Holopulp Elements of Rice Straw in Relation to Their Papermaking Properties

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製紙特性に関連するイネワラのホロパルプ構成要素

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Abstract

The characteristics of holopulp elements from rice straw were studied to obtain fundamental knowledge related to their papermaking properties. Various methods to prepare rice straw holopulp were examined, and the chlorite-sodium hydroxide method was found to be most suitable. In this method the sodium hydroxide treatment was very effective for defibration and desilication. The classification of holopulp to separate the fiber elements from the non-fiber elements was achieved successfully. Although rice straw contains a considerable amount of fines elements, the fiber elements have much higher slenderness ratio and are slightly shorter than those of hardwood fibers.

要　旨

製紙特性に関連する基礎的な知見を得るため，イネワラのホロパルプ構成要素の特徴について検討を行った。イネワラからホロパルプを調製する方法について検討し，亜塩素酸一水酸化ナトリウム法が適当と推定されたが，この過程でアルカリ処理が解繊と脱シリカに非常に有効であることがわかった。ふるい分け試験により繊維要素の分離に成功した。また，イネワラには多量の非繊維要素が含まれているが，その繊維は広葉樹よりやや短く，幅に対する長さの比が大きいことを確認した。

1. Introduction

Rice straw has been playing an important part in papermaking resources in Asian countries, especially in China where about 60 percent of pulp production is made of rice and wheat straw. Since the consumption of paper in China is less than 10 kg per capita annually, without doubt special attention would be paid to rice and wheat straw in the near future.

A number of reports have been published on the pulping of rice straw, of which before 1965 are listed elsewhere[1]. Regarding the papermaking characteristics of rice straw pulp, Morimoto *et al.*[2] have investigated the beating behavior of rice straw pulps, and Madelung[3] has studied the papermaking properties of straw pulp. However, more detailed information on rice straw fibers, especially on their papermaking characteristics, is required to better utilize rice straw pulp. This paper presents a method to prepare holopulp from rice straw with a minimum loss of polysaccharides and information on the holopulp elements related to their papermaking characteristics.

2. Experimental

2.1 Material

Rice straw, *Oryza sativa* L., which was grown in the Research Farm of Faculty of Agriculture of Kyoto University was used in this study. Part of the rice straw was divided into stalk and leaf stem, and cut into chips 2 cm long for the preparation of holopulp.

For light microscopic observation of the distribution of fiber elements in the rice straw tissue, cross sections 2 μm thick were prepared from blocks 2 mm long that had been treated with a 20% hydrofluoric acid for 10 hours at room temperature to remove silica, and then embedded in an epoxy resin. Figure 1 shows photographs of a cross section stained with safranin. Fiber elements occur in the cortex and the vascular bundles in the tissue of both stalk and leaf stem. The fibers in the cortex are smaller in diameter and have a thicker cell wall than those in the vascular bundles.

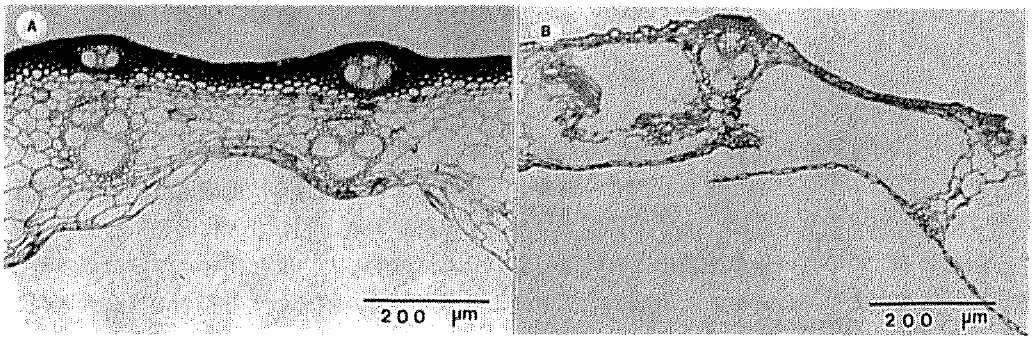

Fig. 1 Micrographs of cross section of rice straw stalk (A) and leaf stem (B).

The results of chemical analysis for stalk, leaf stem and whole rice straw acerding to TAPPI Standards are shown in Table 1. Leaf stem is higher in holocellulose, pentosan, lignin and ash contents but lower in cold and hot water extractives, and 1% NaOH extractives than stalk. However, whole rice straw is lower in lignin content but higher in pentosan, ash, cold and hot water extractives, and 1% NaOH extractives than common soft- and hardwood, as suggested by El-Taraboulsi and Salem[4].

2.2 Preparation of holopulp

To select the best method for the preparation of holopulp from the rice straw chips,

Table 1 Chemical composition of rice straw (%, oven-dried basis)

	Holo-cel-lulose	Pent-osan	Lignin	Extractives: Cold water	Hot water	1% NaOH	Alcohol-benzene	Ash
Stalk	58.6	20.8	13.0	19.9	25.6	49.7	4.4	11.5
Leaf stem	64.8	24.9	16.4	10.4	10.9	47.8	4.6	18.1
Whole straw	62.9	23.6	15.4	13.3	15.5	48.4	4.5	16.1

three methods were attempted : (1) modified chlorite method (chlorite method) in which chips were soaked in sodium chlorite solution for 8 hours at room temperature before the prescribed times of acid chlorite treatment proposed by Wise *et al.*[5], (2) modified peracetic acid method (peracetic acid method) which is a variation of Leopold's method[6] and was proposed by Wai and Murakami[7] for use on bamboo chips, and (3) chlorite-sodium hydroxide method in which the insolubles obtained by the procedure (1) were further treated with 0.5% sodium hydroxide solution (20 or 60 ml/g sample) for 15 minutes at 100℃. After the above treatments, the insolubles from each method were defibrated gently to avoid mechanical damage to the pulp elements. The holopulps obtained were monitored under a microscope.

2.3 Classification test for holopulps

The holopulps prepared carefully without any loss of fines were subjected to a one-batch JIS type classifier with prescribed mesh screens to classify the holopulp elements. For the classified fractions of whole rice straw holopulp, fiber dimensions and coarseness were measured according to the method proposed by Hasuike[8].

3. Results and Discussion

3.1 Method for the preparation of holopulp

In evaluation of plants producing fiber as papermaking raw material, fundamental information on the tissue elements is often more desirable than that obtained by the conventional pulping test. For this reason, a method to prepare rice straw holopulp was investigated in this study. In the preparation of holopulp, three conditions are required : (1) the tissue elements should be defibrated completely without any damage to the elements, (2) the weight loss of polysaccharides should be as little as possible, and (3) the extraneous components, such as silica, should be removed. A comparison among the three holopulping methods (i.e., chlorite method, peracetic acid method, and chlorite-sodium hydroxide method) was made.

The yield and the pentosan content (based on rice straw) of holopulps are the highest in the chlorite method and the lowest in the peracetic acid method, as shown in Figs. 2 and 3. Plots of pontosan content against yield of holopulp apparently fall on one curve, regardless of the method. This result suggests that the lower yield product was suffered more damage in hemicellulose. However, the products obtained by the methods of chlorite and peracetic acid were difficult to defibrate even in the lowest

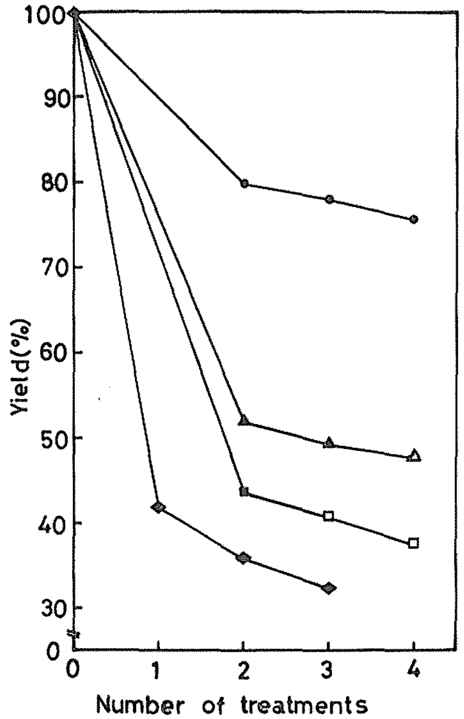

Fig. 2 Holopulp yild for chlorite (●), chlorite-sodium hydroxide (20 mℓ/g, ▲; 60mℓ/g, ■), and peracetic (◆) methods. Solid symbols indicate that the insolubles were difficult to defibrate, and open symbols completely defibrated.

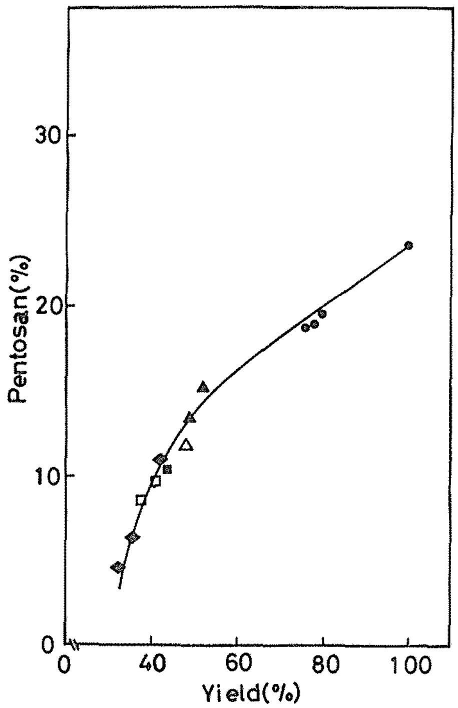

Fig. 3 Relationship between pentosan content and yield of insolubles. The symbols are the same as in Fig. 2.

yield. This suggests that defibration can not be achieved merely by delignification or by attack on hemicellulose. The presence of pectin in rice straw has been reported elsewhere[9], and it is thought that this pectin prevents defibration of the tissue elements. To avoid this difficulty, treatment with sodium hydroxide solution was tried for the products obtained by the chlorite method. It was found that treatment with sodium hydroxide solution was quite effective for the defibration of rice straw tissue. If the 0.5% sodium hydroxide solution was applied at a level of 60 ml/g sample, three treatments with acid chlorite were sufficient. However, if a level of 20 ml/g sample was used, four acid chlorite treatments were necessary (Fig. 2, open symbols). Ash content of the holopulp varies depending on the method used, but does not change significantly when the number of treatments changes for one method, as shown in Table 2. The treatment with sodium hydroxide solution was very effective for removing ash.

The above results suggest that the chlorite-sodium hydroxide method is suitable for the preparation of thoroughly defibrated holopulp from rice straw. Considering lower pentosan loss, lower ash content and shorter treatment time, the method which consists of three treatments with acid chlorite followed by 0.5% sodium hydroxide extraction (60

Table 2 Ash content of insolubles (%, oven-dried straw chips)

Method	Number of treatments			
	1	2	3	4
Chlorite	—	12.6	12.7	11.7
Peracetic acid	7.4	8.1	8.1	—
Chlorite-sodium hydroxide (20ml/g)	—	3.4	2.7	2.9
Chlorite-sodium hydroxide (60ml/g)	—	3.2	2.1	1.8

ml/g sample) was chosen in this study.

3.2 Morphological properties of holopulp elements

Several micrographs of screened holopulp elements are shown in Fig. 4. It was observed that almost all of the fiber elements of the holopulp retained on a 100 mesh screen, while the non-fiber elements, such as parenchyma cells, mostly passed through. No significant differences in morphology between stalk and leaf stem elements were found.

The screen results of holopulps are shown in Table 3. The fines fraction of rice straw is even higher than that of bamboo, which contains a substantial amount of fines[7]. The weight fraction of fiber elements was only about 35% of holopulp, and the weight fraction of fines that passed through a 300 mesh screen exceeded 40%. These results are due to the fact that vascular bundles and cortex occupy only a small area in the cross

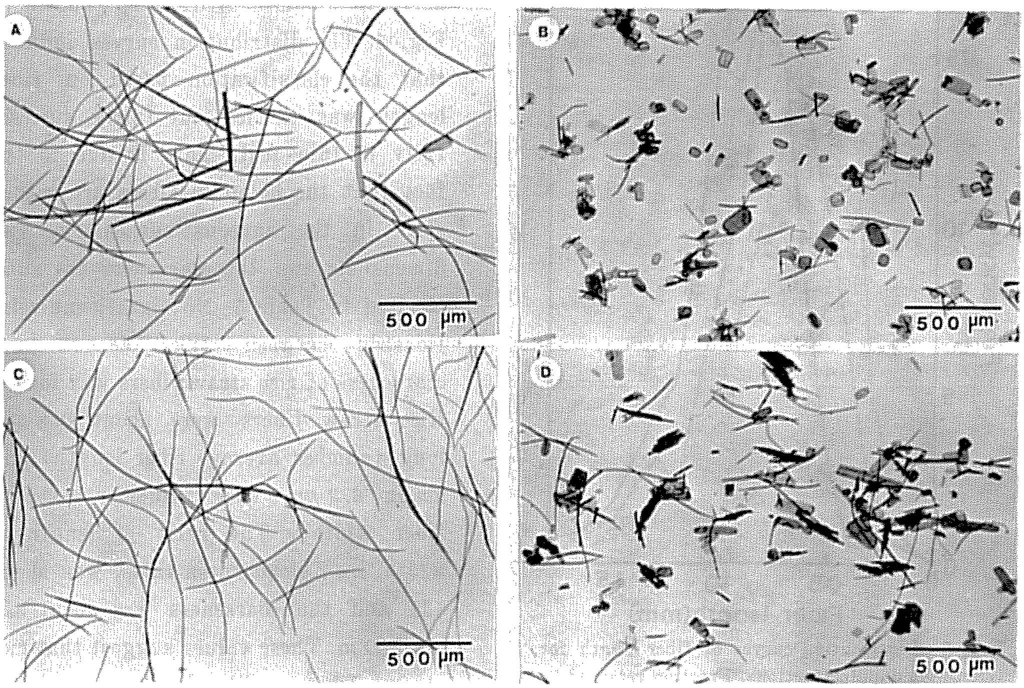

Fig. 4 Micrographs of holopulp fraction. Fraction retained on 100 mesh screen (A) and passed thorough (B) from stalk; fraction retained on 100 mesh screen (C) and passed thorough (D) from leaf stem.

Table 3 Screen results of holopulps (%, oven-dried basis)

	Weight fraction (mesh)						Total yield
	-48	48-60	60-100	100-200	200-300	300-	
Stalk	18.1	9.0	11.6	10.9	11.5	38.9	38.8
Leaf stem	11.6	9.3	13.9	7.9	13.9	43.5	41.3
Whole straw	13.6	9.2	13.2	8.8	13.2	42.0	40.6

Table 4 Ash content of holopulp fractions (%, oven-dried basis)

	Fraction (mesh)					
	-48	48-60	60-100	100-200	200-300	300-
Stalk holopulp	1.6	1.5	1.6	2.7	2.6	2.7
Leaf stem holopulp	1.9	2.3	3.0	4.5	6.6	7.5
Whole straw holopulp	1.8	2.1	2.6	3.8	5.5	6.2

section of the tissue. The stalk holopulp is higher in fiber elements and lower in fines than the leaf stem. As shown in Table 4, the finer mesh was used, the higher the ash content was resulted. Further, holopulp from the leaf stem is higher in ash content than that from the stalk.

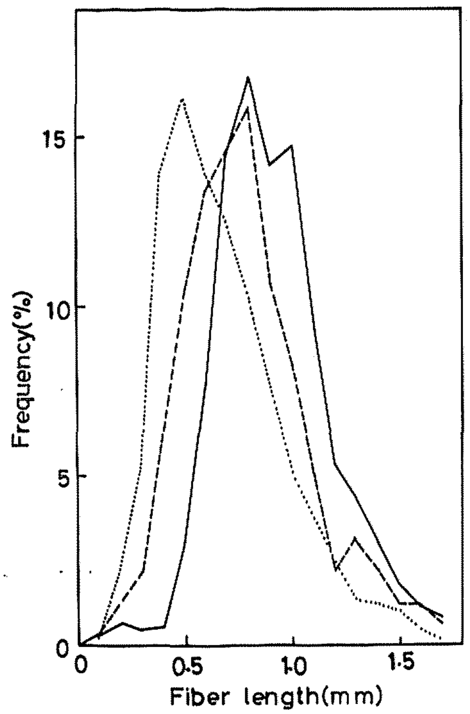

Fig. 5 Distribution curves of fiber length for holopulp fractions. Fraction retained on 48 mesh screen (——), through 48 on 60 mesh screen (-----), and through 60 on 100 mesh screen (······).

The distribution of fiber length for the fiber fractions from whole rice straw holopulp was measured, and is shown in Fig. 5. The distribution curves indicate that the classification based on fiber length was carried out fairly successfully in this test. This is due to the fact that the holopulp fibers are rather stiff in the aqueous suspension. The dimensions and the coarseness are summerized in Table 5. No significant relationship between fiber length and coarseness of rice straw fibers was found. Rice straw fibers were about 0.8 mm long (number average fiber length) and about 6.3 μm wide (number average fiber width). The ratio of length to width, i.e., slenderness ratio, was about 130 and the coarseness was about 3.2 mg/100 m. These values suggest that rice straw fibers will give paper sheets having unique properties such as high opacity and fine texture.

Table 5 Dimensions and coarseness of rice straw fibers

Fraction (mesh)	Number average fiber length (mm)	Number average fiber width (μm)	Coarseness (mg/100m)
-48	0.88	6.3	3.0
48-60	0.78	6.3	3.2
60-100	0.65	5.8	3.3

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