Green Degumming Technology of Hemp and a Comparison between Chemical and Biological Degumming

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ABSTRACT: This paper provides an efficient and environmentally friendly biochemical degumming method for hemp fiber, which can address the problems of high temperature, high pressure, and extreme pollution of the traditional chemical method and the harsh reaction conditions of biological degumming, such as a long reaction time and pH. In the biochemical method, dilute solutions of alkali pectinase lyase and chemical additives were used to process the hemp fiber and then the fiber composition and structure were investigated. A comparison of the chemical, biological, and biochemical degumming methods shows that the biochemical method can replace the chemical one causing a similar degumming effect, both being better than the biological method. The best proportion of the biochemical solution was found to be 1.5% alkali pectinase lyase, and for chemical auxiliaries the total amount of alkali was ≤0.4% and the total amount of salt was ≤0.8%. The best conditions of the biochemical degumming process were determined to be a bath ratio of 1:10, reaction temperature of 60 °C, and the time of 60 min. After degumming, the composition of the fiber was as follows: lignin 3.69%, pectin 4.09%, hemicellulose 13.34%, and cellulose 78.87%. The fiber quality index of fibers dealt by the biochemical method shows that the linear density was 4.66 dtex, length was 35.6 mm, and fracture strength was 64.5 cN/dtex, which were higher than those treated by the chemical method. This shows that the biological degumming method can be a green degumming method with higher efficiency, lower consumption, and pollution, as well as has a broad application scope.

1. INTRODUCTION

Hemp has strong adsorption, superior antibacterial activity, anti-odor, excellent permeability, and heat transfer properties. However, raw hemp (phloem) contains 25–30% colloidal complex, which wraps the hemp fiber on the outside. Because of the above reason, the hemp fibers are cemented to each other and cannot be used directly for textiles. It is necessary to release the fiber from "the bound state" by degumming treatment, which is a vital process for its production, as shown in Figure 1. The traditional chemical degumming of hemp fiber is done mainly with sodium hydroxide, uses strong acid and alkali as the steaming solution, and also requires high-temperature and high-pressure steaming conditions. The hemp fiber fabric prepared by the above-mentioned traditional chemical degumming has the complicating problems of rough texture, non-ideal performance, and serious pollution. To solve these complicating problems, an enzymatic degumming method produced by microbial strains has been invented. In the enzymatic degumming process, the pollution problem is solved, but there are still many bottlenecks that cannot be broken through, such as high requirements for bacterial strain culture, low production capacity of pectinase, unstable activity of pectinase, low degumming effect, and long degumming time.

This paper researches and develops the biochemical degumming technology, providing a new degumming solution composed of alkali pectinase lyase and a chemical auxiliary, which has a total content of alkali of ≤0.4% and a total amount of salt of ≤0.8%. This biochemical degumming solution can achieve the degumming effect at 60 °C and constant pressure. Degumming effects are observed by scanning electron microscopy (SEM), Fourier transform infrared (FTIR) spectroscopy, and X-ray diffraction (XRD); also, the consistent and the breaking strength of hemp fibers and whether the degumming with the biochemical degumming solution makes the hemp better or not are discussed.

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2. MATERIALS AND EXPERIMENTS

2.1. Materials. Hemp was grown in Yunnan; high concentrations of alkali pectinase lyase were produced by Sunsonzymes Catalase Co., Ltd. in Shanghai; sodium hydroxide (AR), sodium carbonate (AR), sodium chloride (AR), calcium chloride (AR), ethylene glycol (AR), sodium formate (AR), and glycerol (AR) were purchased from Tianjin Kaitong Chemical Reagent Co., Ltd.

2.2. Experiments.

2.2.1. Hydrolase Activity of Alkali Pectinase Lyase. The hydrolase pectinase assay was performed by the DNS method. A specific quantity of the pectinase sample was absorbed and diluted with a buffer solution of glycine and NaOH, which resulted in the absorptivity of 0.3–0.6 for the diluted sample. The result of hydrolase activity of alkali pectinase lyase was 108.6 U/mL.

2.2.2. Lyase Activity of Alkali Pectinase Lyase. No. 1 and no. 2 color-comparison tubes or test tubes were prepared as blank samples; to each tube containing 0.2 mL of the diluent pectinase sample, 2 mL of polygalacturonic acid solution was added, which was then immediately added to 10 mL of diluted solution of hydrochloric acid for inactivating the above solution. Following that deionized water was added until a volume of 25 mL was achieved, shaken well, and its absorbance value determined at 235 nm as comparison blanks.

No. 3, no. 4, and no. 5 color-comparison tubes were prepared as sample tubes; to each tube containing 0.2 mL of the diluent pectinase sample, 2 mL of polygalacturonic acid solution was added, reacted for 15 min in a 55 °C water bath. To this reaction, 10 mL of diluted solution of hydrochloric acid was added immediately to inactivate the above solution, following that deionized water was added until a volume of 25 mL was achieved, shaken well, and their absorbance value was determined at 235 nm as the samples.

The amount of pectinase required that lyase polygalacturonic acid produce unsaturated oligomeric galacturonic acid per minute, which is called the pectinase activity unit (U). The lyase activity of alkali pectinase lyase was calculated using the below formula (A.A.1) 

\[ X_l = \frac{(A - A_0) \times 10^6 \times n \times V_1}{10^3 \times 4600 \times t \times b \times V_2} \]  

(A.1)

In the A.A.1 formula, \(X_l\) is the lyase activity, U/mL; \(A\) is the absorbance average of the pectinase sample solution; \(A_0\) is the absorbance average of the pectinase blank solution; \(n\) is the dilution multiple; \(V_1\) is the total volume of the reaction system, mL; \(V_2\) is the volume of the diluted pectinase solution sample, mL; \(t\) is the reaction time, min; and \(b\) is the thickness of color-comparison tubes, cm. The result of lyase activity of alkali pectinase lyase was 25.2 U/mL.

2.2.3. Degumming Process: Biochemical Method. The degumming solution used for the process contained different ratios of 0–2.4% alkaline pectinase lyase with chemical auxiliaries, which were 0.4% sodium hydroxide, 0.13% sodium carbonate, 0.17% sodium chloride, 0.13% calcium chloride, 0.03% sodium phosphate, 0.02% sodium formate, 0.2% sodium silicate, 0.12% sodium sulfite, 0.15% ethylene glycol, and 98.65% water. The bath ratio was 1:10; the temperature range was 0–100 °C; and the time range was 0–120 min at a pH of 9.48.

Biological method parameters: the ratio of alkaline pectinase and xylanase was 1:2; the amount of the enzyme was 0.8% (w/w); the temperature was 30 °C; the bath ratio was 1:10; and the degumming time was 60 h at a pH of 8.5.

Chemical method parameters: the concentration of NaOH was 14%; the bath ratio was 1:10; the temperature was 130 °C; the cooking time was 1 h; and the pressure was 0.5 MPa.
2.2.4. Hemp Fibers’ Composition Analysis. The degumming performance, that is, the evaluation of the change in the content of hemp fibers’ pectin, hemicellulose, lignin, and cellulose was determined following the method provided by National Standard GB 5889-1986, which is called the ramie fiber chemical composition analysis method.

2.2.5. FT-IR Analysis. A Spectrum-One B infrared spectrometer (FT-IR, PE Company, America) was used to analyze the chemical structure of hemp fibers, so as to check whether degumming is better or not. Before measurements, powdered samples of hemp fibers were mixed with a powder of potassium bromide in the ratio of 2.5: 3 mg of the sample to 300 mg of potassium bromide and pressed into pills. The test scan wavenumber range is 4000 – 300 cm⁻¹.

2.2.6. SEM Analysis. The morphology of hemp fibers was studied to check whether degumming is better or not using an S-4800 scanning electron microscope (HITACHI, Japan), and the accelerating voltage was 10 kV.

2.2.7. XRD Analysis. A Max-3B X-ray diffractometer (XRD, RIKEN, Japan) was used to test the crystallization properties of hemp fibers so as to determine whether degumming is better or not. The test conditions are as follows: tube voltage: 40 kV, tube current: 2–80 mA, 2θ range: 5–70°, and scanning speed: 4 (°)/min.

The relative crystallinity of the structure was calculated using the below formula

\[ C = \frac{I_{002} - I_{am}}{I_{002}} \times 100\% \]  

(A.2)

In the A.A.2 formula, \( I_{002} \) is the diffraction strength of the crystal surface, around \( 2\theta = 22.5° \), %, and \( I_{am} \) is the diffraction strength of the amorphous structure, around \( 2\theta = 18° \), %.

2.2.8. Physical and Mechanical Property Analysis. The tensile fracture test was carried out by the isokinetic elongation method. The test was performed using an LLY-06E electronic single wire strength meter (Laizhou Electronic Instruments Co., Ltd., China), with the stretch spacing called D selected to be between 20 and 30 mm. The stretch speed was set to 10/15/20/30 mm/min in each stretch interval. The number of test roots, N, was 250. Using the Y171 fiber length cutter (Changzhou Electromechanical Technology Co., Ltd., China), the length of the combed fiber bundles was cut to 1 mm, which were then evenly distributed on the cover glass. The fineness was automatically measured using a YM-1X fiber fineness meter (Laizhou Electronic Instruments Co., Ltd., China).

3. RESULTS

3.1. Biochemical Degumming Process. 3.1.1. Effect of Alkali Pectinase Lyase Ratio in the Biochemical Solution. The ratios of alkali pectinase lyase in solution were 0.6; 0.9; 1.2; 1.5; 1.8; 2.1; and 2.4%. The conditions were as follows: the bath ratio was 1:10; temperature was 80 °C; and processing time was 60 min. The components pectin, hemicellulose, lignin, and cellulose of hemp fibers are tested, as shown in Figure 3; 60 °C was chosen as the optimal temperature.

3.1.2. Effect of Degumming Temperature. The degumming steaming conditions were as follows: the ratio of alkali pectinase lyase was 1.5%; the bath ratio was 1:10; processing temperature was 60 °C, and times were 20, 40, 60, 80, 100, and 120 min. The contents of pectin, hemicellulose, lignin, and cellulose of hemp fibers are tested, as shown in Figure 4, and 60 min was selected as the optimal time.

3.2. Evaluation of the Degumming Performance by Biological/Chemical/Biochemical Methods. The biochemical degumming method was analyzed with the above-mentioned best conditions and compared with the traditional chemical and biological degumming methods.

3.2.1. FT-IR Analysis of Hemp Fibers Treated by Three Different Methods. The hemp fibers were treated by three methods, and degumming effects were further confirmed by FT-IR analysis, as shown in Figure 5. The vibration intensities at 1032 and 1735 cm⁻¹ of the chemical and biochemical methods are blunt, compared with the raw and biological methods. This passivated vibration indicated that the chemical...
and biochemical methods can remove lignin and pectin profoundly, which is the ideal effect.

3.2.2. Hydroxyl Bond Impact by Different Methods. A large number of hydroxyl groups and hydrogen bond receptors existed in internal cellulose. Figure 6 shows that the second derivative spectrum of four samples at 3000−3800 cm\(^{-1}\), which is raw hemp and hemp treated by three methods. A 15-point cubic function Savitzky−Golay method was used to smooth the curve to obtain its second-order derivative spectrum. It was found that a significant change in absorption at the 3000 to 3800 cm\(^{-1}\) band, which is related to the change of hydrogen bonds.\(^{22,23}\)

By fitting the Gao Si peak at the origin, the sub-peak distribution intensity of different hydrogen bond types is obtained, which is shown in Figure 7. Each sub-peak and the relative percentage content of various hydrogen bonds were calculated and counted, the results of hydrogen bond fitting are shown in Table 1. These methods extract cellulose with a changing hydrogen bond, and hydrogen bonds are absorbed within a certain wavenumber range, as shown in Figure 7:

\[ I(-\text{OH} \text{ is at } 3580 \text{ cm}^{-1})^{24} \quad II(\text{OH} \cdots \pi \text{ is at } 3510 \text{ cm}^{-1})^{25} \quad III(O_2(n)H \cdots O_2((n + 1) \text{ and } O_2H \cdots O_6(n + 1) \text{ are at } 3366 \text{ cm}^{-1})^{27} \quad IV(O_2H \cdots \text{OH is at } 3410 \text{ cm}^{-1})^{28} \quad V(O_2H \cdots N_2^* \text{ is at } 3100 \text{ cm}^{-1})^{26} \quad \text{and VI(OH cyclic polymer is at } 3261 \text{ cm}^{-1})^{24} \]

Table 1 indicates that in the raw materials of hemp, it mainly consisted of an OH cyclic polymer, indicating that more lignin and pectin are present in the raw materials of hemp.

For the hemp treated by the biological method, the removal rate of lignin and pectin was minor.

For the hemp treated by the chemical method, the results show that the lignin and pectin are removed dramatically, causing the intermolecular hydrogen bonds to mainly exist by OH−π and the intramolecular hydrogen bonds are dominated by O3H−O6(n+1).

Table 1 indicates that in the hemp treated by the biochemical method, lignin and pectin were removed dramatically, which can replace the chemical method.

3.2.3. SEM Analysis. Figure 8a shows a large amount of presented pectin, which linked the cellulose together. Figure 8b provides the surface morphology of the hemp fiber treated by the biological method more smooth, but the fibers are still in an adhesive state. As shown in Figure 8c,d, the chemical and biochemical treatments of hemp fibers show clearly that the cellulose extracted through the adhesive of lignin and pectin achieved a great degumming effect.\(^{29,30}\)

3.2.4. XRD Analysis. It had clearly strong diffraction peaks in the range of 22° characterized by cellulose I, which belonged to the 002 crystal plane. The peaks in the range of 16° characterized by cellulose II, which belonged to the 101 crystal plane.\(^{31,32}\)

Table 2 shows data for the crystallinity of the raw hemp and the hemp after degumming by different processes, from which it can be concluded that the strength of the absorption peak of the fibers processed by three methods has increased compared with that of the raw hemp. The increase in the crystallinity of the hemp fiber after the biological degumming process was less than that of the chemical method because of the poor ability of removing the amorphous non-crystal substance. The crystallinity of hemp subjected to the biochemical degumming

![Image](https://pubs.acs.org/journal/acsomega)
method was found to be the highest from 55.47% to 78.40% as compared to the original hemp fiber, indicating that its amorphous substances, such as pectin and lignin were moved.

Biochemical crystallization is slightly higher than that of the chemical method; the lower crystallization of the damaged fibers may be due to the high temperature and strong alkali

Figure 6. Second derivative spectrum of the four samples.

Figure 7. Gaussian fit peak of the four samples: (a) raw hemp, (b) biological method, (c) chemical method, and (d) biochemical method.
factors, although the chemical method had slightly better degumming effect than the biochemical method. Provided the mild degumming method by biochemical.

3.2.5. Analysis of the Chemical Composition of the Four Samples. Comparing the degumming effect of chemical, biological, and biochemical methods, the results are presented in Figure 10. The degumming effect of hemp fibers by the biological method was improved but not significantly. The degumming effect of the chemical method is better than the biological method, causing the content of lignin, pectin, and hemicellulose to be lower than the hemp treated by the biological method and the content of cellulose more than that. By comparison, the cellulose constitution of hemp fibers treated by the biochemical method was 78.87%, which is similar to the content of cellulose in hemp treated by the chemical method, 80.66%, due to which it is expected to replace the chemical method.

3.2.6. Analysis of Physical and Mechanical Properties. Shown in Table 3 are wearability results of the fibers that were

| Table 1. Assignment of the FTIR Region Bands of the Four Samples |
|---------------------------------------------------------------|
| Samples | Hydrogen bond types | Assignments | Wavenumbers/cm⁻¹ | Proportion |
| Raw Hemp | ─OH Region Free Hydroxyl | I ─OH⁻¹⁶ | ~3580 | 27.93 | 27.93 |
| | Multimer Intermolecular association | V ΔH·N₆⁺ | ~3100 | 1.30 | 23.04 |
| | Intramolecular association | III Oₛ═O₂═O₃═O⁻¹⁷ | ~3366 | 0.76 | 49.04 |
| | ─OH Region Free Hydroxyl | I ─OH | ~3580 | 21.69 | 21.69 |
| Biological | Multimer Intermolecular association | V ΔH·N₆⁺ | ~3100 | 5.84 | 21.14 |
| | Intramolecular association | III Oₛ═O₂═O₃═O⁻¹⁷ | ~3366 | 20.70 | 57.17 |
| | ─OH Region Free Hydroxyl | I ─OH | ~3580 | 25.67 | 25.67 |
| Chemical | Multimer Intermolecular association | V ΔH·N₆⁺ | ~3100 | 3.72 | 8.13 |
| | Intramolecular association | III Oₛ═O₂═O₃═O⁻¹⁷ | ~3366 | 22.45 | 66.17 |
| | ─OH Region Free Hydroxyl | I ─OH | ~3580 | 25.83 | 25.83 |
| Biochemical | Multimer Intermolecular association | V ΔH·N₆⁺ | ~3100 | 3.64 | 6.57 |
| | Intramolecular association | III Oₛ═O₂═O₃═O⁻¹⁷ | ~3366 | 26.21 | 67.60 |

“The representation of other molecular chains.

Figure 8. SEM diagram of the four samples: (a) raw hemp, (b) biological method, (c) chemical method, and (d) biochemical method.

| Table 2. Structure of Relative Crystallinity of the Four Samples |
|---------------------------------------------------------------|
| Samples | I₀₀₂ | Iₐm | C (%) |
| raw hemp | 2180 | 949 | 56.47 |
| biological method | 4357 | 1124 | 74.20 |
| chemical method | 5547 | 1270 | 77.10 |
| biochemical method | 5947 | 1284 | 78.40 |

| Table 3. Test Results of Hemp Fiber Technical Specifications |
|---------------------------------------------------------------|
| biological method | chemical method | biochemical method |
| linear density (dtex) | 5.02 | 4.54 | 4.66 |
| fiber length (mm) | 40.7 | 34.4 | 35.6 |
| fracture strength (cN/dtex) | 46.2 | 63.2 | 64.5 |
treated and bleached by the three methods, such as the linear density, fiber length, and fracture strength.33,34 Because a large amount of amorphous pectin and lignin was still bonded to the surface of cellulose treated by the biological method, causing a minus function, its linear density was 5.02 dtex, the length of the fiber bundle was 40.7 mm, and the fracture strength was 46.2 cN/tex.

On the contrary, the linear density of hemp treated by the biochemical method was 4.66 dtex, smaller than that of hemp treated by the biological method, which was caused by the decrease in the amount of pectin and lignin. It was also better than the linear density of hemp treated by the chemical method, 4.54 dtex. The 34.4 mm length of the hemp fiber treated by the chemical method was shorter than the 35.6 mm of the fiber treated by the biochemical method, which was caused by the distinguished injury on the hemp surface. The fracture strength of the fiber treated by the biochemical method was 64.5 cN/tex, which was slightly higher than that of the fracture strength of 63.2 cN/tex of the chemically treated hemp, which indicates that its properties are better than those of the chemical method.

4. DISCUSSION

The contents of pectin, hemicellulose, lignin, and cellulose of the hemp fiber were determined at different temperatures and are shown in Figure 3. It shows that the better degumming effect with the increasing temperature, causing chemical auxiliaries have the swelling effect that promote alkali pectinase lyases acting the pectin of fiber at the appropriate temperature. The removal rate of pectin and lignin was increased at the former 80 °C and then obviously decreased above 80 °C. The results show that the degumming effect tends to be stable at 60–80 °C, but considering the stability and persistence of energy consumption and alkali pectinase lyase activity, 60 °C was chosen as the optimal temperature.

The contents of pectin, hemicellulose, lignin, and cellulose of the hemp fiber was tested at different times and are shown in Figure 4. It can be seen from the diagram that the content of cellulose increased and that of pectin decreased with increasing time. The swelling effect by chemical auxiliaries was better with the increase of time. With time, the viscosity of pectin decreased rapidly, causing alkali pectinase lyase to act on the pectin glued to the fibers’ surface, which converts the glycosidic bond into galacturonic acid ester with an unsaturated bond. The degumming effect was gentle and did not changed obviously after 60 min, so 60 min was selected as the optimal time.

For the hemp fibers treated by the three methods, degumming effects were further confirmed by FT-IR spectroscopy, as shown in Figure 5. The main characteristic peaks are basically the same, peaks are observed at 3440 cm⁻¹ attributed to the −OH band and at 2923 cm⁻¹ attributed to −CH₂ bands, which substitute the cellulose of hemp;35 the vibration intensity at 1735 cm⁻¹ of the fibers treated by chemical and biochemical methods were less intense as compared to the raw hemp and hemp treated by the biological method. This passivated vibration indicated that chemical and biochemical methods can remove lignin and pectin profoundly, which achieve the ideal effect.

Table 1 shows that in the raw materials of the hemp, the proportion of intermolecular hydrogen bonds is 23.04, the proportion of intramolecular hydrogen bonds is 49.04, and the proportion of free hydroxyl groups is 27.93. The intermolecular hydrogen bonds mainly existed as OH···π and the intramolecular hydrogen bonds mainly existed as the OH cyclic polymer, indicating more lignin and pectin in the raw materials of the hemp.

Table 1 indicates that in the hemp treated by the biological method, the proportion of intermolecular hydrogen bonds was 21.14, intramolecular hydrogen bonds was 57.17, and free hydroxyl groups was 21.69. The main types of intermolecular hydrogen bonds were O₃H···O₆(π+1), indicating that the removal rate of lignin and pectin was minor.

Table 1 shows that in the hemp treated by the chemical method, the proportion of intermolecular hydrogen bonds was 8.13, intramolecular hydrogen bonds was 66.17, and free hydroxyl groups was 25.67. The content of intermolecular hydrogen bonds was greatly reduced and that of intramolecular hydrogen bonds was greatly increased. These results show that the lignin and pectin were removed significantly, causing the intermolecular hydrogen bonds to mainly exist as OH···π and to be dominated by O₃H···O₆(π+1).

Table 1 indicates that in the hemp treated by the biochemical method, the proportion of intermolecular hydrogen bonds was 6.57, intramolecular hydrogen bonds was 67.60, and free hydroxyl groups was 25.83, and the intramolecular hydrogen bonds mainly existed as O₃H···N⁵⁺, indicating that alkali pectinase lyase can act effectively on the intermolecular bonds of hemp cellulose with the help of chemical auxiliaries. The main types of intermolecular hydrogen bonds were O₃H···O₆(π+1), indicating that lignin and pectin were removed significantly, which can therefore replace the chemical method.

Figure 9 shows that at the 101 crystal plane, a large number of lignin, hemicellulose, and other amorphous substances exist in the raw hemp and biological method fiber, forming a smooth and gentle peak; the lignin and pectin were removed significantly, which can therefore replace the chemical method.

Figure 9. XRD patterns of the four samples.
by chemical and biochemical methods, resulting in two small sharp peaks. The peaks in the 002 crystal plane show that pectin, lignin, and other substances on the fiber surface were removed dramatically, causing an enhanced intramolecular effect which is beneficial to the formation of a more perfect structure (cellulose model I). The peak patterns of fibers of chemical and biochemical methods were sharper than those of raw hemp and biological fibers, which means that the degumming effect of the biochemical method is similar to the chemical one.

Figure 9 shows that in the 101 crystal plane, a large amount of lignin, hemicellulose, and other amorphous substances existed in the raw hemp and fiber treated by the biological method, as indicated by the formation of a smooth and gentle peak; lignin and pectin were removed by chemical and biochemical methods, which resulted in two small sharp peaks. The peaks in the 002 crystal plane show that pectin, lignin, and other substances on the fiber surface were removed dramatically, causing an enhanced intramolecular effect which was beneficial to the formation of more perfect structure (cellulose model I). The peak patterns of fibers of chemical and biochemical methods were sharper than those of raw hemp and fibers treated by the biological method, which means that the degumming effect of the biochemical method is similar to that of the chemical one (Figure 10).

5. CONCLUSIONS

After biochemical degumming, the contents of lignin, pectin, and hemicellulose decreased with the increase in the content of alkali pectinase lyase and times. The optimized degumming conditions are as follows: 1.5% alkali pectinase lyase; chemical auxiliaries, the total amount of alkali was \( \leq 0.4\% \), the total amount of salt was \( \leq 0.8\% \), the bath ratio was 1:10, the optimal temperature of the reaction was 60 °C, and the optimal time of the reaction was 60 min. Under these conditions, each component consisted of 3.69% of lignin; 4.09% of pectin; 13.34% of hemicellulose, and 78.87% of cellulose.

A comparison of the biochemical, chemical, and biological degumming performances showed the lowest contents of lignin, pectin, and hemicellulose and the highest content of cellulose in fibers dealt by the chemical method, while the results of biochemical method were slightly lower than those of the chemical method and those of biological degumming were obviously poor. Multimer intermolecular association decreased from 23.04% for raw materials to 21.14% for the biological method to 8.13% for the chemical method to 6.57% for the biochemical method, which also proved the similarity in effectiveness between biochemical degumming and chemical degumming. The crystallinity of the fibers was almost similar after degumming, which followed the order: raw materials (56.47%) < biological (74.20%) < chemical (77.10%), and biochemical (78.40%). The linear density and strength of the fibers prepared by the biochemical method, which are 4.66dtex and 64.5cN/dtex, are slightly larger than those of the fibers treated by the chemical method.

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### Notes

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