

Compositional Variability Among Corn Stover Samples

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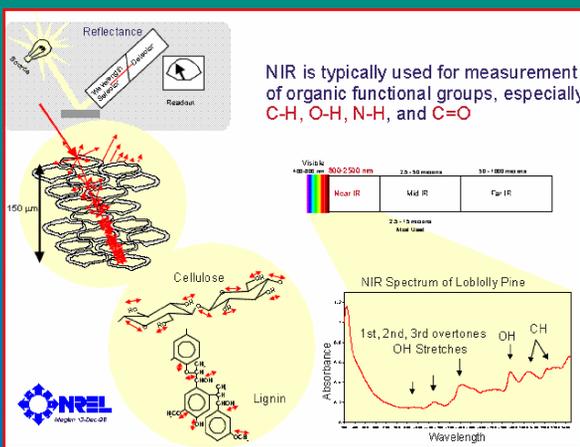
1. Abstract

Corn stover (stalks+leaves+cobs) is currently employed in the DOE-funded Biofuels Program as a model feedstock for integration of enzymatic cellulose hydrolysis-based biomass conversion technology. The chemical composition of corn stover is quite variable from lot to lot, and there are also indications that different lots of stover exhibit differential reactivity to dilute acid pretreatment, as practiced at NREL. These observations are also likely to apply to other herbaceous feedstocks. Biomass composition and quality have therefore emerged as important issues in the development of integrated conversion technology.

Since input feedstock chemical composition directly influences process yield, process economics can be dramatically impacted by changes in feedstock quality. Our goal is to determine the range of compositional variation as well as the potential causes of variability in mature corn stover. Over 1000 specimens from the 2001 North American crop were obtained from a wide variety of sources, including various commercial grain trials, experimental plots, and germplasm collection seed renewal plots. Samples therefore include a fairly broad cross-section of the maize germplasm, including commercial hybrids, inbreds, open-pollinated varieties, foreign accessions, primitive landraces, and related species. Samples were also obtained that had been produced under a variety of conditions in order to evaluate the relative extent to which genetic and environmental factors impact stover quality. We report here on the statistical analysis of the composition of over 700 stover specimens measured using a calibrated near-infrared spectroscopic method developed at NREL, including the results of an analysis of variance of these data as a function of genetic and environmental factors. Results show that corn stover composition varies over an unexpectedly large range and that both genetic and environmental factors are important influences on stover composition.

2. Methods

- Five to ten pound stover samples (10–20 stalks) were collected by suppliers at several institutions.
- Samples were thoroughly dried at 50°C and milled individually to pass a 0.25-inch screen.
- Representative aliquots were selected for NIR spectroscopy.
- Compositions of samples were determined using a calibrated NIR/PLS1 method developed at NREL.
- Analysis of variance was performed using the Analysis ToolPak functions in Microsoft Excel 2001.



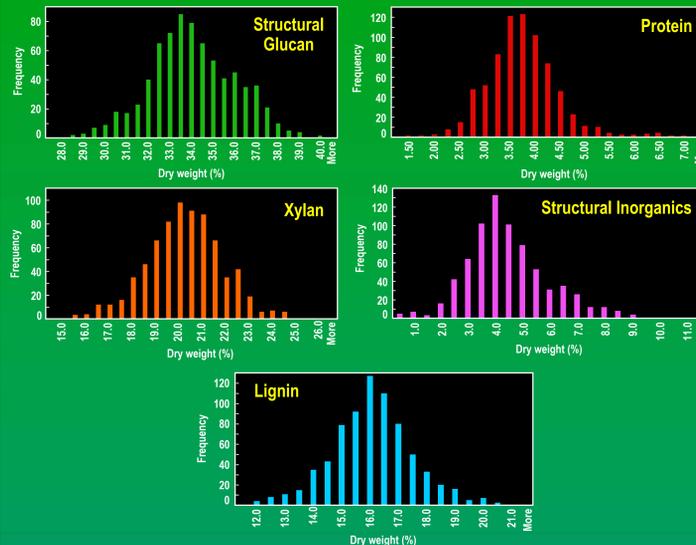
3. Sources of 2001 Corn Stover

Source	Contacts	# Samples	Comments
Monsanto	Diane Freeman, Brad Krohn, Dale Sorensen	221	this study
University of Minnesota	Dale Hicks, Tom Hoverstad, Steve Quiring	150	this study
University of Wisconsin, Madison	Joe Lauer	202	this study
USDA/ARS, Lincoln, NE	Wally Wilhelm	96	this study
University of Nebraska, Lincoln	Ken Russell	61	this study
Iowa State University	Wayne King	30	
ARS, Ames, IA	Linda Pollak	45	
ARS, NCPIS, Ames, IA	Mark Millard	242	
ProdiGene, Inc.	Donna Delaney, Beth Hood	14	
Total		1061	

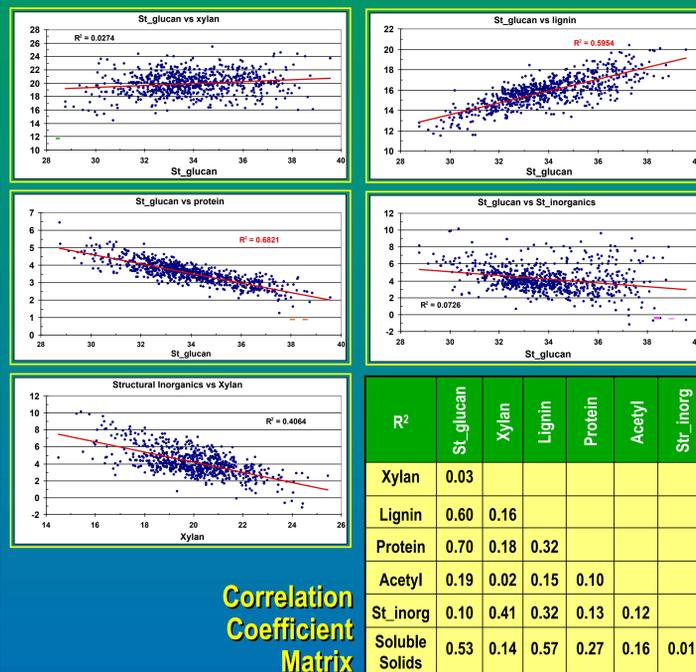
4. Population Statistics

	Total_glucon	Struc_glucon	Xylan	Lignin	Protein	Acetyl	Uronic Acids	Structural Inorganics (Silica, Ash)	Soil	Calculated Soluble Solids	Total	Struc_glucon + Xylan	Total Structural Carbohydrates
Minimum (% dry wt.)	34.5	27.9	14.5	11.5	1.3	0.9	1.4	-1.2	0.9	2.0	90.0	43.3	45.3
Maximum (% dry wt.)	50.3	39.6	25.5	20.4	7.0	3.9	3.9	10.2	1.7	19.6	101.9	63.3	68.5
Span (% dry wt.)	15.8	11.7	11.0	8.9	5.7	3.0	2.5	11.3	0.8	17.5	11.9	19.0	23.2
Mean (% dry wt.)	42.0	33.8	20.0	15.8	3.6	2.7	2.9	4.2	1.3	8.2	97.4	53.8	58.7
Standard Deviation (% dry wt.)	1.5	2.0	1.6	1.4	0.7	0.5	0.3	1.6	0.1	2.2	1.7	2.8	3.2
Total Values	738	738	738	738	738	738	738	738	738	738	738	738	738

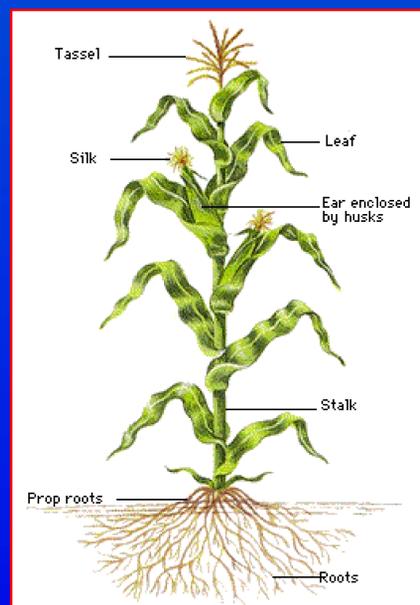
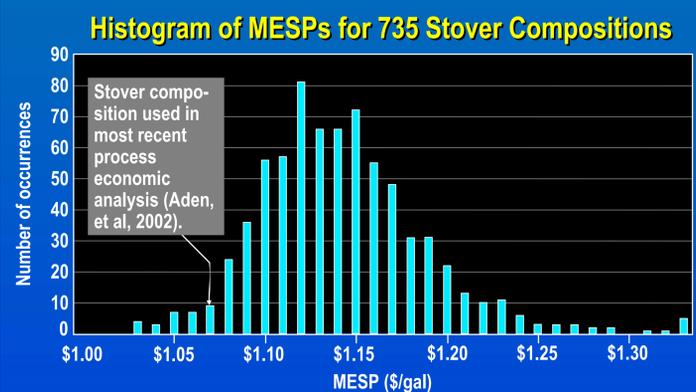
5. Population Distributions (n = 738)



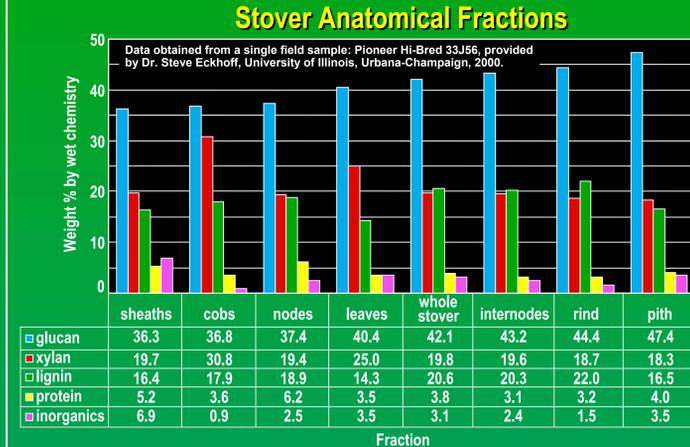
6. Correlations Between Constituent Pairs



7. Effect of Stover Composition on Ethanol Cost



8. Composition vs. Plant Anatomy



9. ANOVA: University of Wisconsin Samples

Example: Structural glucon (South Central zone)

Hybrid	Replicate	Galesville, WI	Fond du Lac, WI	Hancock, WI
Dekalb DKC51-88	1	32.76	33.66	32.57
	2	34.29	33.85	32.67
Mycogen 4111	1	32.22	34.33	33.39
	2	32.24	34.13	34.39
Northrup King N58-D1	1	33.36	34.00	33.59
	2	31.26	34.66	33.92
Pioneer 37H26	1	32.44	35.77	33.09
	2	32.12	35.56	31.86
Pioneer 37H26	3	31.77	35.10	31.93
	1	32.14	35.24	32.18
Pioneer 37H26	2	32.99	33.54	32.70
	3	31.30	35.12	33.16

ANOVA: Two-factor with replication

Source of Variation	SS	df	MS	F	P-value	F crit
Rows (genetics)	0.5644	3	0.18813	0.41495	0.7438103	3.00879
Columns (environment)	30.6548	2	15.3274	33.8064	1.04E-07	3.40283
Interaction (G x E)	9.92103	6	1.65351	3.64701	0.0102649	2.50819
Within	10.8813	24	0.45339			
Total	52.0215	35				

Summary of ANOVA results (P-values)

Constituent	Genetics	Environment	Interaction
Struc_glucon	0.744	1.04E-07	0.010
Xylan	0.015	4.30E-08	0.903
Lignin	2.02E-05	0.469	0.029
Protein	0.545	1.98E-08	0.135
Str_inorg	0.008	4.97E-06	0.142
Struc_glucon + Xylan	0.181	8.38E-06	0.175

10. ANOVA: USDA/ARS, Lincoln Samples

Example: Xylan

Hybrid	Replicate	No fertilizer	Irrigated fertilizer
Pioneer 3162	1	16.31	17.42
	2	19.01	15.24
Pioneer 3394	1	17.39	21.22
	3	17.39	18.14
Pioneer 33R88	2	18.63	19.89
	3	20.71	17.97
Pioneer 34G82	1	18.98	17.74
	2	18.21	18.99
B73 x Mo17	1	19.32	20.22
	3	20.85	16.25
B73 x Mo17	2	17.13	18.75
	3	20.45	19.36
B73 x Mo17	1	20.66	19.72
	2	17.64	18.80
B73 x Mo17	3	18.87	19.16

ANOVA: Two-factor with replication

Variation	SS	df	MS	F	P-value	F crit
Sample	14.8383	4	3.70957	1.79713	0.14845	2.60597
Columns	60.4766	3	20.1589	9.7661	5.8E-05	2.83875
Interaction	78.5386	12	6.54488	3.17072	0.00298	2.00346
Within	82.5666	40	2.06417			
Total	236.42	59				

Summary of ANOVA results for major constituents

Constituent	Genetics	Environment	Interaction
Struc_glucon	1.06E-07	1.28E-05	0.175
Xylan	0.148	5.81E-05	0.063
Lignin	0.002	0.062	0.112
Protein	1.46E-06	9.45E-11	0.435
Str_inorg	0.171	0.355	0.014
Struc_glucon + Xylan	0.001	0.002	0.086

11. Summary and Conclusions

- Corn stover composition varies widely
- Total structural carbohydrates range from 45.3–68.5%
- Statistically normal distributions for most major constituents
- Stover composition has a large influence on Minimum Ethanol Selling Price (MESP)
- The stover composition used to produce the most recent ethanol process economic model is overly optimistic
- A few weak correlations between constituent pairs
 - Struc_glucon positively with Lignin ($r^2 = 0.60$)
 - Struc_glucon inversely with Protein ($r^2 = 0.69$)
 - Xylan inversely with Str_inorganics ($r^2 = 0.47$)
 - Struc_glucon inversely with Soluble Solids ($r^2 = 0.56$)
 - Lignin inversely with Soluble Solids ($r^2 = 0.58$)
 - All other pairs are not correlated
- Preliminary analysis of variance results indicate that stover composition varies as a function of:
 - Genetics
 - Location grown (environmental influences)
 - G x E interaction



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