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Ecological Agricultural Technologies

Evaluation of the Agronomic Adaptability, Economic Productivity and Industrial Utilization Potential of Kenaf in Wisconsin

Introduction:

The focus of our project was to determine the agronomic adaptability, economic productivity and industrial utilization of Kenaf (Hibiscus cannibinus L.) for Wisconsin. This was done in a cooperative research project with AGRECOL Corporation, UW-Madison, Dept. of Agronomy and the U.S. Forest Service Forest Products Laboratory.

Kenaf was selected by the Agricultural Research Service of the USDA out of over 500 plant species as the most promising nonwood fiber plant for pulp and paper manufacturing. In Wisconsin AGRECOL was has been interested in its potential both as a substitute for wood in the paper pulping industry and as a substitute for petroleum in plastic manufacturing. Both industries are important to Wisconsin's economy but may cause serious environmental problems. Kenaf is likely to become and important alternative crop in the future and has seen extensive international research investment over the past 50 years. It is now in the final stages of commercialization, and our objective was to evaluate its potential in Wisconsin.

Results:

Agronomic performance and forage quality:

In 1991, a field experiment was conducted in 6 locations across Wisconsin including the site at AGRECOL CORPORATION in Madison, WI. Sites included Hancock, Marshfield, Arlington, Spooner and Madison. Experimental design and data analysis at these five sites was conducted at the UW-Madison. The average yield for Tainung #1 was 4.4 DMtons/A and for C-108 was 4.0 DM tons/A.

In 1992, kenaf was evaluated for both yield and forage quality. Dry matter yields (averaged across four replications) were reported as 4.84, 4.23 and 1.18 for Lancaster, Arlington and Marshfield respectively. Plant population and row spacing evaluation suggest that there is no significant differences in yield between 10" and 30" rows. However, it appears that increasing plant population correlates with an increased yield.

Data analysis for forage quality shows that kenaf may be higher in forage quality than might be expected for a forage crop. It may be quite a decent forage for beef cattle and maybe even non lactating dairy cattle. Forage quality of kenaf (averaged across five varieties) at 64 days after planting was 33.02% NDF, 20.72% ADF and 27.5% CP. At 159 days after planting kenaf averaged 48.95% NDF, 34.8% ADF and 12.15% CP. Averaged across five varieties, dry matter yield at 64 days was 0.63 dm T/A. At 159 days after planting dry matter yield increased to 4.23 dm T/A.

Substitute for wood filler in melt blended composites;

In addition to field testing, we explored the possibility of using natural fibers (both kenaf and wood) to substitute for petroleum based materials in the manufacturing of plastic products. To test the feasibility of injection molding kenaf fiber, a trial run using wood fiber was injected molded into small office supplies

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at the then W.T. Rogers Corporation in 1991. Except for a bad smell, the results showed it may be feasible to injection mold kenaf, provided the properties are similar to wood.

Additional research from the U.S. Forest Products Laboratory compared the structural properties of kenaf core as a reinforcing filler in melt processed thermoplastic composites (extrusion molding). Kenaf core was compared with wood flour as reinforcing filler in polypropylene and polypropylene to determine its utilization in extrusion molding. Their results indicated that the properties of kenaf are very similar with wood and that the kenaf core fiber performed well in the melt blend formulations that they tested. They report that kenaf could serve as substitute filler for wood flour in melt processed composites.

Bio fibers offer a number of advantages as reinforcing fillers in plastic composites. These include high specific strength and stiffness, low cost, low weight and lower abrasion to processing equipment. In fact, for nearly a decade the American Woodstock Co. in Sheboygan, WI has been manufacturing composite sheets that are composed of equal weights of wood flour and polypropylene. These sheets are made by melting the mixture and forcing it through a die. The sheet is heated and pressed into interior automobile panels.

Potential Economic Impact:

This project has shown that although lower yielding than the more southerly states, kenaf can be grown in Wisconsin for fiber. Its quality as a forage was higher than anticipated, exceeding that of prime quality hay, and may have potential as feed for livestock in Wisconsin, particularly as a bi-product of an industrial application.

Whether kenaf can be used as an alternative for wood flour in the plastics industry will depend primarily on its delivered cost to a plastic compounder relative to that of wood flour, on local supply advantages and perhaps local environmental factors.

Using kenaf as a new crop with local value-added processing and manufacturing could have significant impacts on local communities. New technologies that use a lower economy of scale should positively impact local communities and farming systems. Other community impacts would result from the demand of new equipment, labor, buildings an other needs and services.

The bottom line continues to be the driving force for kenaf in Wisconsin. More work, particularly in product development and marketing needs to be done to explore the full potential of kenaf in Wisconsin. AGRECOL will continue to explore the utilization of kenaf in Wisconsin, and remains cautiously optimistic of the possibilities for the grower in Wisconsin.

Acknowledgments:

AGRECOL Corporation would like to thank the Wisconsin Department of Agriculture, Trade and Consumer Protection for its support of this project. We also thank our cooperators at the University of Wisconsin Department of Agronomy and the U.S. Forest Service, Forest Products Laboratory, Division of Performance Designed Composites.

FIELD EXPERIMENT HISTORY

Year: 1992

Expt. Nos. 9285, 9287, 9289
Title: Kenaf Row Spacing and Plant Population Evaluation at Three Wisconsin Locations
Personnel: E.S. Oplinger, J.M. Gaska, G.C. Mayne, D. Wiersma, T. Wood and K. Silveira
Location: Arlington Research Station, Arlington, WI (9285)
Marshfield Research Station, Marshfield, WI (9287)
Lancaster Research Station, Lancaster, WI (9289)
Supported by: Agrecol and HATCH Project 1890

FIELD INFORMATION

Field: Arlington–374, Marshfield–2, Lancaster–915
Soil type: Arlington–Plano Silt Loam, Marshfield–Withee Silt Loam, Lancaster–Rozetta Silt Loam

Soil Test Results:	Date	pH	P(ppm)	K(ppm)	O.M.(%)
Arlington	1991	7.0	54	215	3.1
Marshfield	1991	6.6	65	185	3.4
Lancaster	1991	7.6	80	250	3.0

Nitrogen Applied (lbs/a): 100 Analysis: 33–0–0 at Arlington and Marshfield
82–0–0 at Lancaster
Tillage Operations: Conventional (Plow, Field Cultivate, Cultimulch)
Previous Crop: wheat at Arlington, soybean at Marshfield, corn at Lancaster
Previous Herbicide: Arlington–none
Previous Herbicide: Marshfield–Dual, Basagran, Poast
Lancaster–Dual, Bladex
Irrigation: None

EXPERIMENTAL PROCEDURE

Exp. Design: RCB Split plot

Replicates: 4

Variables: 2 Row Spacings: 10–inch and 30–inch
4 Plant Populations/acre:

Arlington	Marshfield	Lancaster
25,000	20,000	20,000
50,000	30,000	30,000
75,000	40,000	40,000
100,000	50,000	50,000

Cultivar: Tainung 2

Plot Size: Planted: 10' x 25'
Harvested:

Marshfield	Arlington and Lancaster
5.00' x 23' in 30–inch rows	5.00' x 21' in 30–inch rows
2.50' x 23' in 10–inch rows	3.33' x 21' in 10–inch rows

Planting: Date: Arlington–5/20, Marshfield–5/21, Lancaster–5/18
Equipment: Planter Junior
Depth: 1/4"

Thinning: Date: Arlington–7/9, Marshfield–7/21, Lancaster–7/17

Harvesting: Date: Arlington–10/29, Marshfield–10/2, Lancaster–10/30
Equipment: one–row forage chopper at Arlington and Lancaster
forage plot harvester at Marshfield

Herbicides:		Material	Rate	Method
	All locations	Dual	2.25pt/A	PPI

Results: Table D3

FIELD EXPERIMENT HISTORY

Year: 1992

Expt. Nos. 9284, 9286, 9288
Title: Kenaf Variety Evaluation at Three Wisconsin Locations
Personnel: E.S. Oplinger, J.M. Gaska, G.C. Mayne, D. Wiersma, T. Wood and K. Silveira
Location: Arlington Research Station, Arlington, WI (9284)
Marshfield Research Station, Marshfield, WI (9286)
Lancaster Research Station, Lancaster, WI (9288)
Supported by: Agrecol and HATCH Project 1890

FIELD INFORMATION

Field: Arlington−374, Marshfield−2, Lancaster−915
Soil type: Arlington−Plano Silt Loam, Marshfield−Withee Silt Loam, Lancaster−Rozetta Silt Loam

Soil Test Results:	Date	pH	P(ppm)	K(ppm)	O.M.(%)
Arlington	1991	7.0	54	215	3.1
Marshfield	1991	6.6	65	185	3.4
Lancaster	1991	7.6	80	250	3.0

Nitrogen Applied (lbs/a): 100 Analysis: 33−0−0 at Arlington and Marshfield
82−0−0 at Lancaster

Tillage Operations: Conventional (Plow, Field Cultivate, Cultimulch)
Previous Crop: wheat at Arlington, soybean at Marshfield, corn at Lancaster
Previous Herbicide: Arlington−none
Marshfield−Dual, Basagran, Poast
Lancaster−Dual, Bladex

Irrigation: None

EXPERIMENTAL PROCEDURE

Exp. Design: RCB

Replicates: 4

Variables: Six Varieties:
- C−108
- Cubano
- EV 41
- EV 71
- Tainung 1
- Tainung 2

Plot Size: Planted: 10' x 25'
Harvested: 5' x 21' at Arlington and Lancaster, 5' x 23' at Marshfield
Row Spacing: 30"

Planting: Date: Arlington−5/20, Marshfield−5/21, Lancaster−5/18
Equipment: Planter Junior
Depth: 1/4"

Thinning: Date: Arlington−7/9, Marshfield−7/21, Lancaster−7/17
Plants/A: 75,000

Harvesting: Date: Arlington−10/29, Marshfield−10/2, Lancaster−10/30
Equipment: one−row forage chopper at Arlington and Lancaster
forage plot harvester at Marshfield

Herbicides:		Material	Rate	Method
	All locations	Dual	2.25pt/A	PPI

Results: Table D2

Table D2. Kenaf Variety Evaluation at Three Wisconsin Locations
Arlington (9284), Marshfield (9286) and Lancaster (9288)

	Location								
	Arlington			Marshfield			Lancaster		
Variety	Dry Matter	Plant Moisture	Ht	Dry Matter	Plant Moisture	Ht	Dry Matter	Plant Moisture	Ht
	tons/a	%	ft	tons/a	%	ft	tons/a	%	ft
C108	3.78	53.6	5.8	1.09	77.5	2.9	4.39	47.8	6.4
Cubano	4.23	52.7	5.9	1.60	76.1	3.2	4.45	49.3	6.4
EV 41	4.14	52.5	5.2	1.17	77.3	2.9	4.79	50.4	6.1
EV 71	3.51	51.8	5.1	0.84	76.4	2.8	4.54	51.3	6.1
Tainung 2	4.85	49.6	6.6	0.84	76.9	3.4	5.65	50.2	7.3
Tainung 1	4.87	50.7	6.3	1.57	77.1	3.4	5.23	49.2	7.0
Means	4.23	51.8	5.8	1.18	76.9	3.1	4.84	49.7	6.5
Probability(%)									
Variety	<0.1	43.8	<0.1	2.1	>50	<0.1	10.0	>50	0.3
LSD(10%)									
Variety	0.42	NS	0.4	0.43	NS	0.2	0.83	NS	0.5
CV(%)	8.1	5.5	5.1	29.2	1.6	4.9	13.8	5.6	6.1

Table D3. Kenaf Row Spacing and Plant Population Evaluation at Three Wisconsin Locations Arlington (9285), Marshfield (9287) and Lancaster (9289)

atments		Location: Arlington			Marshfield			Lancaster		
ow Width	Plant* Pop	Dry Matter	Plant Moisture	Ht	Dry Matter	Plant Moisture	Ht	Dry Matter	Plant Moisture	Ht
in	x1000	tons/a	%	ft	tons/a	%	ft	tons/a	%	ft
10		4.26	49.9	6.0	0.80	77.8	3.4	5.15	50.8	7.0
30		4.51	48.6	6.1	1.69	77.8	3.3	4.79	49.6	7.0
	25/20	3.86	48.9	6.2	1.10	77.6	3.3	4.88	50.3	7.0
	50/30	4.25	49.2	6.0	1.11	79.0	3.4	4.76	50.6	6.9
	75/40	4.78	49.3	6.1	1.40	77.3	3.3	4.56	50.8	7.0
	100/50	4.64	49.6	5.9	1.36	77.2	3.4	5.69	49.1	7.0
10	25/20	3.76	48.7	6.1	0.70	77.7	3.3	5.53	51.2	7.1
10	50/30	4.25	48.8	6.0	0.78	78.6	3.4	4.99	51.5	7.0
10	75/40	4.90	50.6	6.1	0.78	77.4	3.4	3.89	50.8	6.9
10	100/50	4.14	51.6	5.8	0.94	77.5	3.4	6.21	49.9	6.9
30	25/20	3.96	49.0	6.3	1.51	77.6	3.2	4.24	49.3	7.0
30	50/30	4.26	49.7	6.1	1.44	79.4	3.4	4.52	49.7	6.9
30	75/40	4.66	48.1	6.0	2.02	77.1	3.2	5.24	50.9	7.1
30	100/50	5.15	47.6	6.1	1.79	77.0	3.3	5.18	48.4	7.1
eans		4.38	49.3	6.1	1.24	77.8	3.3	4.97	50.2	7.0
Probability(%)										
Row Spacing(S)		12.5	16.6	28.0	2.6	>50	>50	8.0	33.8	44.3
Plant Population(P)		0.1	>50	2.2	21.9	0.8	>50	18.3	>50	>50
S x P		3.9	15.7	9.1	>50	>50	>50	8.3	>50	>50
LSD(10%)										
Row Spacing(S)		NS	NS	NS	0.51	NS	NS	0.32	NS	NS
Plant Population(P)		0.36	NS	0.1	NS	0.9	NS	NS	NS	NS
S x P		0.49	NS	0.2	NS	NS	NS	1.14	NS	NS
CV(%)		9.4	4.8	2.3	28.4	1.3	5.0	21.0	5.6	4.4

*Plant populations at Arlington were 25,000, 50,000, 75,000 and 100,000 plants/acre
Plant populations at Marshfield and Lancaster were 20,000, 30,000, 40,000 and 50,000 plants/acre

KENAF CORE FIBER FOR MELT BLENDED COMPOSITES

Final Report

for Agreement # FP-92-1881

with

Agrecol Corporation
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Madison, WI 53716-4153

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SUMMARY

The Forest Products Laboratory carried out a preliminary examination of the utility of kenaf core as a reinforcing filler in melt-processed thermoplastic composites. Kenaf core was hammermilled and sieved to provide a fine, particulate material that could be dispersed into polypropylene using a small high intensity mixer. The resultant blends were injection molded into test specimens for mechanical property measurements.

The comminuted kenaf core was compared to wood flour as reinforcing fillers in polypropylene at 20/80 and 40/60 weight ratios of filler to polypropylene. The effect of increasing the filler level for both fillers was to increase strength and stiffness and decrease impact resistance. The differences in composite mechanical properties and melt viscosity using the two fillers were marginal.

This study indicates that kenaf core might serve as a substitute filler for wood flour in these composite systems. Achieving that substitution will depend on whether ground kenaf core can be delivered to a plastic compounder at a price competitive with wood flour, on local supply advantages, and possibly on local environmental factors. Additional knowledge about the behavior of kenaf core and its composites will also be needed, and areas for further study are outlined.

INTRODUCTION

Bio fibers offer a number of advantages as reinforcing fillers in plastic composites. These include high specific strength and stiffness (property value divided by weight), low cost, low weight, and lower abrasion to processing equipment. In fact, for nearly a decade the American Woodstock Co. in Sheboygan, WI has been manufacturing composite sheets that are composed of equal weights of wood flour (WF) and polypropylene (PP). These sheets are made by compounding the ingredients in an extruder and forcing the molten mixture through a slit die. Subsequently, the sheet is heated and pressed into interior automobile panels.

The objective of this study was to assess what capability kenaf core, currently a waste material, might have as a reinforcing filler in melt-processed plastic composites.

APPROACH

Laboratory screening experiments were conducted to establish the following:

- a workable method for reducing the core material to individual fibers or particles that could be used as feed material for the melt blending step.

- blending parameters to disperse the kenaf core homogeneously into the plastic matrix by means of a laboratory K-mixer.

- rheological behavior of the composite melt and mechanical behavior of the solid composite at two kenaf core/plastic ratios and in comparison with similar WF/plastic composites.

From these tests it was expected that recommendations could be made for studies that would be required for optimization and scale up.

EXPERIMENTAL

Materials:

The following materials were used in these tests:

- Kenaf core (KC) pieces (ca 6 to 10 mm) from Kenaf International, Texas. (Chuck Taylor: 512-687-2619)

- Wood flour (- 40 mesh) from American Wood Fibers Co., WI.

- Polypropylene (PP) from Solvay Polymers, Inc., Texas, as 12 melt flow index (MFI) pellets and as 3 MFI fine flakes. High impact polypropylene copolymer as 1.8 MFI pellets from Eastman Chemical Co., Texas.

- Epolene G-3002 maleated polypropylene from Eastman Chemical Co., Texas.

Comminution of kenaf core:

The KC pieces were hammermilled using a 3 mm screen in a small hammermill. A portion of the hammermilled kenaf was screened in a Tyler Ro-Tap to measure the fiber size distribution. Each screen size was examined under an optical microscope to determine whether the materials were fibrous or particulate.

A sample of the hammermilled kenaf was run in the K-mixer at 5500 RPM (36 m/s tip speed) for 30 s to determine whether blending (see next section) after the initial comminution might cause further size reduction. This material was also screened in the Ro-Tap to obtain its size distribution.

Melt blending

A 1-L K-mixer was employed for melt blending the kenaf core and PP. This apparatus consists of a cylindrical chamber in which several blades rotate at high speed and impart kinetic energy to solids that are present. When the plastic reaches its melting or softening point, fluxing and mixing begin and the temperature begins to rise very rapidly. Within seconds thereafter, the molten mixture usually is discharged through a bottom door which is temperature-activated. For most systems, total blending time may be from 20 seconds up to perhaps 2 minutes. The effectiveness of blending in the K-mixer can be a function of several parameters -- plastic and filler properties, batch size, starting temperature, blade speed, time, discharge temperature.

To establish a useful, but non-optimized, melt blending process, a screening experiment was conducted in which over 30 batches were prepared in the K-mixer, varying the mixer parameters and a number of material parameters. The resultant blends were pressed while hot into thin disks, which were examined visually for completeness and uniformity of the kenaf core dispersion.

From the screening blending experiments, decisions were made as to the mixing and material parameters to be used in preparing blends for this preliminary rheological and mechanical characterization of kenaf core/PP composites.

Stabilizers (antioxidants) were added to each batch, and each blend was produced in two sequential batches of 175 g each, for a total of 350 g per blend. Each blend was granulated and dried at 105°C for 4 hours and then injection molded into ASTM test specimens for mechanical property measurements. The following tests were performed:

- Izod Impact Energy (ASTM D256-90b)
  - -- notched and unnotched (J/m)
- Cantilever Bending (ASTM D 747)
  - -- 9° secant modulus (GPa)
  - -- maximum strength (MPa)
- Flexural (ASTM D790-84a)
  - -- modulus of elasticity (GPa)
  - -- maximum strength (MPa)
- Tensile (ASTM D638-84)
  - -- modulus of elasticity (GPa)
  - -- maximum strength (MPa)
- Density

The rheological behavior of two kenaf core and two wood flour blends was characterized using triplicate melt index measurements. This procedure involves measuring the weight of material that flows through a capillary in 10 minutes at 190°C under a specified force.

RESULTS AND DISCUSSION

Kenaf core comminution

Measured screen size distributions are shown in Fig. 1 (H is the total hammermilled material; H1, H2, and H3 are replicate measurements; K refers to the hammermilled material that was run in the K-mixer). We note:

- Reproducibility of the size distribution measurement itself is good.

- K-mixer treatment of the kenaf core after hammermilling and without plastic leads to small losses in large particles and corresponding increases in the smallest. These changes may well be magnified in the presence of the plastic due to the shear forces during melt fluxing.

- approximately 60 % of both materials falls between 10 and 40 mesh.

Figs. 2 to 8 are photomicrographs of the various mesh sizes from the original hammermilled kenaf core. The particles appear to be fiber bundles rather than individual fibers. Moreover, their aspect ratio (length divided by diameter) does not appear to change greatly as the size decreases, that is, the particles are decreased in both dimensions with greater milling.

Blending parameter screening

A variety of blending conditions and material parameters were used in initial blends to determine the best conditions for good blending of the kenaf fiber. Appendix A contains a representative listing of the runs performed. Blending parameters included mixer speed, starting and discharge temperatures, time, and batch size. Material parameters included:

- particle size range of the kenaf core. Total hammermilled = entire material after passage through the 3 mm screen of the mill (defined as H). Sieved portion = fraction of the hammermilled material that passed through a 40 mesh screen (i.e., smaller than approximately 0.4 mm); this fraction was about 40 percent of the kenaf core and is referred to hereafter as H-S.

- 20/80 vs 40/60 weight ratio of kenaf to PP.

- three different types of PP.

- zinc stearate lubricant.

Important observations and conclusions were:

- In general, the kenaf core material was more difficult to disperse in the PP than was wood flour. Surprisingly, the largest particles in the total hammermilled (H) portion were not reduced in size during the blending. Moreover, after the blending a very small amount of fine kenaf core particles remained unmixed.

- The 12 MFI PP pellets did not melt and flux well, a significant portion remaining as pellets. This was true up to a discharge temperature of 193°C, above which the blend stuck to the wall of the mixing chamber instead of discharging out of the bottom door. Using zinc stearate as lubricant decreased the sticking problem but not sufficiently to permit complete PP melting. The lower-melting 1.8 MFI copolymer pellets did not stick to the chamber and therefore allowed longer fluxing and somewhat improved dispersion. Finally, substituting the 3 MFI fine flakes appeared to resolve the problem, presumably because the small particles melted more rapidly and permitted good fluxing and dispersion before sticking occurred.

- None of the other variables, e.g., batch size, kenaf content, or reducing speed near the fluxing temperature, influenced the blending in a major way.

Composite mechanical and rheological behavior

Based on the screening results, a 2-level, 3 factor, (2x2x2), unreplicated factorial design experiment was set up (Table 1). For comparison, four blends (WF1 to WF4) were also prepared with 40 mesh wood flour as filler; these matched Blends 1 to 4 containing kenaf core. Blending conditions for these twelve blends are summarized in Appendix B. Because Blends 5 to 8 exhibited somewhat erratic mechanical properties, these blends were replicated (Blends 5R to 8R), and the replicate blends were characterized as to density, impact energy, and cantilever beam modulus and strength.

Mechanical property and densities are summarized in Table 2. The original Blends 5 to 8 and their replicates all showed large standard deviations, and notched impact in particular showed large differences between the replicate blends. This variability may derive from segregation (differential settling) among the wide range of particle sizes in H during storage prior to blending into composite and/or from variations in the number and size of large particles in injection molded specimens. Whatever the underlying cause, we concluded that the broader distribution kenaf core (H) produced composites that were too non-reproducible to warrant further study. The remainder of the discussion, therefore, deals with the composites from the narrower distribution kenaf core from which particles larger than 40 mesh had been removed (H-S).

Within Blends 1 to 4 and WF1 to WF4, the densities of all composites containing 20 percent filler were just under 1.0 whereas the densities of those containing 40 percent filler were slightly over 1.0. This result is consistent with the greater density of the filler (ca 1.4 assuming loss of voids) compared to polypropylene (ca 0.95). Other experience with cellulosic composites has demonstrated that during melt processing the cellulosic material is either compressed by the pressure or its voids are filled with the molten plastic; thus its effective density is close to 1.4.

Figs. 9 to 16 compare the effects on mechanical properties of three variables: wood flour versus kenaf core (H-S), 20 versus 40 percent filler, and 0 versus 3 percent G3002. Some of the property differences appearing in the figures are not statistically significant. A standard factorial analysis of the data was performed to determine the statistical significance of any differences. The results are summarized in Table 3 for the main effects at the 95 percent confidence level; no interaction effects of the variables were found at the same confidence level. The following points are noteworthy:

- Overall, increasing the filler level from 20 to 40 percent had the most effect, increasing strength and modulus values and decreasing the impact resistance. These effects are consistent with experience for these types of composites.

- Using kenaf core (H-S) instead of wood flour caused a small decrease in notched impact but no practically significant changes in other properties.

- G3002 coupling agent brought about marginal property changes.

Melt flow indices were measured in triplicate on Blends 3, 4, WF3, and WF4 with the results shown below. While the MFI's for the WF blends were statistically higher than thos for the kenaf core (lower viscosity for the

Blend	Melt flow index (g/10 min)	Standard deviation (g/10 min)
3	0.70	0.03
4	0.71	0.02
WF3	0.78	0.01
WF4	0.87	0.05

WF systems), the differences were very likely not significant from the viewpoint of practical processibility.

CONCLUSIONS

The following conclusions are warranted on the basis of this preliminary study:

- Particles larger than about 40 mesh must be removed from kenaf core to achieve reproducible behavior of composites in a polypropylene matrix.

- Kenaf core can be melt-blended with polypropylene using a 1-L K-mixer and finely ground polypropylene.

- Kenaf core/polypropylene composites exhibit mechanical and rheological properties that are very similar to those of wood flour/polypropylene composites.

- Thus, it appears that kenaf core represents a possible substitute for wood flour in composites. Whether kenaf core will achieve that status will depend primarily on its delivered cost to a plastic compounder relative to that of wood flour, on local supply advantages, and perhaps on local environmental factors.

- For kenaf core to achieve significant usage in melt-blended composites additional research would be needed. That research should include the following: (1) optimize its conversion to a particulate form, (2) establish the ability to achieve good blending with equipment other than the K-mixer, (3) determine its contributions as a reinforcing filler in plastics other than polypropylene and optimize the mechanical properties of the composites as appropriate by examining the influence of carefully chosen additives, and (5) demonstrate scale-up preparation and performance in commercial melt processing equipment.

Table 1. Kenaf core test matrix

Blend #	Kenaf core content[2]	Kenaf core fraction[3]	Epolene G3002[1]	Blend sequence
1	20	H-S	0	3
2	40	H-S	0	7
3	20	H-S	3	1
4	40	H-S	3	6
5	20	H	0	4
6	40	H	0	2
7	20	H	3	5
8	40	H	3	8

[1] 3 weight percent of kenaf core.
[2] Weight percent of (kenaf core plus PP).
[3] H-S = hammermilled portion passing through 40 mesh sieve. H = total hammermilled portion.

Table 2 -- Mechanical Properties of Kenaf Core/PP and Wood Flour/PP Blends[a]

Blend	Density	Kenaf core or WF content[d]	G3002	Izod Impact		Cantilever[b]		Flexural[c]		Tensile[c]	
				Notched	Unnotched	Modulus	Strength	Modulus	Strength	Modulus	Strength
	(g/cc)	(%)	(%)[e]	(J/m)	(J/m)	(GPa)	(MPa)	(GPa)	(MPa)	(GPa)	(MPa)
1	< 1	20	0	35.8	219	1.51	63.2	5.28	57.2	3.12	34.5
2	1.01	40	0	23.8	88	2.00	60.8	7.47	52.0	4.30	30.7
3	< 1	20	3	26.6	284	1.73	77.4	5.31	57.4	2.63	39.3
4	1.04	40	3	20.3	169	2.36	84.8	7.78	69.1	3.77	36.3
WF1	< 1	20	0	48.4	242	1.74	68.4	5.00	52.1	2.79	32.6
WF2	1.03	40	0	28.5	135	2.31	66.2	7.06	51.3	3.91	28.5
WF3	< 1	20	3	37.2	217	1.66	73.8	4.75	56.2	2.90	39.0
WF4	1.04	40	3	24.7	157	2.07	73.4	7.13	60.3	4.11	40.0
Coefficient of variation (%)[f]				6	15	9	3	10	6		
5	< 1	20	0	15.8	202	1.52	64.1				
5R	< 1			42.4	241	1.55	58.3				
6	1.02	40	0	33.6	111	1.84	62.1				
6R	1.02			33.0	137	2.00	65.9				
7	< 1	20	3	27.4	220	1.51	73.6				
7R	< 1			34.5	268	1.58	74.1				
8	1.02	40	3	5.9	121	1.84	78.1				
8R	1.02			26.1	160	1.95	79.2				
Coefficient of variation (%)[g]				22	17	6	5				

[a] Blends 1 to 4 contained sieved kenaf core (H-S). Blends 5 to 8 and 5R to 8R contained the total hammermilled kenaf core (H) 5R to 8R were replicate blends of 5 to 8.

[b] 9° secant modulus and maximum strength.

[c] Youngs modulus and maximum strength.

[d] Percent of (PP + filler).

[e] Percent of filler.

[f] Averaged over all variables within Blends 1 to 4 and WF1 to WF4.

[g] Averaged over all variables within Blends 5 to 8 and 5R to 8R.

Table 3. Main effects of variables on mechanical properties[1]

Variable	Izod impact (J/m)		Cantilever beam[2]		Flexural[3]		Tensile[3]	
	Notched	Unnotched	Modulus (GPa)	Strength (MPa)	Modulus (GPa)	Strength (MPa)	Modulus (GPa)	Strength (MPa)
Overall mean[4]	30.7	189	1.92	71.0	6.22	61.1	3.53	36.7
Filler level 20 to 40 %	-12.7 (-34)	-104 (-75)	0.53 (32)	12.7 (18)	2.28 (45)	NS[5]	1.34 (47)	NS
Filler type Kenaf to WF	8.1 (30)	NS	NS	NS	-0.48 (-8)	NS	NS	NS
G3002 level 0 to 3 %	-7.0 (-20)	NS	NS	NS	NS	NS	NS	7.5 (24)

1 Main effect of a particular variable is the difference between the property value at the "+" level (averaged over all other variables) and the property value at the "-" level (averaged over all other variables). Values in parentheses are percentage change from "-" level to "+" level.
2 Secant modulus at 9° and maximum strength.
3 Youngs modulus and maximum strength.
4 Average over all variables and trials.
5 Not significant at the 95 percent confidence level.