Hydrolysis of Abandoned Bovine Hair by Pulping Spent Liquor and Preparation of Degradable Keratin-based Sprayable Mulch Film

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Pulping spent liquor was used to hydrolyze abandoned bovine hair, and the resulting keratin hydrolyzate was blended with polyvinyl alcohol (PVOH), polyacrylamide (PAM), N,N-methylenebis (acrylamide) (MBA), and glycerol (GL) to prepare the low-cost degradable keratin-based sprayable mulch film (KSMF). The prepared KSMF contained elements required for plant growth, such as N, P, K, S, Ca, Si, and the water absorbency reached 380% in deionized water. A degradation of 23.1 wt% was attained while it was buried for 50 d in soil. The KSMF was easy to apply and needed to be diluted for spraying on the soil surface and formed a physical barrier to reduce evaporation of water and heat preservation. The KSMF had good degradability and entered the soil to become a high-quality biomass organic fertilizer during the growth of the crop, thus avoiding "white pollution" and realizing the recycling of waste, which would extend the application prospects in sustainable modern agriculture.

Keywords: Abandoned bovine hair; Pulping spent liquor; Hydrolysis; Keratin-based; Sprayable mulch film; Degradable

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INTRODUCTION

Film mulching technology, which is an effective way to increase the yield of grain in agriculture, is extensively applied to satisfy the increasing food demand due to population growth and limited arable land area (Godfray *et al.* 2010). Rational use of this technology can effectively reduce the evaporation of water in the soil and promote the growth of crops (Miles *et al.* 2012; Berger *et al.* 2013; Li *et al.* 2014). However, the traditional plastic mulch film used in the film mulching technology is made of non-renewable petroleum-based resources. The residue of the traditional film remains left on the field and cannot be decomposed by microorganisms, which will lead to decreased soil quality, reduced crop yield (Gu *et al.* 2017; Hou *et al.* 2019), and serious "white pollution". Therefore, plastic mulch film needs to be recycled (Briassoulis *et al.* 2012; Kasirajan and Ngouajio 2012), and many farmers employ centralized stacking or incinerate the plastic mulch film, which will not only cause soil and air pollution, but also affect the health of residents (Hayes *et al.* 2012; Briassoulis *et al.* 2015). In recent years, natural polymer materials, which would be an alternative material to meet the needs for mulch film, have attracted increased attention due to their regenerative and degradable properties (Zhao *et al.* 2016; Yi *et al.* 2017). Starch-polymer blend films are a hot spot in current research, but

they are not 100% degradable (Guilbert and Gontard 2005; Liu 2005) and lead to secondary pollution to the soil. Therefore, it is important to develop a low-cost, degradable mulch film based on renewable resources for agricultural development (Liu *et al.* 2014).

The main non-water component of papermaking black liquor is lignin, which is the second largest biomass resource in nature after cellulose (Zhang *et al.* 2019). In addition, pulping spent liquor also contains polypentoses, cellulose, hemicelluloses, and organic matter. If the pulping spent liquor is improperly treated, for example, directly discharged or burned after concentration, it will pollute the environment and lead to a lot of waste of resources (Ragauskas *et al.* 2014). In addition, lignin contains a variety of reactive groups with ion exchange and chelation properties (Sipponen *et al.* 2016), and lignin is regarded as a precursor to humus substances, so it can be used as raw material for the preparation of slow-release fertilizers and organic fertilizers, which is conducive to the growth of crops.

At present, due to the development of the leather industry, a large quantity of bovine hair is generated during the processing of leather (Olk *et al.* 2006; Laurichesse and Avérous 2014; Liu *et al.* 2015). Abandoned bovine hair is a rich renewable keratin resource (Zhang *et al.* 2014; Oladele *et al.* 2018; Valeika *et al.* 2019), but its use is limited in practice because it generally has a dark color and is resistant to degradation (Gousterova *et al.* 2005; Lateef *et al.* 2010). Most of the abandoned bovine hair is landfilled and incinerated, which will cause potential pollution to soil and air (Tesfayel *et al.* 2017). Hence, it is necessary to develop green and effective methods to recycle these wastes. Studies in recent years indicate that the degradation of keratin by microorganisms is an effective alternative for the management of keratin wastes and for improving their value added (Jayalakshmi *et al.* 2012). Abandoned bovine hair is a solid protein that is difficult to degrade. However, the liquid protein is obtained after the solid protein is hydrolyzed with disulfide bonds and stable structure are destroyed. At the same time, this protein is full of peptides and easily degraded by microorganisms into amino acids that can provide supplementary nutrients for crops.

In this work, abandoned bovine hair was hydrolyzed by pulping spent liquor, and the novel degradable keratin-based sprayable mulching film (KSMF) was prepared by the mixture solution, which contained keratin hydrolyzate, polyvinyl alcohol (PVOH), polyacrylamide (PAM), N,N-methylenebis (acrylamide) (MBA), and glycerol (GL). In addition, this work explored preparation of a type of low cost and eco-friendly agricultural mulch film based on renewable animal and plant resources. The KSMF became a high-quality organic fertilizer after degradation to replace the chemical fertilizer to some extent, which is the necessary direction for the development of modern agriculture. Additionally, it provided effective ways to solve the problems of resource utilization of waste solid protein in tanning, comprehensive utilization of pulping black liquor, and "white pollution" of agricultural film. This not only conforms to the current green development concept, but also achieves sustainable development of agriculture, economy, and environment.

EXPERIMENTAL

Materials

Corn stalk pulping spent liquor from cellulose pulp production was obtained from Jilin Province in Northeast China. The black liquor had a pH of 11, a solids content of 10.31%, an organic content of 71.35 g/L, and an effective alkali of 9.29 g/L. The bovine hair obtained from the hair-saving un-hairing process (Huanghua Defu Leather Co., Ltd.,

Hebei, China) had a keratin content of 81.9%, a fat content of 4.85%, and an ash content of 4.92%. The KOH, 30 wt% hydrogen peroxide (H_2O_2), PAM, GL, PVOH, and calcium superphosphate were purchased from Tianjin Damao Chemical Reagent Company, Ltd. (Tianjin, China). The MBA was purchased from Tianjin Fuchen Chemical Reagent Company, Ltd. (Tianjin, China). All the chemical reagents were analytical grade.

Bovine Hair Hydrolyzed by Black Liquor

An appropriate amount of KOH, 5 g of bovine hair, and 50 mL of black liquor were added to a 250-mL three-necked flask, which was equipped with a mechanical stirrer and reflux condenser. The KOH was added to increase the pH. After reacting at 95 ℃ for 1 h, 30 wt% H_2O_2 was added to the three-necked flask, which oxidized the bovine hair to make the bovine hair fluffy, easy to break, and increased the probability of the bovine hair keratin reaction. Thereby it increased the hydrolysis rate of the bovine hair. After hydrolysis for 5 h, the hydrolysate was filtered, while the residue was filtered off and the filtrate was stored. The mass of the filter residue was optimized for orthogonal experiment. According to the orthogonal table of $L_9(4)^3$ (Table 1), the following experiments were conducted. Letter A indicates for the hydrolysis time, whereas B, C, and D stand for the hydrolysis temperature, KOH dosage, and H_2O_2 dosage, respectively. Q_{fs} stands for the quality of the filter residue.

Table 1. Factors and Levels of Hydrolysis Orthogonal Experiment

Factor Level	A (h)	B (°C)	C (%)	D (%)
1	3	85	12	10
2	4	90	14	12
3	5	95	16	14
A is the hydrolysis time, B is the hydrolysis temperature, C is KOH dosage, D is H_2O_2 dosage, and Q_{fs} is the quality of the filter residue				

Preparation of KSMF

Approximately 20 mL of the hydrolysate, 1 wt% GL, 0.05 wt% MBA, and an appropriate amount of PVOH and PAM were added to a 50-mL three-necked flask, which was equipped with a mechanical stirrer and reflux condenser. The mixture solution was obtained after stirring at 95 ℃ for 1 h. Next, the mixture solution was filtered to filter out insoluble macromolecular substances, and the filtrate was poured into a Petri dish. The resulting film was uncovered after drying under natural conditions. Then the water absorption performance was measured. The film-forming experiment was conducted according to the orthogonal table of $L_9(3)^3$, as shown in Table 2.

Table 2. Factors and Levels of Preparation of KSMF Orthogonal Experiment

Factor Level	A (h)	B (%)	C (%)
1	1	4	0.10
2	2	6	0.15
3	3	8	1.20
A is the film forming time, B is PVOH dosage, C is PAM dosage			

Finally, $Ca(H_2PO_4)_2 \cdot H_2O$ was used to adjust the pH of the mixture solution under optimal conditions to neutral to obtain KSMF. Column A indicates the film forming time; column B and C stand for the PVOH dosage and the PAM dosage, respectively.

Determination of Hydrolysis Rate

An appropriate amount of bovine hair was weighed (W_0) and hydrolyzed. First, the filter cloth was dried at 65 ℃ to constant weight, and the filter cloth weighed (W_1). Next, the hydrolysate was filtered with the filter cloth and the filter residue was washed with deionized water. Finally, the filter cloth and filter residue were baked at 65 ℃ for 6 h and the mass was weighed (W_2). The hydrolysis rate (*HR*%) of bovine hair was calculated from Eq. 1,

$$HR(\%) = [W_0 - (W_2 - W_1)]/W_0 \times 100\% \quad (1)$$

where *HR*% is the hydrolysis rate, W_0 (g) is the mass of the dry bovine hair, W_1 (g) is the mass of the filter cloth, and W_2 (g) is the mass of the filter cloth and the filter residue.

Preparation of KSMF

Approximately 20 mL of the hydrolysate, 1 wt% GL, 0.05 wt% MBA, 8 wt% PVOH, and 0.20 wt% PAM were added to a 50-mL three-necked flask, which was equipped with a mechanical stirrer and reflux condenser. The mixture solution was obtained after stirring at 95 ℃ for 1 h. Next, the mixture solution was filtered and poured the filtrate into the Petri dish. Finally, the $Ca(H_2PO_4)_2 \cdot H_2O$ was used to adjust the pH of the mixture solution to neutral to obtain KSMF.

Material Characterization

The KSMF was analyzed by pouring the filtrate into the Petri dish and uncovering the film after drying under natural conditions. Scanning electron microscopy (SEM) (Tescan Vega 3 SBH; Tescan, Brno, Czech Republic) and energy dispersive spectrometry (EDS) (Tescan Vega 3 SBH; Tescan, Brno, Czech Republic) were used. Fourier transform infrared (FTIR) spectra were recorded on an infrared spectrometer from 4000 cm^{-1} to 400 cm^{-1} (Vertex 70; Bruker, Karlsruhe, Germany). X-ray diffraction (XRD) was recorded on an X-ray diffractometer (D8 Advance; Bruker, Karlsruhe, Germany) by using Cu Kα radiation at 40 kV and 40 mA. The diffraction angle ranged from 5° to 75°. Thermogravimetric analysis was measured using a system provided by Mettler Toledo (Netzsch STA 449 F5 TG/DSC; Mettler Toledo, Karlsruhe, Germany) in air at a heat rate of 10 ℃/min up to 500 ℃.

Water Absorption Capacity of KSMF

The dried film was cut into a size of 2 cm × 2 cm and weighed (M_1). The sample was immersed in 500 mL of deionized water for 30 min at room temperature to absorb water to achieve a swelling equilibrium. The swollen sample was filtered through a 100-mesh nylon mesh and suspended for 10 min until there was no free water on the surface and weighed (M_2) (Qiao *et al.* 2016). The equilibrium water absorption (Q_{eq}) was calculated as follows,

$$\mathrm{Q_{eq}}(\%) = (\mathrm{M_2} - \mathrm{M_1})/\mathrm{M_2} \quad (2)$$

where Q_{eq} (%) is the water absorption, M_1 (g) is the mass of the dried film, and M_2 (g) is the mass of the film after swelling by water absorption.

Water Retention Capacity of KSMF

Approximately 50 g of soil was added to two Petri dishes of the same size and quality. The prepared KSMF was sprayed equally onto the petri dish of the experimental

group and weighed (G_{01}). Another Petri dish was used as a control group and weighed (G_{02}). The Petri dishes were placed at room temperature and the mass of the Petri dishes was weighed (G_t) at the same time every day for up to 7 d. The mass difference was used as an indicator to compare the evaporation of water (Tang *et al.* 2017; Cheng *et al.* 2018). The water retention in soil (G_{wr}, g) can be described as shown in Eq. 3,

$$G_{wr}(g) = G_t - G_{0i} \quad (3)$$

where G_{wr} (g) is water retention capacity, G_{0i} (g) is the mass of the Petri dish and soil at beginning, and G_t (g) is the mass of the Petri dish and soil after the same time interval.

Growth Experiments

Approximately 800 g of soil were added to the two identical pots, and four wheat seeds were planted in each pot. Then, each pot was watered until moisture seeped out and covered 1 cm of soil. One pot was used as CK (without KSMF) and the other pot was sprayed with KSMF as the experimental group. Each pot was planted for three groups. The growth of the seeds was observed within 12 d. Then, the roots, leaf length, fresh weight, dry weight, and length of the seeds were measured (Xiang *et al.* 2018). Each treatment was repeated three times.

Natural Soil Degradation of KSMF

The degradation behavior was evaluated by measuring the weight loss of KSMF buried in the soil at different times. Approximate 0.1 g of KSMF was placed in a nylon bag and then buried in a plastic cup 5 cm below the surface of the soil and incubated for up to 50 d. In the experiment, the soil moisture was kept at 30% by regular weighing and adding distilled water. At every 5d interval, it was dug out. After being washed carefully with distilled water and dried to constant weight at 65 ℃, the KSMF was weighed to determine the weight loss (Liu *et al.* 2017). The degradation rate (D_e%) can be calculated as follows,

$$D_e(\%) = (Q_1 - Q_2)/Q_1 \times 100\% \quad (4)$$

where D_e (%) is degradation rate, and Q_1 and Q_2 (g) are the weights of the dry KSMF before and after the soil burial (g), respectively.

Statistical Analysis

Comparisons of various treatments were evaluated using the analysis of variance (ANOVA). Duncan's multiple range tests were used to determine significant differences among treatments ($P < 0.05$).

RESULTS AND DISCUSSIONS

Optimization of Hydrolysis Experiment Synthesis Conditions

When the black liquor was used to hydrolyze the bovine hair, it was necessary to add KOH due to the alkalinity of the black liquor being insufficient. The KOH was supplemented, to adjust the composition of the black liquor, increase the pH, and improve the utilization of various components. In addition, H_2O_2 promoted the hydrolysis of bovine hair. The mass of the filter residue, which as an indicator to optimize the hydrolysis experiment, was filtered by keratin hydrolysate. The weight of the residue was less, which further indicated that lignin generated hydrogen bonds with the amino acid in the

hydrolysate to form a macromolecular polymer. Orthogonal experiments with four factors and three levels were performed to find suitable conditions for bovine hair hydrolyzed by black liquor.

The composition of black liquor is complicated, but the main component is lignin. During the hydrolysis process, hydrophilic groups in the hydrolysate was increased. At the same time, lignin and keratin formed a large molecular chain due to hydrogen bonding between the reactive groups. The analysis results are exhibited in Table 3. The factors affecting the hydrolysis rate were C > B > A > D. The dosage of KOH had the greatest influence on the hydrolysis rate, the hydrolysis temperature degree followed, then the hydrolysis time, and the dosage of H_2O_2 was last. The optimal experimental combination was $A_3B_3C_3D_2$, and the corresponding conditions were as follows: the hydrolysis temperature of 95 ℃, the hydrolysis time of 5 h, KOH dosage of 16%, and H_2O_2 dosage of 12%. Under those conditions, the quantity of the filter residue was 1.158 g. The hydrolysis percentage was 76.8%.

Optimization of KSMF Synthesis Conditions

The water absorption properties of the film were different under different film forming conditions. To seek the optimal water absorption of the film, the three-factor and three-level orthogonal experiments were set up, and the analysis results are exhibited in Table 4. Factor A indicates the film forming time, B indicates PVOH dosage, C indicates PAM dosage, and Q_{eq} indicates equilibrium water absorption. The factors affecting the water absorption were B > C > A. The dosage of PVOH had the greatest influence on the water absorption, the dosage of PAM followed, and the reaction time was last. The optimal experimental combination was $A_1B_3C_3$, and the corresponding conditions were as follows: 1% of glycerol dosage, 0.05% of MBA dosage, 8% of PVOH dosage, 0.20% of PAM dosage, and 1 h reaction time, the water absorbency reached 380% in deionized water.

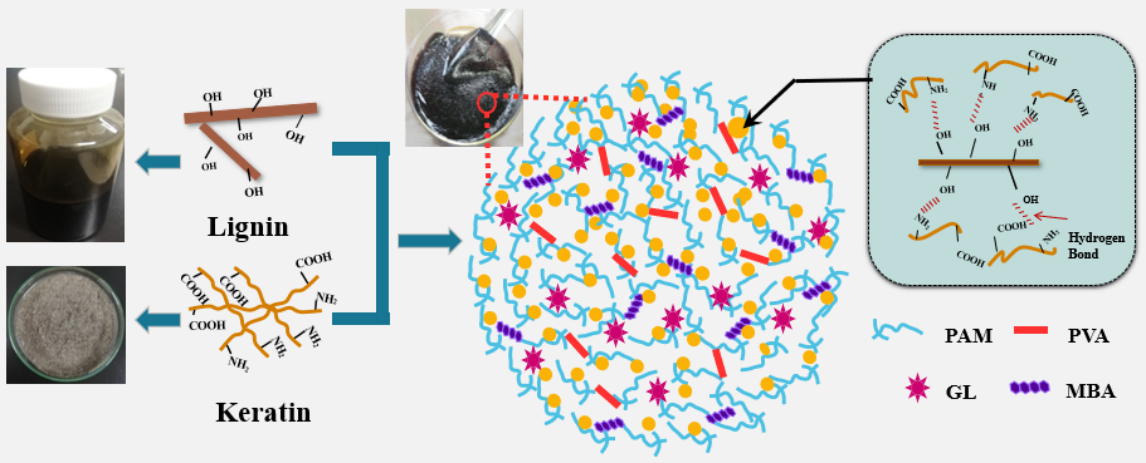

Fig. 1. Schematic diagram for the preparation of the KSMF

The PVOH has good film forming and adhesion properties, and PAM has excellent water absorption, adhesion, and film forming properties. The swelling ratio of KSMF reached approximately 380% after drying and immersion in deionized water. This indicated that KSMF had excellent water absorption and contributes to the growth of crops. This may be because the molecular chain formed by hydrolysis, the polymers of PVOH and PAM were crosslinked by the crosslinking action of the crosslinking agent MBA and

the physical entanglement of PVOH to form a relatively stable three-dimensional network polymer macromolecular structure. Additionally, a small amount of GL was added as plasticizer to enhance the film forming property to make the film dense. Therefore, the novel degradable keratin-based sprayable mulch film was obtained, which had good properties of warming, water retention, and water absorption. The schematic diagram for KSMF is shown in Fig. 1.

Water Retention of KSMF in Soil

The sprayable mulch film is a macromolecular polymer, and its functional groups and active sites in the soil can combine effectively to reduce the evaporation of water. The spraying process of KSMF is shown in Fig. 2(a).

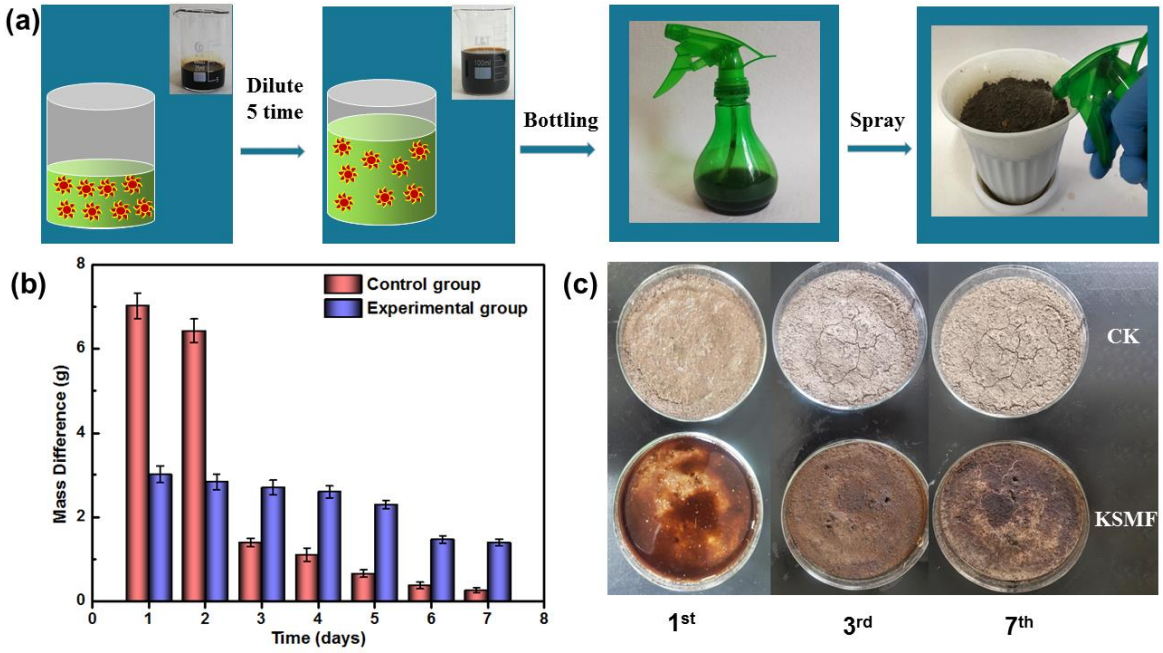

Fig. 2. (a) Spraying process of the KSMF, (b) the mass of soil and Petri dish over time, and (c) water retention of KSMF and CK at the same time interval

The KSMF was diluted according to the required concentration and sprayed on the soil surface. It combined with the soil particles on the soil surface, and then the soil particles were bridged by various chemical interactions, thereby promoting the collection of soil particles. Figure 2(b) shows that with the increase of time, the Petri dish without spraying the KSMF volatilized a large amount of water in two days before experiment, and the volatilization rate of moisture was extremely fast. In contrast, the Petri dish with the sprayed KSMF volatilized less water and the volatilization of water was slower. It can be observed from Fig. 2(c) that the surface particles on the soil surface were bound tightly to form a physical barrier to resist the volatilization of water on the soil surface. Additionally, the soil of KSMF was still wet on the 7th day, while the soil of CK was dry and cracked on the 3rd day. Therefore, it can be concluded that the application of KSMF could retain and supply moisture for plants and reduce water consumption.

FTIR Analysis

Figure 3(a) shows the FTIR spectra of keratin, lignin, hydrolysate, and KSMF. The characteristic absorption peaks were observed at 1660 cm^{-1} and 1542 cm^{-1} for the bending of the Amide I band and Amide II band. The characteristic peaks in the lignin spectra were attributed to the following: the peak at 3475 cm^{-1} corresponded to the -OH stretching vibration, and the characteristic absorption of 1610 cm^{-1} and 1514 cm^{-1} could be ascribed to the aromatic nucleus and lilac nucleus.

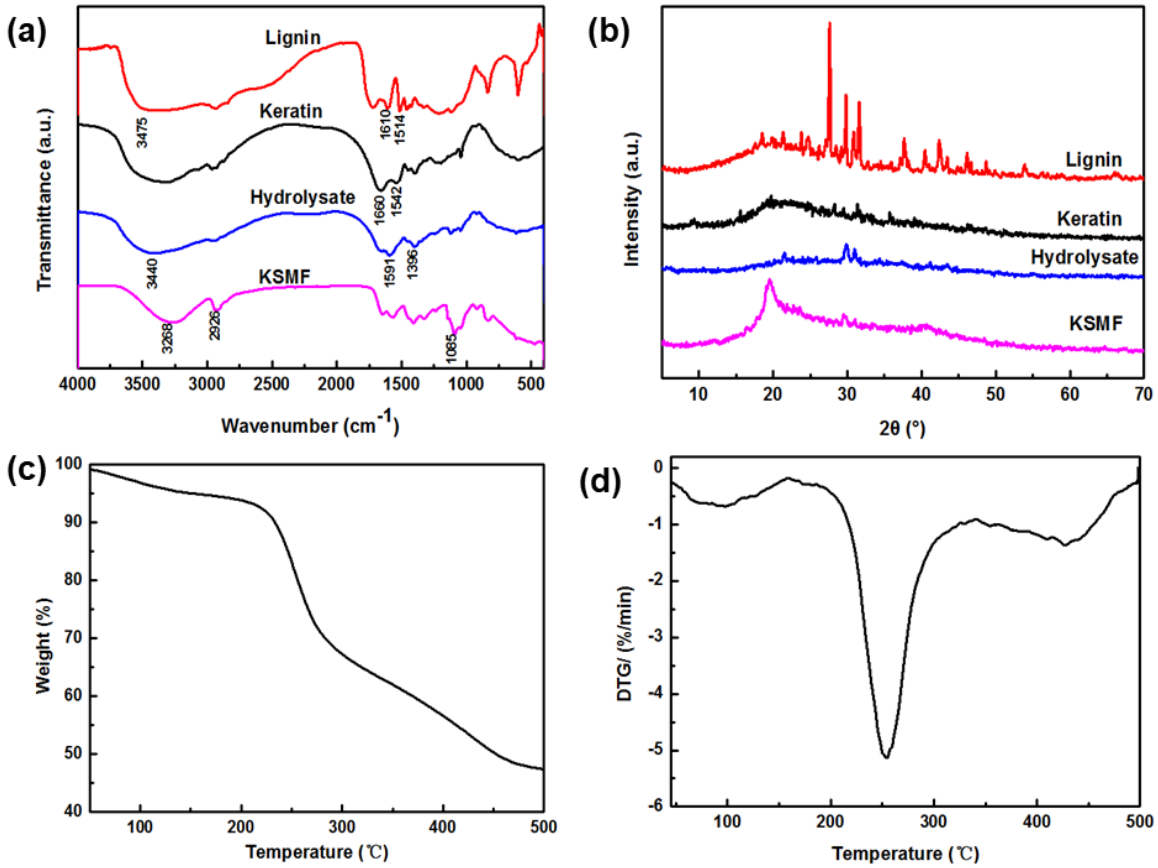

Fig. 3. (a) FTIR spectra of keratin, lignin, hydrolysate, and KSMF, (b) XRD patterns of keratin, lignin, hydrolysate, and KSMF, (c) Thermogravimetric curves of KSMF, and (d) Derivative thermogravimetric curves of KSMF

For hydrolysate, the characteristic absorption peak at 3440 cm^{-1} was assigned to the -OH stretching vibration, which was wider than that of keratin and lignin. This may be due to the formation of hydrogen bonds between lignin and keratin during hydrolysis. Moreover, compared with keratin, the characteristic absorption peak of the Amide I band and Amide II band were weakened and redshifted from 1660 cm^{-1} and 1542 cm^{-1} to 1591 cm^{-1} and 1396 cm^{-1}. This indicated that the bovine hair was dissolved in the black liquor, and the lignin in the black liquor interacted with the keratin molecules to improve the compatibility of the two components.

For KSMF, the characteristic absorption peak at 3268 cm^{-1} could be attributed to the -OH stretching vibration. The -OH stretching vibration, compared with hydrolysate, was strengthened and redshifted from 3440 cm^{-1} to 3268 cm^{-1}. This may be due to the polymerization, which would result in the formation of the three-dimensional network.

Additionally, the peak at 2926 cm^{-1} and 1084 cm^{-1} could be assigned to the -CH_2 and C-O stretching of PVOH, respectively, indicating that PVOH penetrated successfully into the three-dimensional network of KSMF. Taken together, these results confirm the formation of KSMF material.

XRD Analysis

Figure 3(b) shows the XRD patterns of keratin, lignin, hydrolysate, and KSMF. For keratin, it was an amorphous substance. For lignin, the characteristic peaks at 2θ = 27.60°, 29.86°, and 31.57° indicated that lignin was a crystalline phase structure. For hydrolysate, the characteristic peaks at 2θ = 29.86° and 30.99° confirmed the hydrolysate had the same crystal as lignin. Moreover, the hydrolysate showed a characteristic peak at 2θ = 21.52°, indicating that the bovine hair participated in the dissolution reaction, interacted with lignin and influenced the structure and crystallinity of lignin. It was noteworthy that KSMF appeared as one strong, broad peak at approximately 2θ = 19.58°. This result may be due to the macromolecules in the solution that were crosslinked together by polymerization. It also proved that keratin and lignin in KSMF had a good combination, rather than simple physical blending. This was consistent with the FTIR analysis results.

Thermogravimetric (TG)-Derivative Thermogravimetric (DTG) Analysis of KSMF

The TG and DTG curves of KSMF are shown in Fig. 3(c) and (d). It can be seen from Fig. 2 that there was a slight weight loss phenomenon below 157 ℃, which may have been due to the loss of moisture. The temperature ranged from 157 to 371 ℃, wherein severe weight loss occurred, with weight losses of 31.3%. Within the temperature range from 371 to 500 ℃, a slight weight loss occurred with weight losses of 15.83%. It could be because there was hydrogen bonding between lignin and keratin as well as copolymerization, which led the macromolecules to be crosslinked together, thereby improving the thermal stability of KSMF.

Degradation of KSMF in Soil

As shown in Fig. 4, the increased weight loss with prolongation of time demonstrated the degradability of the KSMF (Wen *et al.* 2017). The surface of the soil buried sample was coarse and loose. Comparing Fig. 4(a) and (b), many dots and cracks emerged on the surface of the KSMF buried in soil after 50 d. The main reason was that lignin was degraded into low molecular weight phenol compounds with an increase in burial time（Sipponen *et al.* 2016）.

The small molecule peptides obtained after the abandoned bovine hair had been hydrolyzed were a good source of microbial nutrition and energy for microorganisms; they boosted the microbial activities in the soil, and accelerated the degradation of KSMF (Shavandi *et al.* 2017; Adelere and Lateef 2019). As shown in Fig. 4(c), the degradation rate of KSMF buried in soil after 50 d was 23.1%. Lignin and the keratin hydrolyzate belonged to biomass materials with good degradability, which made KSMF eco-friendly. Therefore, the prepared KSMF can be regarded as a low-cost and degradable sprayable mulch film.

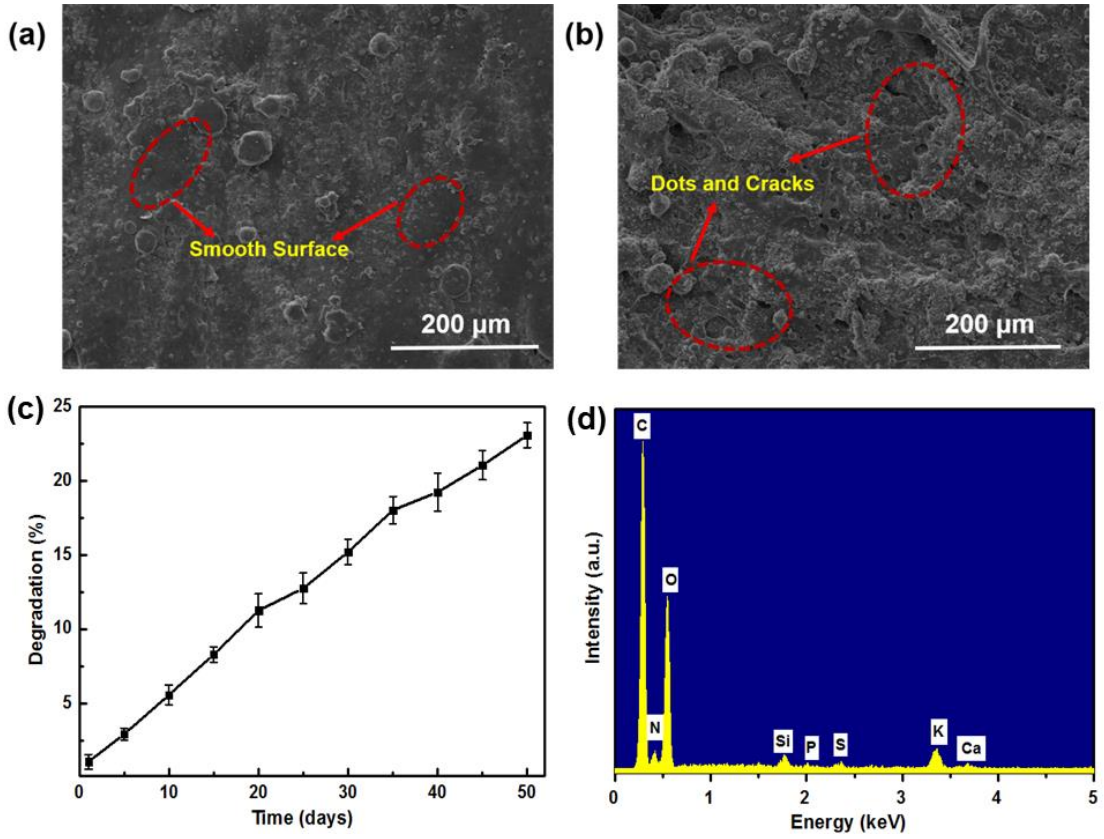

Fig. 4. SEM images of KSMF: (a) before degradation (0 d), (b) surface morphologies of the KSMF buried in soil after 50 d, (c) degradation rates of KSMF, and (d) EDS spectra of KSMF

Growth Experiment

As shown in Fig. 4(d), KSMF contains elements required for plant growth such as N, P, K, S, Ca, and Si. As shown in Fig. 5(a), the height of the wheat seeds in the CK was much lower than that in the KSMF after 12 d. The wheat leaves sprayed with KSMF were firmer and thicker than those of the unsprayed group. As shown in Fig. 5(b) and Table 3, the average fresh weight of wheat sprayed with KSMF was 0.339 g, the average dry weight was 0.065 g, the root length was 9.975 cm, and the average length of the trunk was 16.000 cm. The reason for this was the low molecular weight phenolic compounds after lignin degradation, which improved soil fertility and created favorable conditions for plant growth. At the same time, the keratin hydrolyzate obtained after abandoned bovine hair was hydrolyzed, which contain amino acids, provided nutrition for the growth of plants. These results indicated that the prepared KSMF had the function of promoting seed development and root growth.

Table 3. Average Fresh Weight, Dry Weight, Root Length, and Leaf Length of Wheat in CK and KSMF

Sample	Fresh Weight (g)	Dry Weight (g)	Root Length (cm)	Stem Length (cm)
CK	0.25 ±0.04	0.04±0.01	9.08±0.08	14.78±1.10
KSMF	0.34±0.06	0.07±0.02	9.98±0.07	16.00±1.23

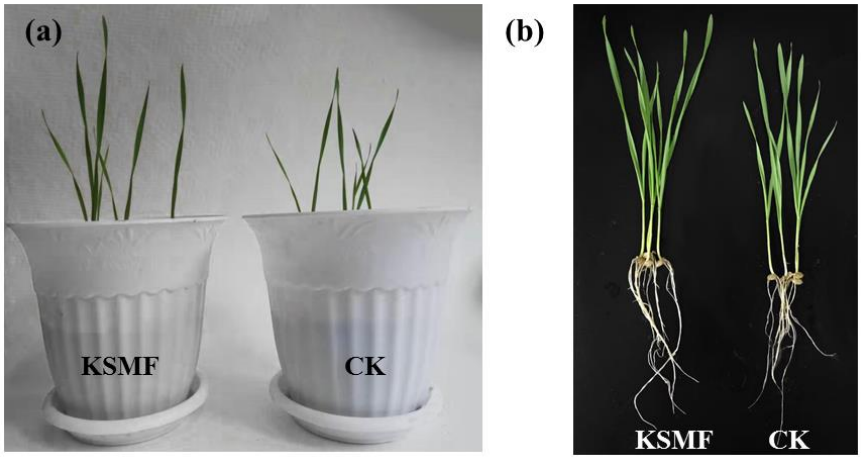

Fig. 5. (a) Wheat growth after 12 d and (b) the wheat was pulled out after 12 d

CONCLUSIONS

In this work, corn stalk pulping spent liquor and abandoned bovine hair from leather processing were used as low-cost sources to prepare a novel degradable keratin-based sprayable mulch film. The KSMF is sprayed on the soil surface and forms a physical barrier to prevent the evaporation of water. This does not prevent the seedlings of the plant from passing through the film layer. At the same time, KSMF contains natural protein and lignin, and directly enters the soil, and is degraded by microorganisms during the growth of the crop, becoming a high-quality biomass organic fertilizer. In addition, KSMF can improve the physical and chemical properties of the soil, promote the growth of crops, and have the same application effects (water retention and warming effects) as the plastic mulch film, and can also reduce the "white pollution". This can help to solve the problem of the resource utilization of waste keratin in tanning and provide a new method for the comprehensive application of pulping spent liquor, reduce the "white pollution", thereby achieve sustainable green development of agriculture and economy.

ACKNOWLEDGMENTS

This study was supported by the Key Scientific Research Plan (Key Laboratory) of Shaanxi Provincial Education Department (17JS016) and the International Joint Research Center for Biomass Chemistry and Materials, Shaanxi International Science and Technology Cooperation Base (2018GHJD-19).

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Article submitted: February 27, 2020; Peer review completed: April 18, 2020; Revised version received and accepted: May 10, 2020; Published: May 14, 2020.
DOI: 10.15376/biores.15.3.5058-5071