they were mainly distributed on the bottom and middle part of the seeds. The length of the *M. floridulus* fibers is in the range of 8−12 mm, which is shorter than those of most of the natural textile fibers, such as kapok (8−34 mm), fine cotton (25−35 mm), and linen (17−25 mm), but longer than that of jute (2−4 mm).[39,40]

Figure 1b shows the optical picture of *M. floridulus* fibers, which exhibits that the fineness of the main part of fibers is relatively uniform. Figure 1d displays that the tip of *M. floridulus* fibers is closed and only a small section near the top tends to become fine gradually. The fiber surface is not smooth with full of chaps and grooves and covered with a waxy layer. Furthermore, Figure 1e exhibits that the cross section of *M. floridulus* fibers is approximately circular and presents a hollow structure. As shown in Figure 1c, taking the fiber cross section as a circle, the diameter of the middle section of the *M. floridulus* fibers was measured through the length of the fiber. Its average diameter was around 6−12 μm, meanwhile the diameters of kapok and cotton were 20−45 μm and 16−20 μm, respectively.[39,40] Consequently, from the results, it can be speculated that *M. floridulus* fibers are not suitable to be spinned because of their very short length and fine diameter; however, fiber aggregates could be manufactured through the apposite non-woven processing.

After calculations, the hollow degree of 200 *M. floridulus* fibers was found to be 50−63%, which was higher than that of the common synthetic chemical fibers (40%) and lower than that of the kapok fibers (91%)[39] reported in the literature. The hollow structure could enable the fibers to be filled with a large amount of still air, and the branched structure between fibers

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and the grooves on the fiber surface could also store air. These indicated that the *M. floridulus* fibers can be a potential natural thermal insulation filling material for textiles.

2.2. FTIR Analysis. The FTIR spectra of the *M. floridulus* fibers were collected and presented in Figure 2. The strong

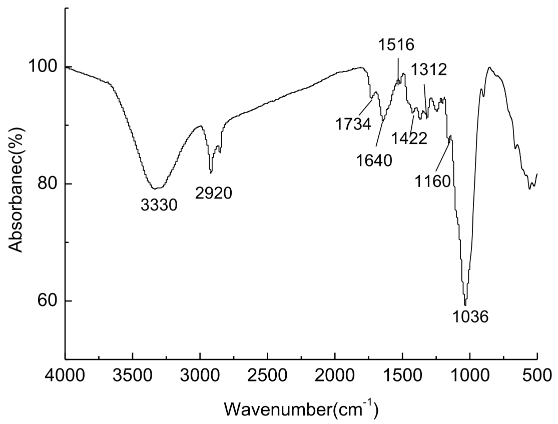

Figure 2. Infrared spectra of the *M. floridulus* fiber.

absorption peak at 3330 cm^{-1} was the stretching vibration peak of −OH, the peak at 2920 cm^{-1} corresponded to the antisymmetric stretching vibration of $-CH_2$, and the absorption peak at a wavelength of 2849 cm^{-1} was ascribed to the symmetrical stretching vibration of the aliphatic CH_3, indicating that the *M. floridulus* fiber contained a waxy material. Additionally, the peaks at 1422, 1160, and 1036 cm^{-1} were the characteristic peaks of the cellulose fingerprint area, the peak at 1312 cm^{-1} was the vibration peak of C−C and C−O frameworks, and the peak at 1734 cm^{-1} was ascribed to the stretching vibration of C═O on the acetyl group of hemicellulose and methyl pectinate and the carboxyl group. Moreover, the small vibration peaks of the lignin aromatic ring skeleton at 1640 and 1516 cm^{-1} indicated that there was a small amount of lignin in the *M. floridulus* fiber.[41] Consequently, the FTIR analysis revealed the main chemical components of the fiber. Undoubtedly, the *M. floridulus* fiber belongs to natural cellulose fibers such as kapok and cotton fibers, and the macromolecular chain was composed of the glucose residues connected by β-1-4 glycoside bonds. As we know, there are at least four crystal configurations, which are cellulose I, cellulose II, cellulose III, and cellulose IV. The crystal configuration of natural cellulose is ascribed to that of cellulose I and other variants derived from it. According to the characteristics of the IR spectrum, it can be considered that the crystal configuration of *M. floridulus* fiber belongs to cellulose I.[42]

2.3. Chemical Composition of the Fiber. The chemical composition of the *M. floridulus* fiber was tested and compared with those of kapok and cotton, as displayed in Table1. The chemical composition of the *M. floridulus* fiber mainly included cellulose, lignin, hemicellulose, pectin, and wax of 66.98, 6.97, 13.86, 1.99, and 4.38, respectively. Additionally, the *M. floridulus* fiber also contained 5.82% of other substances, such as ash. As seen from Table 1, the cellulose content of the *M. floridulus* fiber was higher than that of kapok, but lower than that of cotton, and its lignin content was lower than that of kapok.[39,40] Moreover, a wax content of 4.38% in the *M. floridulus* fiber was much higher than those in kapok and cotton, which could provide a low surface free energy environment for the fiber capillary transportation of oils because the fiber surface possessed strong lipophilicity. It indicated that the *M. floridulus* fiber was a potential natural biomass oil absorption material.

2.4. XRD Analysis. The *M. floridulus* fiber is a natural compound with a supramolecular structure. Its aggregate structure is composed of a crystalline region and an amorphous region. The macromolecular segments in the crystalline region are regularly arranged and have high density, showing a clear XRD pattern.[43] The XRD patterns of the *M. floridulus* fiber are shown in Figure 3. The fiber diffraction peaks were observed

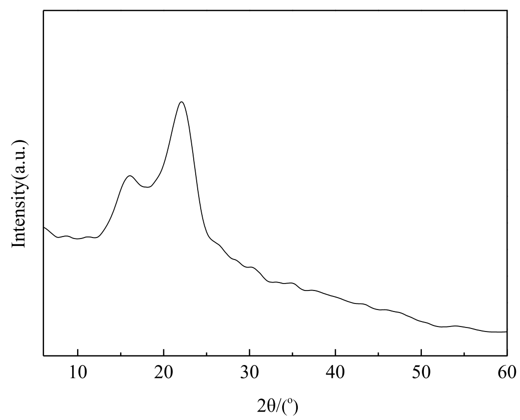

Figure 3. XRD pattern of *M. floridulus* fibers.

mainly at 16.1, 22.5, and 35°, which were the same as those of cellulose I and corresponded to the diffraction peaks of 101, 002, and 040 planes, respectively, indicating that the *M. floridulus* fiber has the crystal structure of cellulose I. According to the crystallinity calculation formula, the crystallinity index (CI) of the *M. floridulus* fiber was 36.2%, which was close to that of kapok (33%) and much lower than those of ramie (71.7%) and cotton (64.1%).[39,40] The lower degree of crystallinity of the *M. floridulus* fiber suggested that the amorphous region with an irregular arrangement and a loose structure was much larger than the crystal region with a neat and tight structure, which was also the main reason for the low tensile force and high breaking elongation of the single *M. floridulus* fiber.

2.5. Physical Properties of the Fiber. Table 2 shows the test results of physical properties of the *M. floridulus* fiber. It could be found that the breaking strength of the *M. floridulus* fiber was far lower than those of kapok and cotton, and thin and soft characteristics of the fiber combined with a hollow

Table 1. Chemical Composition of the *M. floridulus* Fibers and Other Fibers

types of fibers	cellulose/%	lignin/%	hemicellulose/%	pectin/%	wax/%	other substances/%
M. floridulus	66.98	6.97	13.86	1.99	4.38	5.82
kapok[39,40]	35−50	13	23.5−45	<1	0.8	12−13.2
cotton[39,40]	94.5			1.2	0.6	3.7

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Table 2. Performance Comparison of the *M. floridulus* Fiber and Other Common Fibers

types of fibers	tensile force/cN	breaking elongation/%	density/g cm^{-3}	moisture regain/%
M. floridulus	0.41	3.14	0.67	16.2
kapok[39,40]	1.44−1.71	1.83−4.23	0.29	10.0
cotton[40]	2.94−4.50	6.00	1.58	10.4

structure result in its weak tensile property. The weak tensile property limited its processing and application in the field of spinning. In addition, the density of the *M. floridulus* fiber was 0.67 g cm^{-3}, which was considerably lower than that of cotton (1.58 g cm^{-3}).[40] Therefore, the *M. floridulus* fiber could be considered as a light natural fiber. The moisture regain value of the *M. floridulus* fiber was 16.2%, which was higher than those of kapok and cotton and close to that of Ramie (16.3%).[39,40] The high hygroscopicity of the *M. floridulus* fiber might be related to its large specific surface area and hollow structure.

2.6. Relative Heating and Cooling Rates. Relative heating and cooling rates of *M. floridulus*, kapok, cotton, wool, viscose, and polyester were measured, as shown in Figure 4. Figure 4a shows that the relative heating curve of the *M. floridulus* fiber was similar to those of wool and kapok. Among the six fibers tested, polyester had the shortest heating time (212 s), and the shorter the heating time, the better the warmth retention of the fibers as the filling material. The *M. floridulus*, wool, and kapok can be heated up rapidly in a short time, showing that they have good warmth retention property. In addition, as seem from Figure 4b, among the six filling fibers, kapok had the longest cooling time from 40 to 20 °C, followed by *M. floridulus* fiber and wool, their cooling times were 201 s, 181 s, and 170 s, respectively. Polyester has the shortest cooling time (140 s), which facilitates its fastest cooling rate and poor warmth retention property for practice use. Because the *M. floridulus* fiber had a same hollow structure and low tensity as kapok, it exhibited a good warmth retention property, which indicates that it is a promising candidate for application in the field of filling fibers.

2.7. Filling Power and Warmth Retention Property. Warmth retention property of filling materials depends on their thermal conductivity and assembly density. For the same material, the higher the filling power, the more static air the material contains, the better the thermal insulation.[44] Fill power is an important index to appraise the thermal performance of filling materials. In this study, fill power and warmth retention property of the *M. floridulus* fiber, kapok, cotton, polyester, viscose, and wool as filling materials were determined. As shown in Table 3, the fill power of the *M. floridulus* fiber was lower than that of kapok, but slightly higher than those of wool and cotton, the reasons for good bulkiness of *M. floridulus* fiber were its small fineness, hollow structure, and surface groove.

The warmth retention ratio is the amount of energy required to keep a hot body at a constant temperature, which represents resistance to radiation, conduction, and heat loss. The heat transfer coefficient reflects the ability of fiber's heat transfer, which is inversely proportional to the clo value abbreviated as CLO. The higher the CLO is, the better the thermal insulation of the fiber. It could also be seen from Table 3 that the warmth retention ratio and CLO as well as the heat transfer coefficient of the *M. floridulus* fiber were very close to that of wool and higher than those of cotton, polyester, and viscose. This also shows that the *M. floridulus* fiber is a good natural thermal insulation filling material.

2.8. Surface Adsorption Performance. The static wetting properties of the *M. floridulus* fiber were measured using the sessile droplet method. Figure 5 shows the wetting of distilled water droplets on the fiber surface. It could be seen that water presented in a spherical droplet state on the surface of the fiber in equilibrium, and the measured static contact angle was 123.7°, reflecting that water cannot wet the surface of the fiber, in other words, the *M. floridulus* fiber has hydrophobicity. At the same time, vegetable oil was also selected to characterize the surface absorption of the *M. floridulus* fiber. It was observed that vegetable oil rapidly spread and infiltrated into the fiber, therefore measurement was carried out through a contact angle meter equipped with a camera to take video of the spreading process of an oil droplet falling on the surface of the fiber, and the pictures captured are shown in Figure 6. It was found that vegetable oil could completely spread on the *M. floridulus* fiber surface within 0.8

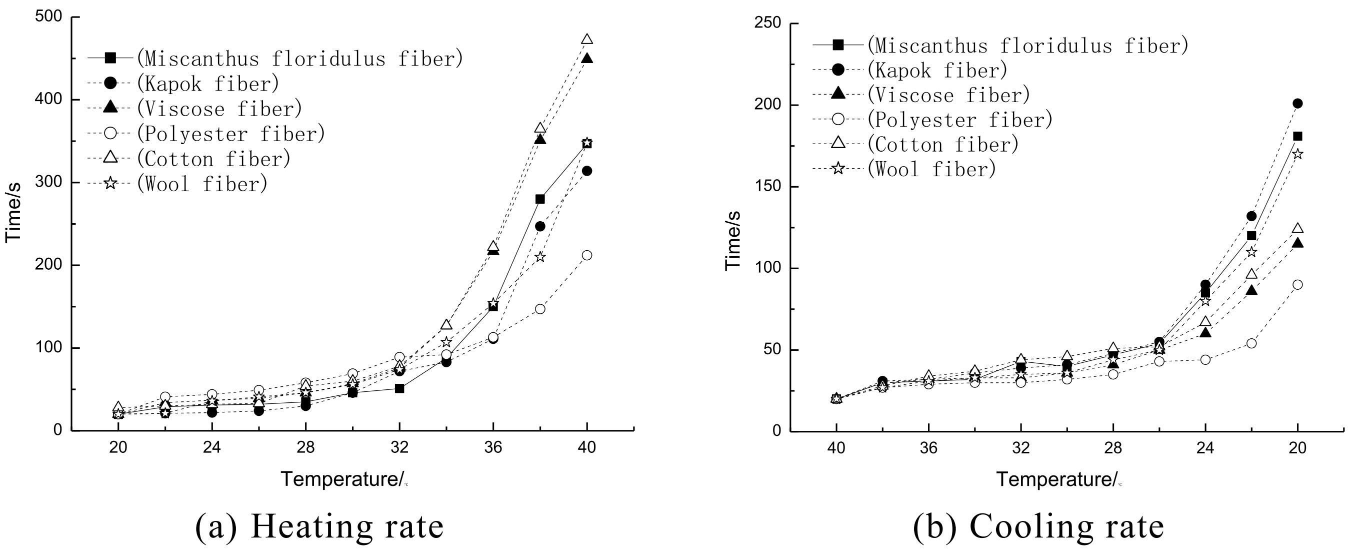

Figure 4. Relative heating and cooling curves of the fibers.

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Table 3. Fill Power and Thermal Resistance Data of Pillows Filled With Different Fibers

types of fibers	*M. floridulus*	kapok	wool	polyester	cotton	viscose
fill power/cm	11.2	14.58	9.88		8.96	
warmth retention ratio/%	71.2	75.4	72.4	62.7	68.7	61.9
CLO	1.453	1.772	1.466	0.958	1.237	0.933
heat transfer coefficient/W/m^2 °C	0.103	0.087	0.106	0.162	0.125	0.166

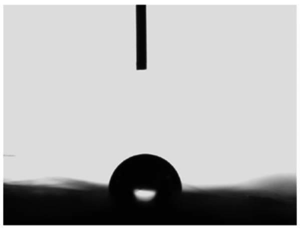

Figure 5. Static contact angle between distilled water and the *M. floridulus* fiber.

s, indicating that the fiber surface had excellent lipophilic properties. Furthermore, during the measurement, we found that the *M. floridulus* fiber floated on the water surface and quickly floated up after being squeezed under water. When the *M. floridulus* fibers were kept in an oil, the oil penetrated into the fiber quickly, became a sticky solid, and floated on the oil surface without sinking. The high wax content and hollow structure of the *M. floridulus* fiber were conducive to improve its oil absorption performance. Particularly, the low density made the fiber assembly float on the oil surface, which was convenient for the recovery of oil absorption materials. Consequently, the abovementioned features enable the *Miscanthus floridus* fiber to be a potential oil absorption material, especially an oil–water separation material.

3. EXPERIMENTAL SECTION

3.1. Materials and Reagents. The *M. floridulus* fibers were collected from the Yangtze River System in Wuhu City, Anhui Province, and their harvest process is shown in Figure 7. Sulfuric acid, sodium hydroxide, ethanol, ammonium oxalate, barium chloride, and so forth were of analytical grade and procured from Nanjing Chemical Reagent Co., Ltd. (Nanjing, China). Vegetable oil (commercial arowana soybean oil) with a density of 0.95 g cm^{-3} and a viscosity of 38.3 mPa s was offered by Yihaijiali Food Marketing Co., Ltd. (Shanghai, China)). Cotton, kapok, wool, viscose, and polyester were offered by Nanning Jinhong Cotton Textile Co., Ltd in Guangxi, China.

3.2. Measurement and Characterization. Prior to use, the fibers were subjected to a pretreatment of gently patting and washing with distilled water to remove the impurities on the fiber surface, then drying in a 45 °C oven, and finally balancing in a standard environment of 20 °C and 65% relative humidity for 24 h.

3.2.1. Scanning Electron Microscopy Analysis. After the samples as well as their film cross sections were sputter-coated with a thin layer of gold, their surface micrographs were taken on a Hitachi S-4800 scanning electron microscope.

3.2.2. Fiber Length and Average Diameter. Because the *M. floridulus* fiber length was short, the fiber length range was obtained by placing the seeded fibers on a black velvet board and measuring the length of 200 fibers separately with a ruler. The cross section of the *M. floridulus* fiber was approximately circular. Thus, the average diameter could be measured by the microscope projection amplification method using a YG002 C fiber fineness analyzer (magnification: 40 × 10 times).

3.2.3. Fourier Transform Infrared Analysis. The FTIR spectra of the powdered *M. floridulus* fibers were collected on a Nicolet Nexus 470 FTIR spectrophotometer (Thermo Electron Corporation, USA) using KBr pellets with 32 scans and in the frequency range of 500–4000 cm^{-1}.

3.2.4. Chemical Composition Analysis. The chemical composition of *M. floridulus* fiber was determined according to a standard method (GB/T5889-86) in China. The wax in the fiber was extracted using the Soxhlet extractor, and the wax, pectin, hemicellulose, and lignin were quantitatively analyzed, finally, the cellulose content was calculated.

3.2.5. XRD Analysis. To reveal the crystal configuration, the X-ray diffraction pattern of the *M. floridulus* fiber was collected

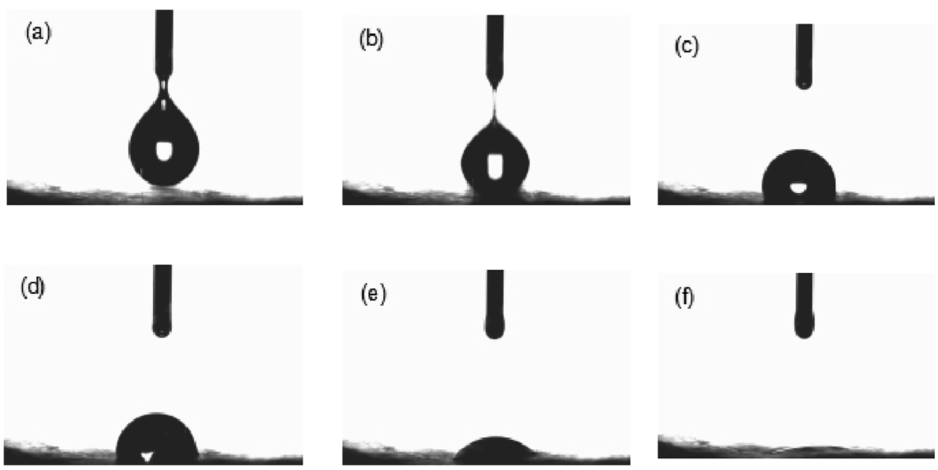

Figure 6. Spreading process of a vegetable oil on the surface of the *M. floridulus* fiber. (a) 0 s, (b) 0.1 s, (c) 0.2 s, (d) 0.40 s, (e) 0.60 s, and (f) 0.80 s.

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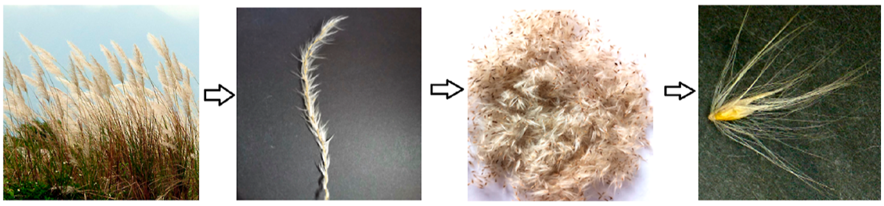

Figure 7. Harvesting process of *M. floridulus* fibers.

using an X-ray diffractometer [(XRD)-6000, Shimadzu Co, Japan] with 0.154 nm monochromatic CuKα radiation at 40 kV and 20 mA. The scanning angle (2θ) ranged from 5 to 60° with a scan rate and a step of 6°/min and 0.027°, respectively. The CI of *M. floridulus* fibers was calculated by the peak strength method,[45] and the calculation formula is as follows.

$$CI = (I_{002} - I_{am})/I_{002} \quad (1)$$

I_{002} is the maximum intensity of the lattice diffraction and I_{am} is the diffraction intensity of the amorphous region.

3.2.6. Moisture Regain, Tensile Property, and Density. The moisture regain of *M. floridulus* fibers was measured according to GB/T9995-"1997 "Determination of moisture content and moisture regain of textile-Oven drying method". Their tensile property was determined using a LY-06 B electronic single fiber strength meter (Nantong Hongda Experimental Instrument Co., Ltd., China) at a clamping distance of 5 mm and a tensile speed of 5 mm/min, and 50 individual fiber samples were tested.

The fiber density was measured by pycnometery[46] according to the following process. The pycnometer was dried and fully cooled in a dryer in advance, and the weight of the pycnometer was denoted m_0. Distilled water was filled fully into the pycnometer and weighed after equilibration for 30 min at 25 °C, and the weight of the pycnometer and distilled water was denoted m_1. Then, 1 g of fibers was stuffed in the clean and dry pycnometer, and the weight of the pycnometer and fibers was denoted m_2. Finally, distilled water was poured into the above pycnometer filled with fibers, which was immersed in the ultrasonic wave for 30 min to remove the air bubbles inside fibers, and the total weight of the pycnometer, distilled water, and fiber was denoted m_3 after equilibration for 1 h at 25 °C. The density (d, g cm^{-3}) of the *M. floridulus* fiber can be calculated using eq 2. The average value of five measurements was computed.

$$d = \frac{m_2 - m_0}{m_1 - m_0 - m_3 + m_2} \quad (2)$$

3.2.7. Determination of Relative Heating and Cooling Rates. The fiber sample (3 g) was weighed and placed in a conical bottle. Then, a digital thermometer induction probe was inserted into the fiber center, and the conical bottle was placed in an oven at 40 °C. The time for fiber heating was recorded, and the heating rate was calculated. After the fiber temperature has reached 40 °C, the fiber was kept at this temperature for 5 min, and the conical bottle was taken out to test the time for cooling the fiber and calculating the cooling rate. In this experiment, the ambient temperature and relative humidity are 18 °C and 65%, respectively.

3.2.8. Measurement of Fill Powers. The fill powers of *M. floridulus*, kapok, wool, and cotton fibers were measured according to GB/T14272-2011. Briefly, the sample was stored at 20 °C and 65% RH for 24 h, the treated sample (28.4 g) was kept into a plastic cylinder (24 cm inner diameter, unlimited height), and then flattened evenly at the bottom of the cylinder with a glass rod. Afterward, 68.4 g of the light piston plate was kept on the top of the sample, which fell naturally. When the plate stopped falling after 1 min, the final height of the sample was recorded. For each case, the measurement was repeated three times.

3.2.9. Determination of Warmth Retention Property. A flat thermal insulation instrument was used to determine the warmth retention property of fiber samples.[47] The specific operations were as follows: fiber samples (30 g) were kept in a cloth sample bag (cloth sample specification: CJ14.5 tex × CJ14.5 tex × 523.5 × 393.5, sample bag size: 30 × 30 cm^2). After sealing, the determination was performed at a test temperature and a relative humidity of (25 ± 5) °C and (65 ± 5) %, respectively. For each sample, the determination was conducted three times, and the average was obtained. The filling density was 0.033 g/cm^{-3}. The kapok, ordinary cotton, wool, viscose, and polyester fibers were used as control samples of *M. floridulus* fibers, and their thermal insulation rate, crow value, and heat transfer coefficient were obtained for revealing the warmth retention property.

3.2.10. Measurement of Surface Adsorption Performance. Briefly, *M. floridulus* fibers (5 g) were flattened and adhered to a glass slide. Then, the surface contact angle was measured with a contact angle measuring instrument (OCA20, Data-Physics, Germany). The liquid (5 μL) was distilled water and vegetable oil, respectively. The contact angle was determined using an angle measurement instrument. Each sample was determined for four points, and the average value was calculated. The static contact angle was captured by the camera equipped with the contact angle measuring instrument, and the image acquisition time interval was 0.1 s.

4. CONCLUSIONS

In this paper, the *M. floridulus* fiber was taken as the study object to explore the morphology structure, physical properties, chemical composition, thermal insulation properties, and its surface absorption properties. The following conclusions were drawn.

The M. floridulus fiber is short and weak, not suitable for spinning. The fiber has low density and an unique hollow structure with a circular cross section, and the density and hollowness of fiber are 0.67 g cm^{-3} and 50−63%, respectively. Its surface is covered with tiny grooves, which keep a static air interior and between the fibers, resulting in a high fill power and thermal insulation of the fiber assembly, which make the *M. floridulus* fiber a natural thermal insulation bulk material. The high wax content and excellent hydrophobic/oleophilic surface properties render the *M. floridulus* fiber itself a potential oil−water separation material. In summary, the results provide a theoretical and experimental basis for the use of the *M.*

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floridulus fiber as a low-price environmental protection material.

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