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Bio-Soda Pulping of Rice Straw with *Pleurotus cornucopiae* under Atmospheric Pressure

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ABSTRACT

This study was carried out to develop the bio-chemical pulping method to enhance the energy saving and decrease the capital cost through the soda pulping under atmospheric pressure (100 ℃). Nonwood substrates, rice straw, were pretreated by white-rot fungi, Pleurotus cornucopiae. Several basic pieces of data that can be applied in soda pulping were acquired. The results of this study were as follows. Under the conditions without any nutrients or with glucose, N and glucose + N, the weight losses of rice straws inoculated by Pleurotus cornucopiae were 12.1 ~ 32.6 %, 12.0 ~ 26.3 %, 13.0 ~ 25.4 % and 15.3 ~ 24.7 % for 5, 10, 15, 20, 25 and 30 days incubation periods respectively. The more the fungal incubation was extended, the more the weight losses were gained. The yield of untreated rice straw was 54.8 % after pulping. When any nutrients was not added or glucose, N and glucose + N were added for the pretreatment, the total yields were ranged to 57.3 ~ 42.9 %, 51.0 ~ 43.3 %, 51.7 ~ 43.9 % and 52.1 ~ 46.1 % for 5 different incubation periods respectively. The yields were gradually decreased based on the extending of the incubation periods. The physical properties of the rice straw soda pulp without fungal treatment, the density, breaking length, burst index, tear index and folding endurance were 0.24g/cm^3, 2.32 Km, 0.91 kPa · m^2/g, 46.7 mN · m^2/g and 21 times, respectively. In the case of pretreatment without any nutrients or with glucose, N and glucose + N as nutrients, the density was 0.24g/cm^3, the breaking length was 3.30 ~ 6.46 Km, the burst index was 1.36 ~ 3.01 kPa · m^2/g, the tear index was 33.0 ~ 57.0 mN · m^2/g and the folding endurance was 14 ~ 381 times at most incubating periods, when pulping was done. The physical properties were increased as the incubation duration was extended. Especially, when N and glucose + N were added, the physical properties showed superior results during each incubation period.

Keywords *: Rice straw, White-rot fungi, Pleurotus cornucopiae, Bio-soda pulping, Atmospheric pressure*

1. Introduction

Nowadays, the consumption of paper from various sources of pulp material is increased with the development of human life progress and a social network system.

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The volumetric growth of pulp usage for making paper, however, makes significant problems in a way to exploit resources in the earth and becomes more serious factors in environmental aspects. (1,2)

Therefore, it was suggested that the alternative consideration is the use of nonwood fibers as a solution for the decrease of environmental damage and the lack of resources. (3-8)

Furthermore, the use of nonwood fiber obtained from the agricultural by-products, can reduce the raw material costs and save the energy. (9-11)

However, the chemical pulping process from rice straw uses the same process conditions from wood chips and requires high temperature and pressure, besides nonwood pulp has the lower qualities in comparison with wood pulp. (12-19) Similar actual processing costs and energy source are also needed for the whole process. Accordingly, this study was carried out to develop the rice straw soda pulping method under atmospheric pressure (100 ℃) using the fungal pretreatment in order to enhance the energy saving and decrease the operation cost.

2. Materials and Methods

2.1 Rice straw media

Rice straws (*Oryza sativa*) obtained from Gimje, Jeonbuk in Korea were used. The rice straws without headparts were chopped to about 20mm long and dried at the shady place. The chopped rice straws were put with distilled water and each nutrient (up to 75 % water content) in polyvinyl bags and sealed and then left for a day to absorb the moisture. At that time, 0.5 % glucose for carbon source and urea (0.25 %) for nitrogen source as nutrient additives were added and mixed into rice straw media for promoting biodegradation. The pretreated rice straw media were transferred into PT bottles and autoclaved at 120 ℃ for 1 hour.

2.2 Fungal source

The fungal source, *Pleurotus cornucopiae* was donated from Korea Forest Research Institute and maintained on Potato agar media at 4 ℃. The organism was subcultured on a PDA plate and, then after it fully grew, one agar piece (5 ℃ 5 mm) with mycelia was inoculated into the liquid potato dextrose broth (4.5 g/1,000 mL) with yeast extract (1.46 g) and incubated at 30 ℃ for 7 days.

2.3 Inoculation and incubation

Prepared liquid media were pulverized with a mixer for 10 seconds, and 30 mL of pulverized liquid media was inoculated into the rice straw media and incubated for 5, 10, 15, 20, 25 and 30 days. During incubation the inoculated media were shaken once a day in early 4 ~ 5 days. After incubation the rice straw were cleaned with tap water and dried at the shady place and then the weight losses were measured.

2.4 Pulping and pulp evaluation

The conditions of soda pulping were NaOH 15 % (Na_2O basis) for alkali charge, 100 ℃ of the temperature, 120 minutes of cooking time and 1/10 for rice straw/liquid ratio. After soda pulping the rice straws incubated in the various kinds of conditions, and washing them, the total yields of pulps were measured and their Kappa numbers

determined by the TAPPI Standard Test Method. Also, the brightness of pulps were measured by a bright tester (GE type).

2.5 Physical properties of pulps

The rice straw soda pulps made as mentioned above were beaten to 300 mL CSF by PFI mill and then formed into handsheets of 60 g/m² dry weights. The conditioning and testing room was set up at 20 ± 1 ℃ and 65° ± 5 % relative humidity. The handsheets were air dried in a controlled conditioning room for over 24 hours and the density, breaking length, burst index, tear index and folding endurance were measured.

3. Results and Discussion

3.1 Weight losses of fungal pretreated rice straws

The weight losses of rice straws pretreated by *Pleurotus cornucopiae* for 5, 10, 15, 20, 25, 30 days are shown in Table 1.

At the stage of pretreatment without adding any nutrients the weight loss of rice straws after 5 days incubation was 12.1 %, but after 30 days incubation the weight loss was increased up to 32.6 %. When 0.5 % glucose was added into rice straw media as a nutrient, the weight loss after 5 days incubation was 12.0 %, but the highest weight loss was obtained up to 26.3 % after 30 days.

When 0.25 % N was added, the weight losses were increased ranging from 13.0 to 25.4 %, according to incubation periods. However, when 0.5 % glucose and 0.25 % N were added, the percentage of weight loss after 5 days was increased to higher ratio, compared with others, while after 30 days showed lower ratio.

It was found that the degradation of rice straw was accelerated in early stages when N or glucose + N were added. However, compared to pretreatment without any

Table 1. Rates of weight losses of rice-straw after pretreatment with *Pleurotus cornucopiae* (Unit:%)

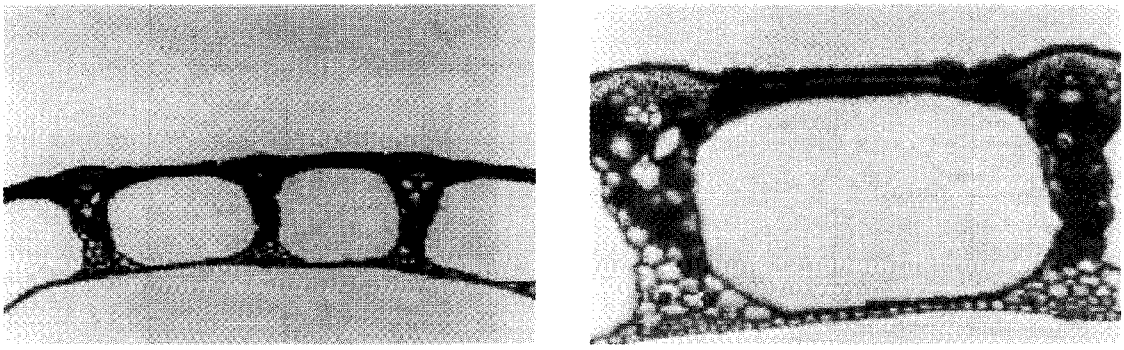
Incubation Period(days) \ Additives	None	glucose	N	glucose+N
Untreate	0	0	0	0
	(100)	(100)	(100)	(100)
5	12.1	12.0	13.0	15.3
	(87.9)	(88.0)	(87.0)	(84.7)
10	17.1	17.6	15.6	19.2
	(82.9)	(82.4)	(84.4)	(80.8)
15	19.4	18.8	20.6	20.7
	(80.6)	(81.2)	(79.4)	(79.3)
20	21.5	19.9	22.3	23.0
	(78.5)	(80.1)	(77.7)	(77.0)
25	26.4	20.7	23.6	24.3
	(73.6)	(79.3)	(76.4)	(75.7)
30	32.6	26.3	25.4	24.7
	(67.4)	(73.7)	(74.6)	(75.3)

* ( ) : Yields after pretreatment
* Glucose : 0.5%, N : 0.25%

nutrients as additives, the degradation of rice straws with nutrients showed lower weight losses in later stage.

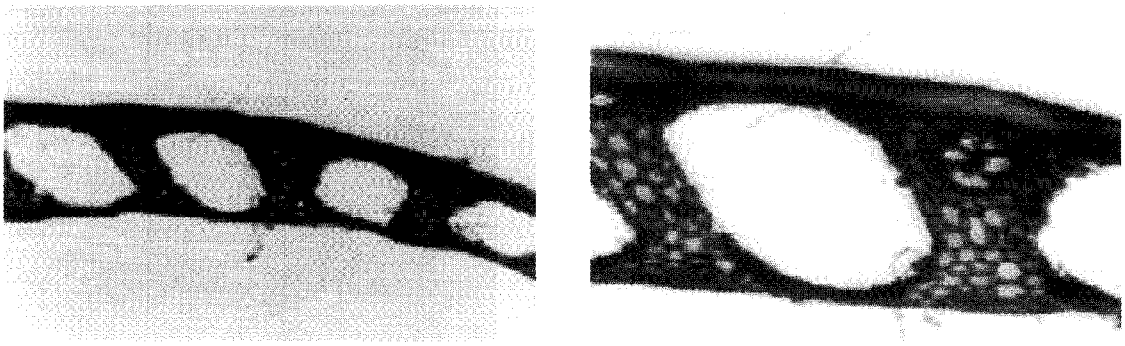
3.2 Observation of pretreated rice straws

After 5, 15, and 30 days of fungal incubation, the pretreated rice straws and non-pre-



(40 X) (100 X)

Fig. 1. Optical micrographs of rice straw before fungal pretreatment.

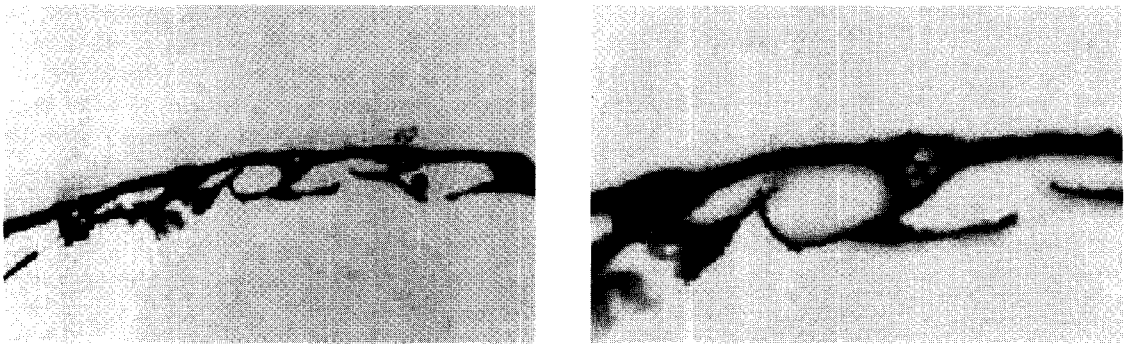


(40 X) (100 X)

Fig. 2. Optical micrographs of rice straw pretreated for 5 days with *Pleurotus cornucopiae*.

(40 X) (100 X)

Fig. 3. Optical micrographs of rice straw pretreated for 15 days with *Pleurotus cornucopiae*.



(40 X) (100 X)

Fig. 4. Optical micrographs of rice straw pretreated for 30 days with Pleurotus cornucopiae.

treated rice straw as a control were observed by a light microscope (Fig. 1 ~ 4).

The microscope observation of transverse sections illustrated the significant changes in cell wall degradation with the different periods of fungal incubation. The microbiological degradation in the structure of rice straw was increased with incubation period. That is, the more the fungal incubation period was increased, the more the microbiological degradation of rice straws was obtained.

3.3 Soda pulping of pretreated rice straw

3.3.1 Total yield

After pretreatment, rice straws were

Table. 2 Yields of rice straw pulps cooked with caustic soda after pretreatment with Pleurotus cornucopiae **(Unit:%)**

Incubation Period(days) \ Additives	None	glucose	N	glucose+N
Untreate	56.1	56.1	56.1	56.1
5	65.2	57.9	59.4	61.5
	(57.3)	(51.0)	(51.7)	(52.1)
10	60.8	60.0	61.9	54.7
	(50.4)	(49.4)	(52.2)	(44.2)
15	58.1	65.0	62.3	56.2
	(46.8)	(52.8)	(49.5)	(44.6)
20	57.3	61.0	61.2	62.1
	(45.0)	(48.9)	(47.6)	(47.8)
25	62.7	61.5	60.9	62.7
	(46.1)	(48.8)	(46.5)	(47.5)
30	63.7	58.8	58.9	61.2
	(42.9)	(43.3)	(43.9)	(46.1)

* Cooking conditions : NaOH 15%(as Na2O), temperature 100°ΔC, time 120 min., rice straw/liquor : 1/10
* Glucose : 0.5%, N : 0.25%
* ( ) : Yields based on original material

cooked under the conditions of 15 % NaOH (Na_2O), liquid ratio 1 : 10 and 100 ℃ for 120 minutes. Table 2 summarizes the total yields of rice straw pulps cooked with caustic soda after pretreatment with *Pleurotus cornucopiae*.

It showed that the total yield of soda pulping of rice straw was 56.1 % when pulping without pretreatment. While, in the case of pulping with pretreated rice straws, total yields were ranged to 42.9 ~ 57.3 % without any nutrients, 43.3 ~ 51.0 % with glucose, 43.9 ~ 51.7 % with N and 44.2 ~ 52.1 % with glucose + N respectively. However, the values of total yield showed no significant tendency on the basis of adding any nutrients or the incubation period. The total yields, as expected, were different based on various nutrient additives. When the glucose + N as a nutrients was added, the total yield showed a little difference between the incubation periods, and comparatively higher yield compared to other additives as a nutrients.

3.3.2 Kappa number

Table 3 summarizes the Kappa numbers of rice straw pulps cooked with caustic soda after pretreatment with *Pleurotus cornucopiae*.

Kappa number of pulp with non-pretreated rice straws was 24.2. However, when pulping was carried out with pretreated rice straws, Kappa numbers were ranged to 23.7 ~ 35.6 without any nutrients, 24.6 ~ 33.7 with glucose, 24.4 ~ 34.5 with N and 23.3 ~ 29.8 with glucose + N, respectively. Kappa numbers, from soda pulp with the pretreated rice straws without any nutrient, were increased with incubation periods. However, in the case of soda pulp of rice straw pretreated with nutrients up to a certain fungal incubation period, the Kappa number was increased, and then decreased or remained consistent at some incubation periods.

The reason for increasing in the Kappa number of pulps made from pretreated rice straws up to a certain incubation period could be explained in terms of sufficient reaction with $KMnO_4$, due to the increases in the degree of defibration. However, it is considered that the decrease of the Kappa number of pulps made from rice straws pretreated with nutrients in the longer incubation period is due to the delignification effect.

3.3.3 Brightness

Table 4 shows the effect of pretreatment of rice straws by *Pleurotus cornucopiae* on

Table 3. Summarizes the Kappa numbers of rice straw pulps cooked with caustic soda after pretreatment with *Pleurotus cornucopiae*.

Incubation Period(days) \ Additives	None	glucose	N	glucose+N
Untreated	24.2	24.2	24.2	24.2
5	23.7	24.6	24.4	26.5
10	27.7	24.9	34.5	27.2
15	28.8	29.4	32.0	29.8
20	31.3	33.7	29.4	27.1
25	34.7	31.0	30.8	24.6
30	35.6	31.4	28.1	23.3

* Cooking conditions : NaOH 15%(as Na2O), emperature 100°ΔC, time 120 min., rice straw/liquor : 1/10
* Glucose : 0.5%, N : 0.25%

Table 4. Brightnesses of rice straw pulps cooked with caustic soda after pretreatment with *Pleurotus cornucopiae*

Incubation Period(days) \ Additives	None	glucose	N	glucose+N
Untreated	30.6	30.6	30.6	30.6
5	26.6	28.9	29.5	26.4
10	26.3	28.6	24.0	25.8
15	25.7	25.4	23.5	25.5
20	25.0	24.1	23.5	23.7
25	26.9	27.2	24.7	22.8
30	27.6	27.6	25.6	23.6

* Cooking conditions : NaOH 15 %(as Na_2O), temperature 100 ℃, time 120 min., rice straw/liquor : 1/10
* Glucose : 0.5 %, N : 0.25 %

brightness. The level of brightness was 30.6 when pulping with non-pretreated rice straws. Those of pulps made from pretreated rice straws showed the ranges of 25.0 ~ 27.6 without any nutrient, 24.1 ~ 28.9 with glucose, 23.5 ~ 29.5 with N and 22.8 ~ 26.4 with glucose + N.

It indicates that pulping with non-pretreated rice straws showed greater brightness value than pulping with pretreated rice straws. And the brightness value decreased up to some point during the incubation period, and after that, increased. A reason for the decrease in brightnesses of pulps from the pretreated rice straw could be explained due to the effect of increased chromophoric group, rather than the delignification of cell wall components of rice straw.

3.3.4 Physical properties

The various kinds of pulps made from non-pretreated or pretreated rice straws were beaten to 300 mL CSF, and then were formed into handsheets of 60 g /m^3 dry weight. Thereafter, physical properties, density, breaking length, burst index, tear index and folding endurance were estimated. The results obtained are shown in Table 5. The densities of handsheets prepared from the pretreated rice straw pulp were higher than those of pulps from the untreated rice straw. On the other hand, considered the differences among the kinds of nutrients, the densities of handsheets from N or glucose + N were higher than other nutrients. The more the incubation period were extended the more the densities were increased.

The breaking length was 2.32 km when handsheets were made of non-treated rice straw pulp as control group. On the other hand, those of handsheets made of pretreated rice straw pulps showed the ranges of 3.35 ~ 4.56 km, 3.31 ~ 4.28 km, 3.80 ~ 6.46 km and 3.30 ~ 5.51 km without any nutrients and with glucose, N and glucose + N, respectively.

The breaking lengthes of pulps made from rice straw pretreated with a fungi were better than those of pulp made from untreated rice straw. Especially, when N was added to the rice straw media as a nutrient, the breaking length of pulp was superior, compared to other pulps.

The burst index was 0.91 kPa · m^2/g when handsheets were made from non-treated rice straw pulp as control group. While, those of handsheets made from pretreated rice straw

Table 5. Physical properties of soda pulps made from rice straw pretreated with *Pleurotus cornucopiae*

Culture period(days)	Additives	Density (g/cm^3)	Breaking length (Km)	Burst index (kPa · m^2/g)	Tear index (mN · m^2/g)	Folding endurance (times)
Untreated		0.24	2.32	0.91	46.7	21
5	None	0.24	3.35	1.57	44.0	14
	glucose	0.24	3.31	1.36	37.4	45
	N	0.25	3.80	1.88	33.0	59
	glucose+N	0.25	3.30	1.70	42.0	111
10	None	0.25	3.54	1.67	44.7	25
	glucose	0.25	3.44	1.61	45.6	50
	N	0.27	4.63	2.26	39.9	85
	glucose+N	0.26	4.02	1.91	42.2	152
15	None	0.25	3.70	1.74	48.3	71
	glucose	0.26	3.77	1.73	46.2	72
	N	0.28	4.85	2.46	42.4	141
	glucose+N	0.27	4.17	1.97	44.1	163
20	None	0.27	4.22	1.81	49.8	77
	glucose	0.26	3.97	1.82	47.8	108
	N	0.28	5.32	2.52	43.0	236
	glucose+N	0.28	4.77	2.17	48.8	209
25	None	0.27	4.27	1.88	50.3	86
	glucose	0.28	3.99	1.83	49.5	115
	N	0.29	5.55	2.72	50.8	246
	glucose+N	0.30	4.80	2.30	49.9	205
30	None	0.28	4.56	1.97	53.0	114
	glucose	0.29	4.28	2.01	57.0	134
	N	0.30	6.46	3.01	55.6	381
	glucose+N	0.31	5.51	2.43	50.1	226

* Freeness of pulps after beating : 300 mL CSF
* Glucose : 0.5 %, N : 0.25 %

pulps showed the ranges of 1.57 ~ 1.97 kPa · m^2/g, 1.36 ~ 2.01 kPa · m^2/g, 1.88 ~ 3.01 kPa · m^2/g and 1.70 ~ 2.43 kPa · m^2/g without any nutrients and with glucose, N and glucose + N, respectively. The data showed the burst index were constantly increased, based on the extending of the fungal incubation period. Especially, the burst index of handsheet made from rice straw pulp pretreated with N as a nutrient was superior, compared to other kinds of pulps.

Considering the results of breaking length and burst index in all conditions of the handsheets made of pretreated rice straw pulps by Pleurotus cornucopiae, the burst index were significantly higher than those of handsheets made from non-pretreated rice straw pulp. This tendency can be an evidence of the positive effectiveness on biological pretreatment by fungi.

The tear index of handsheets from non-pretreated rice straw pulp as control group

was 46.7 mN · m^2/g. On the other hand, those of handsheets made of pretreated rice straw pulps showed the ranges of 44.0 ~ 53.0 mN · m^2/g, 37.4 ~ 57.0 mN · m^2/g, 33.0 ~ 55.6 mN · m^2/g and 42.0 ~ 50.1 mN · m^2/g without any nutrients and with glucose, N and glucose + N, respectively. However, the results of tear index showed significantly different tendency, compared to other physical properties of handsheets. The tear index of handsheet made from rice straw pulp pretreated without nutrients was somewhat higher than those of other pulps at the most of fungal incubation periods. While, when N was added to the rice straw media up to 20 days incubation periods, the tear index was the lowest. But, after 20 days of incubation, the level of tear index becomes constant. These results indicate that pretreatment by *Pleurotus cornucopiae* effects negatively up to certain fungal incubation period, but after that, effects positively much higher.

The folding endurance of handsheets from non-pretreated rice straw pulp as control group was 21 times. Meanwhile, those of handsheets made from pretreated rice straw showed the ranges of 14 ~ 114 times, 45 ~ 134 times, 59 ~ 381 times and 111 ~ 226 times without any nutrients and with glucose, N and glucose + N, respectively. The addition effect of nutrients on the folding endurance was obvious. And, it means that this physical parameter was constantly increased with fungal incubation periods. Up to 15 days of fungal incubation, the folding endurance of handsheet made from rice straw pulp pretreated with glucose + N was highest. However, when N was added, the tear index of pulps were indicated in higest value from 20 days of incubation period.

4. Conclusions

In this research, soda pulping under atmospheric pressure was carried out with non-wood fiberous material, rice straws, which were pretreated by Pleurotus cornucopiae, in order to get more data concerning on optimum conditions of incubation periods and nutrients for improving the bio-chemical pulping method. Conclusions obtained from the results were as follows;

Even though there were individual differences according to different incubation periods, the optimal fungal incubation period was 15 days after fungal inoculation in terms of the weight losses of rice straw and the total yield and properties of pulps. And, as a nutrient additives, N or glucose + N showed the better effect. Over 15 days of fungal incubation period, the physical properties were slightly improved, but other properties were similar each other. Therefore, it would be not so good to extend fungal pretreatment periods over 15 days. Accordingly, it can be concluded that the pretreatment by *Pleurotus cornucopiae* for rice straw soda pulping under atmospheric pressure could save energy and equipment investment for the pulping process.

However, this bio-chemical pulp is not suitable for high-quality paper, because the rice straw soda pulp studied in this research were defibrated uncompletely. So, we suggest this bio-chemical pulp can be used for middle or low quality paper or packaging paper. Therefore, further research should be focused on better defiberation and delignification in order to get a higher quality pulp.

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