

ALTERNATIVE FIBERS FOR HYGIENE CONSUMER GOODS

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ABSTRACT

Global sustainability megatrends are enabling the utilization of alternative non-wood fibers (e.g., agricultural residues) for multiple consumer goods, including hygiene tissue paper. The Sustainable and Alternative Fibers Initiative (SAFI) at NCSU has developed and adapted feasible conversion processes, producing non-wood fibers with promising performance for hygiene tissue paper applications. Different pulping processes, both mechanical and chemical, have been evaluated. Results from this work show that non-wood fibers might provide higher bulkiness, water absorption, and tensile strength without significantly compromising the softness when compared to tissue paper containing conventionally used fibers (like BEK and NBSK) [1]. Results from this work are at the heart of implementing alternative fibers to match consumers' demands for more sustainable tissue products.

Keywords: Alternative Fibers, Non-wood Fibers, Tissue, mechanical pulping, chemical pulping.

INTRODUCTION

Changes in purchasing behavior are opening an opportunity to introduce alternative fibers in a market where conventional wood fibers have historically dominated. The lack of technical know-how and uncertainty about the sustainability of these alternative fibers may be the biggest challenges needed to overcome. For this reason, the Sustainable Alternative Fiber Initiative (SAFI) was founded. SAFI is a consortium with over 20 industry partners located at NC State University. The consortium's goal is to provide data to our partners to facilitate decision-making regarding using non-wood fibers. SAFI counts with seven research areas: Supply chain, characterization; conversion; fiber product and performance; techno-economic analysis; LCA; and consumer perception. Non-wood feedstock comes in limited supply compared to wood. Transportation costs can be high due to their high bulk. Also, their high content of silica creates a highly viscous spent liquor that is harder to pump. The silica also clogs the evaporators increasing the downtime of conventional chemical pulping plants.

Mechanical pulping techniques can be used to bypass these hurdles. They allow the production of high-yield pulp that takes advantage of the limited supply of feedstock. The spent liquor produced in this process is normally not treated through a chemical recovery cycle that's sensitive to silica. And can be economically viable at low production rates [2]–[4].

Alkaline peroxide mechanical pulping (APMP) is a chemo-mechanical technique. This pulping process uses a mild chemical attack using sodium hydroxide to lower the softening temperature of the lignin. Thanks to this the mechanical refining step uses less energy. The soft lignin matrix also produces less fiber cutting. While the peroxide allows for the preservation of the pulp color [5], [6]. The ligning preserving nature of mechanical pulps may produce high coarseness pulp

EXPERIMENTAL.

Feedstock Selection.

The following feedstocks were selected: wheat straw from Montana, US; switchgrass and miscanthus, both from Tennessee, US.

Feedstock preparation.

All samples were reduced in size using a hammermill, then classified using a Chip Class from Testing Machine Inc., 3mm fractions were collected. The rest was disposed of.

Feedstock pre-treatment

A hot water pretreatment was carried out to remove contaminants such as dirt and water-soluble extractives that may compromise the effectiveness of the chemical impregnation. 100 g OD of pulp was weighted and introduced in polyethylene bags, and enough water was added to reach a water-to-solids ratio of 10:1. The bag was sealed and introduced into an isothermal water bath set at 90 °C for 120 minutes. Then the sample was collected and cleaned using DI water. Finally, the samples were centrifuged to remove any excess water.

Chemical impregnation.

The pre-treated samples were subject to three different chemical charges: 6% NaOH+6%H₂O₂, 8% NaOH+6%H₂O₂, and 8% NaOH+8%H₂O₂. This step was carried out in polyethylene bags using a liquor-to-wood ratio of 10:1. The bags with the sample and the liquor were placed in isothermal waster baths at 90 °C for 120 min.

Mechanical refining.

From the previous step, the samples were refined using a single-disk Bauer atmospheric refiner at 3600 rpm. This was a step process. The first step was carried out at a plate gap of 0.01 in and the second one at a plate gap of 0.005 in. The consistency was fixed at 30%. At this point, the mass obtained was noted to calculate the process yield.

Pulp screening.

The refined pulp was screened using a PULMAC Masterscreen. This was carried out in three steps in which the size of the slot was reduced progressively. The screens used were 0.010 in, 0.006 in, and finally 0.004 in.

Handsheet preparation.

All handsheets were made following the TAPPI T 205 sp-02 standard. The target basis weight was 30 and 27 GSM. The handsheets were made using a Testing Machines Inc. handsheets former. The drying was done in a 12” Adirondack Machine Co. cylindrical dryer set at 105 °C and 1 rpm for 5 minutes. Handsheets were not creped.

Fiber Quality Analysis.

The FQA was done using Optest Equipment Inc. FQA-360 fiber quality analyzer, following the TAPPI/ANSI T 271 om-23 standard.

Handsheets testing.

Handsheets were placed for conditioning in a room at 23 °C and 50% relative humidity for 24h. Tests were carried out in the same room. The following properties were measured: basis weight (TAPPI T 410 om-08), thickness and bulk (TAPPI T 580 pm-20) using a Buchel B.V. digital caliper, water absorbency (TAPPI T 432 cm-21), tensile index (TAPPI T 494 om-01) using an Instron model 4443 and brightness (ISO 2470-1) using. Softness was measured using EMTEC Tissue Softness Analyzer, and the TS7 value was reported.

RESULTS AND DISCUSSION.

Pulping results.

To evaluate the performance of the different chemical charges, both the yield and the brightness were tracked, as shown in Table 1

Table 1 Total yield and brightness

Feedstock	6% NaOH+6%H ₂ O ₂		8% NaOH+6%H ₂ O ₂		8% NaOH+8%H ₂ O ₂	
	Total Yield (%)	Brightness (% ISO)	Total Yield (%)	Brightness (% ISO)	Total Yield, (%)	Brightness (% ISO)
Wheat Straw	77.9	36.4	75.6	37.6	74.9	36.9
Switchgrass	82.3	44.8	77.8	42.8		
Miscanthus	81.4	46.1	78.9	45.1	78.1	45.3

Increasing the chemical charge slightly lowered the yield. In chemi-mechanical pulping, the chemical attack is not severe enough to solubilize lignin[5], [6]. Thus, this result was expected. In the case of brightness, peroxide is introduced to inhibit the darkening of the pulp due to the soda attacks [2]. Increasing the amount of peroxide didn't significantly increase the pulp brightness. Suggesting that the peroxide was effective at inhibiting the darkening effect but not at promoting further brightness development. Based on these results the lowest chemical charge was selected for further work.

Fiber quality analysis.

The FQA results are shown in Table 2.

Table 2 Fiber quality analysis results

Parameter	BEK	NBSK	Wheat straw APMP 6%NaOH+6%H ₂ O ₂	Switchgrass APMP 6%NaOH+6%H ₂ O ₂	Miscanthus APMP 6%NaOH+6%H ₂ O ₂
Fiber length mm	0.8	2.3	0.8	0.8	0.9
Fiber width μm	16.4	28.1	29.6	16.4	22.9
Coarseness mg/km	73	216	109	100	176
Fines %	4.5	5.0	7.8	7.8	7.9

Overall, the studied non-wood pulp fibers had similar lengths as BEK. Width presented higher variations, with wheat straw and miscanthus having similar widths as NBSK, while switchgrass was more similar to BEK. Coarseness values for wheat straw and switchgrass were similar, while miscanthus was higher. Softness is the most important property of tissue paper. This quality is extremely subjective but can be related to the fiber's flexibility and the paper's bulk feel. For this reason, fiber coarseness is of the utmost importance since it influences both these properties[7]. The high coarseness of these non-wood fibers might produce a bulkier yet stiffer sheet than BEK. Thus, compromising softness feeling.

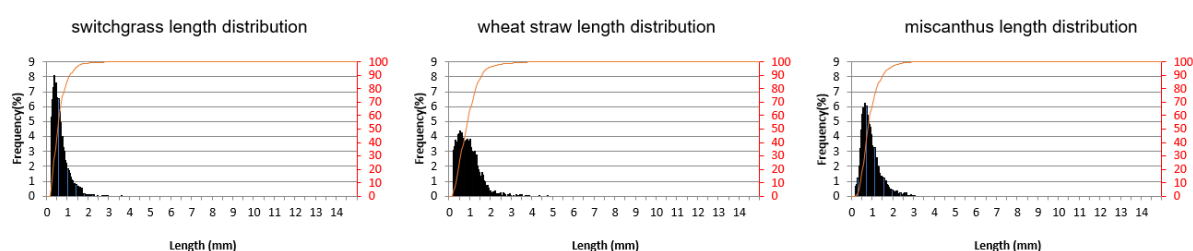


Figure 1 Fiber length distribution for switchgrass, wheat straw, and miscanthus pulp

The length distribution shown in Figure 1 indicates that switchgrass and miscanthus have a higher fraction of short fiber than wheat straw. This may explain why wheat straw pulp allowed for a higher improvement of mechanical properties as shown in Table 3.

Fiber substitution.

Handsheets were made to evaluate the effect of non-wood fibers on selected paper properties. The baseline for comparison was handsheets containing 85%BEK and 15%NBSK to simulate a common premium tissue paper furnish. BEK was chosen for the target of substitution since FQA showed that the non-wood fiber had a similar fiber length, and it was assumed that the mechanical properties of the handsheet would be compromised too much

if the content of the long fiber was decreased[8]. The resulting properties are shown in Table 3. The higher content of non-wood fibers led to an increase in caliper and bulk. This is probably due to the higher coarseness of the mechanical non-wood pulp fiber. This would explain why the handsheets containing miscanthus showed the highest increment in these properties. The paper's water absorbency is related to pore volume in the web and water intake inside the fiber [9]. In the case of mechanical pulp, most of the lignin is still attached to the fiber, inhibiting its capacity to absorb water. Thus, the increase in absorbency must be related to increased pore volume. Increasing the content of both miscanthus and wheat straw resulted in lower softness, represented by a higher TS7 value. The exception seems to be switchgrass which reported better softness values. The results for tensile strength were varied.

Table 3 Paper properties of 30 GSM handsheets with non-wood fibers.

	Base Case	Wheat straw	
	85%BEK+15%NBSK	15%NW+70%BEK+15%NBSK	30%NW+55%BEK+15%NBSK
Freeness ml	605	610	669
Caliper μm	133	144	209
Bulk cm^3/g	4.4	4.8	6.6
Softness TS7	22.4	22.9	24.8
Tensile Index Nm/g	11.2	13.5	21.2
Absorbency g/g	5.8	5.9	6.9
ISO Brightness %	91.3	68.4	41.3
	Base Case	Switchgrass	
	85%BEK+15%NBSK	15%NW+70%BEK+15%NBSK	30%NW+55%BEK+15%NBSK
Freeness ml	605	615	624
Caliper μm	133	135	151
Bulk cm^3/g	4.4	4.3	4.9
Softness TS7	22.4	20.5	20.4
Tensile Index Nm/g	11.2	11.3	12.3
Absorbency g/g	5.8	5.9	6.1
ISO Brightness %	91.3	71.4	61.1
	Base Case	Miscanthus	
	85%BEK+15%NBSK	15%NW+70%BEK+15%NBSK	30%NW+55%BEK+15%NBSK
Freeness ml	605	618	695
Caliper μm	133	163	165
Bulk cm^3/g	4.4	6.0	6.1
Softness TS7	22.4	23.4	26.3
Tensile Index Nm/g	11.2	12.6	10.1
Absorbency g/g	5.8	9.5	9.1
ISO Brightness	91.3	73.0	65.0

In the case of miscanthus, it was evident that the lower substitution scenario yielded enhancements in tensile properties, whereas higher substitution levels had an adverse impact. In the context of switchgrass, a notable increase was only observable at a 30% substitution rate. Conversely, with regard to wheat straw, augmenting its content precipitated a marked rise in the tensile index. Tensile strength bears significance for tissue paper production, as heightened strength reduces instances of paper breaks during manufacturing. However, it's worth noting that heightened tensile strength often exhibits an inverse correlation with pivotal tissue paper attributes like softness and bulk[7]. In this context, the notable elevation in strength combined with improved bulk resulting from wheat straw integration presents a promising prospect. This prospect entails the potential to reduce the basis weight of the sheet while concurrently attaining desirable paper characteristics.

Fiber reduction.

To evaluate the effect of lowering the basis weight, 27 GSM handsheets were made. The non-wood pulp selected was wheat straw, which provided the highest increment in tensile properties. The Table 4 shows the results obtained.

Table 4 Mechanical properties comparison between 30 and 27 GSM handsheets

Parameters	Base Case		Wheat Straw	
	30 GSM	27 GSM	27 GSM	27 GSM
	85%BEK+15%NBSK	85%BEK+15%NBSK	15%NW+55%BEK+15%NBSK	15%NW+55%BEK+15%NBSK
Freeness ml	605	605	610	618
Caliper µm	133	111	120	135
Bulk Cm ³ /g	4.4	4.0	4.4	4.9
Softness TS7	22.4	21.3	22.3	22.9
Tensile Strength N/m	336	284	345	375
Absorbency g/m ²	174	156	159	167
ISO Brightness %	91.3	91.3	68.4	56.4

In the base case scenario, a reduction in basis weight led to diminished softness, water absorbency, bulk, and tensile strength. However, a notable trend emerged upon introducing 15% wheat into the lower basis weight handsheets: the decrease in bulk and waste absorbency was ameliorated, with softness remaining consistent, and an enhancement in tensile strength was observed. Notably, most properties exhibited improvement, though water absorbency experienced a decline at the 30% substitution rate. These findings underscore the potential of incorporating APMP wheat straw fiber into tissue production, offering a viable avenue for cost reduction given the substantial expenses associated with fiber, a primary manufacturing input. Visualized in Figure 1, a comparison of the cross-sections between the base case 30 GSM handsheets and the 27 GSM wheat straw-infused handsheets reveals the progressive impact of increased wheat content. This effect becomes more discernible as wheat content

risers, highlighting the contribution of the non-wood fiber's greater coarseness and width to the augmented bulkiness of the paper web structure.

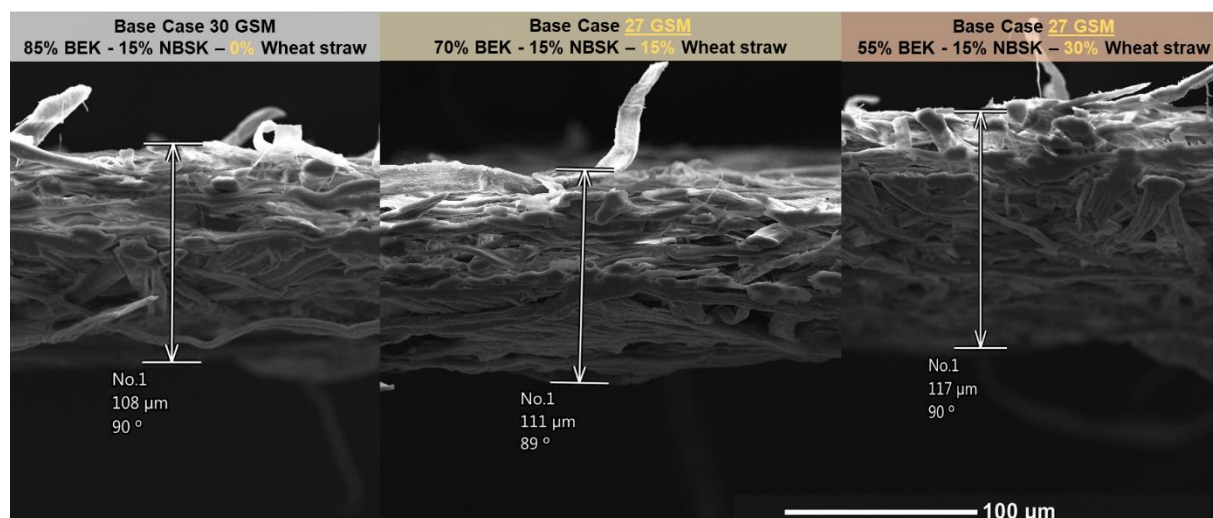


Figure 2 Cross section of 30 GSM base case handsheet vs 27GSM wheat straw containing handsheet.

CONCLUSIONS.

The utilization of non-wood fibers presents several challenges. These challenges include their limited abundance compared to wood fibers, their considerable bulk leading to elevated transportation costs, and their elevated silica content, posing difficulties for integration into conventional chemical pulping techniques like the kraft process. However, implementing alkaline peroxide mechanical pulping offers a solution by enabling a high-yield, small-scale operation that optimizes the use of these non-wood fibers without necessitating chemical recovery cycles sensitive to silica content. The investigation into the selected non-wood feedstock yielded encouraging outcomes, particularly concerning its potential for enhancing tissue paper production.

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