Stellera chamaejasme Roots as Raw Material for Pulp Production

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Cellulosic pulps were prepared from *Stellera chamaejasme* roots using soda, soda-anthraquinone (soda-AQ), and kraft pulping processes. *S. chamaejasme* is composed of 73.5% holocellulose, 39.7% α-cellulose, and 17.6% lignin, similar to wheat straw and other non-wood plant materials. The ethanol–benzene extractives content of 9.2% is higher than other non-woods. The conditions used for all pulping experiments were as follows: a liquid/solid ratio of 5:1; a time-to-maximum temperature of 100 min; a maximum temperature of 160 °C; and a time-at-maximum temperature of 50 min. The results showed that the pulp yield was 31.27 to 36.83%, the kappa number was 16.32 to 19.42, and the pulps' intrinsic viscosity was 854 to 976 mL/g. Tear index, tensile index, burst index, and brightness of the papers made from the above unbleached pulps were 12.60 to 13.62 mN•m^2/g, 20.57 to 22.56 mN/g, 2.16 to 2.38 kPa•m^2/g, and 15.3 to 18.3%, respectively.

Keywords: Stellera chamaejasme; Pulping; Kraft process; Soda process; Soda-AQ process

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INTRODUCTION

Largely due to ecological degradation, there has been massive growth of some toxic plants and deserts in China's Qinghai-Tibet Plateau grasslands. *Stellera chamaejasme* L., known as "LangDu" in Chinese, is a well-known toxic plant in the north and northwest parts of China, and it belongs to a class of plants with severe poison content (Klein *et al.* 2007; Zhang *et al.* 2010; Xu *et al.* 2007). *S. chamaejasme* has been used for a long time in traditional Chinese medicine as an herbal remedy for scabies, tinea, and tuberculosis. Recently, it has been found to exhibit antitumor, antiviral, and anti-HIV activities (Feng *et al.* 2002). The bioactivity chemical constituents of the roots of this plant are mainly of terpenoids, biflavonoids, and lignans (Liu *et al.* 2012b). Excessive consumption and prolonged contact with *S. chamaejasme* for people can also cause severe poisoning; therefore, proper protections such as gas masks and protective suits in the harvesting and production processes of this plant might be needed (Sun 1996). *S. chamaejasme* generally has a large deep root. The *S. chamaejasme* growing area was estimated to be 0.47 million ha in the Qinghai province (Li *et al.* 2009).

Figure 1 shows *S. chamaejasme* in the field. Its total biomass in Qinghai is about 400 million tons. The management of this plant and the potential to make value-added products from it is considered an essential part in the local agricultural community.

Significant effort has been made in extracting compounds/chemicals that are of medicinal value; however, this only accounts for about 1% of the total mass (Jin *et al.* 1999; Xu *et al.* 2001; Feng *et al.* 2002; Tang and Hou 2008; Sun *et al.* 2009; Tsolmon *et al.* 2010; Liu *et al.* 2012a;). Other uses for the remaining 99% of this biomass are needed. Converting it to a cellulosic pulp for paper products may be an option to be further exploited.

Fig. 1. *S. chamaejasme* on the shore of Qinghai Lake

About a thousand years ago, people living on the Qinghai-Tibet Plateau had already started to use *S. chamaejasme* as a raw material for the production of handmade Tibetan-paper. Nowadays its manufacture technology is very fastidious and highly traditional, and mainly includes debarking, mashing, cooking, refining, and papermaking. Tibetan hand-made paper has made important contributions to the social, economic, and cultural development in the region. Many scriptures of Buddhism, printed on Tibetan paper, have been well-preserved for hundreds of years in Kumbum Monastery, Jokhang Temple, and other Tibetan Buddhism temples (Dege Sutra-Printing House 2014). Handmade Tibetan paper production gradually decreased and eventually stopped due to the emerging modern paper industry in the region. In 1998, the production of handmade Tibetan-paper was restarted at Dege Sutra-Printing House. There are some unique characteristics of the paper made from *S. chamaejasme*. For instance, it has anti-moth properties: books, such as scriptures of Buddhism, printed on Tibetan-paper can be stored for a long time without damage induced from chewing by insects; it also has good strength properties and good ink absorbency (Li *et al.* 2009a). The morphology of *S. chamaejasme* root fiber was investigated by Li *et al.* (2009b), and was found to have an average length of 0.95 mm, an average width of 18.8 μm, an average cell wall thickness of 6.7 μm, and a fines fraction of 42.26% in the raw material.

Nowadays, non-woods fibers have become one of the important alternative sources of fibrous material for the 21st century (Ashori and Bahreini 2009). The objective of the present work is to determine the potential for converting *S. chamaejasme* to pulp. Traditional pulping processes, such as kraft, soda, and soda-AQ, were evaluated.

EXPERIMENTAL

Materials

Preparation of raw material

S. chamaejasme root samples of about 200 kg were collected from the southeast shore of Qinghai Lake (36°9′ E; 100°1′ N, in Qinghai province of China) and dried naturally for about 20 days after washing. The whole root was used for the analysis of its chemical constituents. All raw material samples were stored in sealed plastic bags after being chipped into 4- to 6-cm chips. Figure 2 shows whole and sectional views of the samples.

Methods

Characterization of the raw material

The chemical composition of *S. chamaejasme* was determined in accordance with the test methods described in the standards of the Technical Association of Pulp and Paper Industry (TAPPI 1992): T-203, T-204, T-211, T-222, and T-207. These tests were used for α-cellulose, ethanol-benzene extractives, and ash, lignin, and hot-water solubles, respectively. Holocellulose was analyzed based on the chlorite method of Wise *et al.* (1946).

Pulping

Cooking was performed using a 3 L electrically heated laboratory digester. Pulping conditions used for the kraft cooks were as follows: 15% active alkali; 20% sulfidity; liquid/solid ratio of 5:1; time-to-maximum temperature of 100 min; maximum temperature of 160 °C; and time-at-maximum temperature of 50 min. Soda and soda-AQ pulping was also performed under the same conditions as above for kraft except that no sodium sulfide (*i.e.*, 0% sulfidity) was used; the soda-AQ pulping used 1% AQ. After pulping, the cooked materials were defibrillated in a disintegrator at 1100 rpm for 15 min and thoroughly washed. The pulp was then refined in a standard PFI mill (Noram Quality Control and Research Equipment Ltd., Canada) at 3000 rpm to reach a freeness of 33 °SR from soda process, 30 °SR from soda-AQ process and 34 °SR from kraft process, and the pulp was screened on a 0.15-mm mesh screen.

Fig. 2. *S. chamaejasme* root samples

Analyses and characterization

The pulp samples obtained were characterized to determine pulp yield (gravimetrically), kappa number (T-236 cm-85), and viscosity (T-230 om-94) (TAPPI 1992).

Pulp handsheets were prepared using a sheet former (Noram Quality Control and Research Equipment Limited, Canada), and the strength properties were determined in accordance with TAPPI standard methods, including tensile (T-494), burst (T-403), and tear (T-414) indices, as well as brightness (T-452) (TAPPI 1992).

RESULTS AND DISCUSSION

Raw Material Characterization

The chemical constituents of *S. chamaejasme* root are shown in Table 1. Included in the table are those of other non-wood species reported in the literature (Jiménez *et al.* 1990; López *et al.* 2004; 2005; Alaejos *et al.* 2006; Wan Rosli *et al.* 2007; Rodríguez *et al.* 2008), and aspen (Law and Jiang 2001). *S. chamaejasme* root has a holocellulose content of 73.5%, which is higher than that of the other non-wood species listed and is slightly lower than that of aspen (77.8%). The α-cellulose content of *S. chamaejasme* is 39.7%, which is similar to that of rice straw, but slightly lower than that of aspen wood. Removal of lignin is a major objective of the pulping and bleaching processes. The lignin content of *S. chamaejasme* is 17.6%, which is similar to that of both rice straw and trembling aspen. Based on the lignin content level, *S. chamaejasme* can be expected not to require high reaction times or chemical concentrations (Rodríguez *et al.* 2008).

Table 1. Chemical Constituents Comprising Various Raw Materials

Component (%)	*S. chamaejasme*	Rice straw (Rodríguez *et al.* 2008)	Sunflower stalks (López *et al.* 2005)	Trembling aspen (Law and Jiang 2001)
Holocellulose	73.5	60.7	66.9	77.8
α-cellulose	39.7	41.2	37.6	43.6
Lignin	17.6	21.9	10.8	18.1
Hot water soluble	17.7	7.3	21.1	Not reported
Ethanol–benzene extractables	9.2	0.6	4.1	3.7
Ash	3.0	9.2	7.9	0.3

The extractives content (*i.e.*, ethanol-benzene extractables) of a lignocellulosic material is a measure of substances such as waxes, fats, resins, low-molecular-weight carbohydrates, salts, and other water-soluble substances. *S. chamaejasme* contains 9.2% ethanol-benzene extractables, which is higher than that of the agricultural residues and wood species. For some substances, including resins, waxes, and fatty acids, an alkaline pulping process, such as soda or kraft, can effectively remove them (Rodríguez *et al.* 2008).

Pulping Results

The yield, kappa number, and intrinsic viscosity of the pulps obtained from different pulping processes are shown in Table 2. For comparison, the corrected pulp yield (to a kappa number of 16.32) was also made so that the small difference in pulp yield from the difference in lignin content could be taken into consideration according to Ji *et al.*(2009) and Liu *et al.* (2012b).

Table 2. Properties of Pulp from *S. chamaejasme*

	Soda	Soda–AQ	Kraft
Yield (%)	31.27	33.44	36.83
Kappa number	17.91±0.2	16.32±0.2	19.42±0.2
Yield calculated @16.32 Kappa number (%)	31.03	33.44	36.36
Intrinsic viscosity (mL/g)	935± 5	854±6	976±5

The highest yield (36.83%, with the corrected pulp yield of 36.36% at a kappa number of 16.32) was obtained from the kraft process, while the lowest kappa number (16.32%) was gained from the soda-AQ process. The kraft pulp had the highest intrinsic viscosity (976 mL/g).

As given in Table 2, the yields for *S. chamaejasme* root pulp were not high. These yield results were compared to the literature results of other non-woods: 32.12% from vine shoots from the soda process (Jiménez *et al.* 2006); 47.0% from *Eucalyptus citriodora* from the kraft process (Khristova *et al.* 2006); and 55.0% from holm oak from the soda-AQ process (Alaejos *et al.* 2006).

The delignification degree for the three processes employed was reasonable, and the resulting pulps had a range of kappa numbers from 16 to 19. In the literature, various results have been reported: a bagasse sample gave a kappa number of 10.3 from the soda-AQ pulping process (Xilin *et al.* 1997); an abaca sample gave a kappa number of 10.6 from the soda pulping process (Jiménez *et al.* 2005); a rice straw sample gave a kappa number of 21.05 from the kraft pulping process (Rodríguez *et al.* 2008); a holm oak sample gave a kappa number of 23.7 from the soda-AQ pulping process (Alaejos *et al.* 2006); and a wheat straw sample gave a kappa number of 31 from the kraft pulping process (Deniz *et al*. 2004).

The intrinsic viscosities of the pulps were in the range of 854 to 976 mL/g. These viscosity results were compared to the literature results: 1189 mL/g from holm oak from the soda-AQ pulping process (Alaejos *et al.* 2006); 1428 mL/g from abaca from the soda pulping process (Jiménez *et al.* 2005); 929 mL/g from eucalyptus from the soda-AQ pulping process (Khristova *et al.* 2006); and 732 mL/g from rice straw from the soda-AQ pulping process (Rodríguez *et al.* 2008).

Handsheet Properties

The pulp samples obtained from the soda, soda-AQ, and kraft processes were made into handsheets, and the tensile index, burst index, tear index, and brightness were determined. The results are shown in Table 3.

The highest tear index (13.62 mN•m^2/g) was obtained from pulp handsheets from the pulp obtained using a soda process, the highest tensile index (22.56 mN/g) was obtained from pulp handsheets from the pulp obtained using a soda-AQ process, and the highest burst index (2.38 kPa•m^2/g) was obtained from pulp handsheets from the pulp obtained using a kraft process. Conversely, all pulp handsheets obtained by the various processes had low brightness values.

Table 3. Properties of Pulp Handsheets from *S. chamaejasme*

	Soda	Soda–AQ	Kraft
Grammage(g/m^2)	61± 0.5	61± 0.03	59± 0.5
Tear index (mN•m^2/g)	13.62 ± 0.03	12.60± 0.05	12.75± 0.03
Tensile index (mN/g)	20.57± 0.07	22.56± 0.04	20.82± 0.05
Burst index (kPa•m^2/g)	2.16± 0.05	2.31± 0.05	2.38± 0.05
Brightness (% ISO)	18.2± 0.2	18.3± 0.2	15.3± 0.3

The tensile index of the *S. chamaejasme* pulp was in the range of 20.57 to 22.56 mN/g, which is rather typical from non-wood pulps. In the literature, various results have been reported: 11.6 mN/g for holm oak trimmings pulped by soda-AQ and 14.9 mN/g for holm oak trimmings pulped by kraft (Alaejos *et al.* 2006); and 46.6 mN/g for *Eucalyptus tereticornis* pulped by kraft and 47.3 mN/g for *Eucalyptus tereticornis* pulped by soda-AQ (Khristova *et al*. 2006).

The burst index of the *S. chamaejasme* pulp was in the range of 2.16 to 2.38 kPa•m^2/g. These burst indices were compared to the literature results: 1.4 kPa•m^2/g for eucalyptus from the kraft pulping process (Khristova *et al.* 2006); 9.17 kPa•m^2/g for bagasse from the soda-AQ pulping process (Xilin *et al.* 1997); 4.09 kPa•m^2/g for wheat straw from the kraft pulping process (Deniz *et al.* 2004); and 1.01 kPa•m^2/g for vine shoots from the soda pulping process (Jiménez *et al*. 2006).

The tear index of the *S. chamaejasme* pulp was in the range of 12.6 to13.62 mN•m^2/g. These tear indices were compared to the literature results: 19.03 mN•m^2/g for abaca pulped by soda (Jiménez *et al.* 2005), 7.26 mN•m^2/g for bagasse pulped by soda (Xilin *et al.* 1997); 1.9 mN•m^2/g for *Eucalyptus citriodora* pulped by kraft (Khristova *et al.* 2006); 4.57 mN•m^2/g for wheat straw pulped by kraft (Deniz *et al*. 2004); and 0.90 mN•m^2/g for vine shoots pulped by soda (Jiménez *et al.* 2006).

The brightness of the *S. chamaejasme* root pulp from the processes studied was in the range of 15.3 to 18.3% ISO. The soda-AQ process gave the highest brightness of 18.3% ISO, which is in agreement with the lowest kappa number as shown in Table 1. These results may be compared with the literature results: 22.3% ISO for *Eucalyptus citriodora* kraft pulp (Khristova *et al.* 2006); 24.1% ISO for holm oak soda-AQ pulp (Alaejos *et al.* 2006); 42.2% ISO bagasse soda-AQ pulp (Xilin *et al.* 1997); and 48% ISO for rice straw soda-AQ pulp (Rodríguez *et al.* 2008).

CONCLUSIONS

1. The chemical constituents of *S. chamaejasme* root are as follows: 73.5% holocellulose, 39.7% α-cellulose, and 17.6% lignin. It is noted that the holocellulose content is comparable to that of various non-woods, indicating that *S. chamaejasme* root is a potential raw material for lignocellulosic paper production.
2. The experimental results from the soda, soda-anthraquinone (soda-AQ), and kraft processes showed that the pulp quality of *S. chamaejasme* roots was similar to that of wheat straw pulp from the same processes: the yield is 31.27 to 36.83%, the kappa number is 16.3 to 19.42, and the intrinsic viscosity of pulps is 854 to 976 mL/g. The tear index, tensile index, burst index, and brightness of the pulp handsheets are 12.60 to 13.62 mN•m^2/g, 20.57 to 22.56 mN/g, 2.16 to 2.38 kPa•m^2/g, and 15.3 to 18.3%, respectively.

3. Based on these results, it was concluded that the kraft process gave the best pulp yield, while the strength properties were similar for the pulps from the three processes.
4. The present study implied that a holistic utilization of *S. chamaejasme* and the biomass for pulp production can be of practical interest. Such an approach can contribute to the ecological/sustainable management of toxic plants in the grassland of the Qinghai-Tibet region in China.

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