Improving Forage Corn Quality

Improving Forage Quality-Related Characteristics of Corn

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Introduction

Forage corn, preserved as whole-plant silage, can be a high-energy component of ruminant diets. Corn is grown mainly for grain in the US Corn Belt, but in many shorter-season locations, such as Europe, Canada, and the northern USA, it is grown primarily for forage. Whether corn will be harvested for whole-plant forage or grain is often not known at planting in much of the U.S. Corn Belt. The decision often depends on the availability of perennial forages such as alfalfa. Severe winters, resulting in winter kill of perennial forages, or a summer drought can reduce forage supply and result in more corn being harvested for forage. Usually 8 to 10% of the US corn crop is harvested as whole-plant forage for silage (Coors et al. 1994).

Corn silage is becoming more important in dairy rations. It is valued because of its high yield, ability to make excellent silage, and it can be harvested in a single operation without significant leaf loss. Increased use of no-till practices has reduced the soil erosion potential associated with growing forage corn. Corn stover (aboveground vegetation less ears) after grain harvest is also an important feed resource for beef cattle and sheep either as grazed forage or for feed after being conserved by baling (Irlbeck et al. 1993).

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For the reasons noted by Jung and Buxton in these proceedings, the CellWall Group of the US Dairy Forage Research Center began studying fiber characteristics of corn several years ago. We review our work in this report. First, we describe some of the factors that limit digestibility of forage corn. Next, we characterize the enormous amount of genetic variation for most forage

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quality-related traits within public elite Corn Belt inbreds. Finally, we discuss the potential for developing improved corn hybrids for forage by selecting among elite Corn Belt inbreds.

Corn Hybrids for Forage

Development of elite corn hybrids specifically for forage has had low priority in the USA, although some companies now test their hybrids for forage quality traits and report this information to potential customers**.** Often hybrids with high grain yields and high grain-to-stover ratios are recommended as most suitable for forage. Grain contains a large amount of starch, which is highly digestible. Nonstructural carbohydrate concentration of corn stover is inversely related to grain content of the forage because nonstructural carbohydrates are translocated from the stem to the developing grain. The more grain produced, the more nonstructural carbohydrates translocated out of the stems. Nonstructural carbohydrates increase the digestibility of stover when they are present. So, digestibility of whole-plant forage corn may be only minimally affected by the grain-to-stover ratio (Russell et al. 1992). Additionally, unlike other species, corn forage quality is only minimally affected by plant maturity because the highly digestible grain compensates for the decline in quality of the stover fraction with advancing maturity.

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Nearly half the above ground dry matter of corn is stover (Irlbeck et al. 1993). Thus, it is not surprising that stover digestibility has a large influence on corn forage quality. Stover digestibility, in turn, is related to fiber (cell-wall) concentration and fiber digestibility of stems and leaves. Fiber concentration in corn stover is high, as is the situation for most C_4, warm-season species.

Stover Digestibility

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Corn forage can be improved through selection for decreased fiber concentration or increased rate or extent of fiber digestion (Jung and Allen 1995, Buxton et al. 1996). Decreasing fiber concentration of forages and/or increasing fiber digestibility can increase dry matter intake and animal performance. Theoretical models have shown that increasing fiber digestion rates may improve fiber digestibility by permitting a greater extent of digestion before particles pass from the rumen (Allen and Mertens 1987).

Cell-Wall Chemical and Structural Impact

Several chemical and structural features have been identified that may limit fiber digestibility. Of these, lignin is most prominently mentioned (Jung and Deetz 1993). As discussed by Jung and Buxton in these proceedings, lignin is thought to interfere with microbial degradation of fiber polysaccharides by acting as a physical barrier. Recently, the importance of cross-linking of lignin to polysaccharides by ferulate bridges has been implicated as an additional factor inhibiting digestion of grass cell walls.

Plant cell walls provide structure, rigidity, and protection from environmental stresses and pests (Buxton and Casler 1993). Lignin is necessary to provide mechanical support for stems and leaf blades and to impart strength and rigidity to plant walls. Also, much evidence shows that lignin and lignin-like compounds along with other cell-wall constituents provide resistance to diseases, insects, cold temperatures, and other biotic and abiotic stresses. So, practical limits exist about how much lignin and other cell-wall constituents can be reduced in corn through breeding to improve digestibility without adversely affecting the ability of corn to grow and survive in field environments. For example, a reduction in fiber and lignin concentration can reduce field survival of perennial forages (Buxton and Casler 1993, Buxton et al. 1995). Ideally, walls should provide protection and strength, yet be highly digestible by ruminants.

Modern corn hybrids have been selected for increased stalk strength and lodging resistance. Because these are also mediated through cell-wall characteristics, concern has been expressed about the potential for reduced forage

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quality in modern hybrids. These relationships were examined by Albrecht et al. (1986). They found that selection to improve stalk mechanical strength or resistance to *Diplodia* stalk rot increased total nonstructural carbohydrate concentration, which diluted fiber concentration and increased digestibility. On the other hand, Buendgen et al. (1990) showed that European corn borer susceptibility may increase if plant fiber and lignin concentrations are reduced in plant sheaths.

Fiber composition and digestibility vary immensely within leaves and stems, and often vary with cell type. Cell types differ greatly in chemistry and digestion characteristics. Sclerenchyma, vascular tissue, and sometimes stem parenchyma and stem epidermis are digested very slowly and contain a substantial indigestible component. These tissues have thick walls and are the most highly lignified. Wilson and Mertens (1995) presented evidence that anatomical features of thick-walled cells may be equally important as lignin in limiting fiber digestion of grasses like corn. They identified five structural limitations to fiber digestion in grass species: 1) microbial degradation can proceed only from the interior of lignified, thick-walled cells because the lignified middle lamella and primary wall are indigestible, 2) particles pass from the rumen quickly in comparison with the digestion rate so that not more than 20% of thick-walled cells can be digested, 3) access to cell interiors is not instantaneous because many cells comprising fiber particles are not exposed or disrupted by mastication, 4) digestion of thick-walled parenchyma and sclerenchyma cells is limited by their low surface area/volume ratio, and 5) phenolic-carbohydrate compounds may be toxic to fiber degrading bacteria on a microclimate level within cells, though average levels in the rumen are not high enough to be toxic.

The rind of corn is about 1.5 mm thick and composed of densely packed sclerenchyma and vascular bundles embedded in parenchyma cells (Buxton and Casler 1993). The lignin concentration of the rind is several times greater than that of the interior pith and much lower in digestibility (Morrison, Jung, and Buxton unpublished). Genetic variation exists for rind thickness and digestibility of both the rind and pith (Buxton and Casler 1993). So, it may be possible to modify pith and rind digestibility independently of each other.

Identification of Superior Inbreds

We evaluated 45 inbred lines, most of which were elite lines for grain production in the US Corn Belt, for in vitro digestibility and fiber components (Lundvall et al. 1994). Three of the inbred lines were brown-midrib mutants, which are known to have reduced lignin concentration and high digestibility. Leaf blades and elongated basal stem internodes were sampled near silking and stem internodes were sampled again near physiological maturity.

We found large variation in digestibility among these lines (Table 1). Inbred variation was greatest in late-harvest stems and least in leaf blades, similar to our results with other species (Buxton and Casler 1993). Neutral detergent fiber (NDF) concentrations ranged from 48.9 to 66.5% in stems at silking, 51.7 to 60.2% in leaf blades, and 51.0 to 79.1% in stems at physiological maturity. Acid detergent lignin, expressed as a percentage of NDF (lignin/NDF), ranged from 5.6 to 9.6% in stems at silking, 5.4 to 10.1% in leaf blades, and 6.8 to 11.3% in stems at physiological maturity.

At silking, stem and leaf digestibility were only weakly correlated among the

Table 1.
Summary of in vitro drymatter digestibility of 45 corn inbred lines (Lundvall et al. 1994).

	In vitro dry matter digestibility		
		Stems	
	Leaves	Silking	Physiological maturity
	---------------- % of dry matter ------------------		
Minimum	58.0	46.5	26.2
Average	63.0	62.1	47.1
Maximum	67.6	72.7	65.0

"... rate of digestion of the potentially digestible NDF among the inbreds varied from 0.026 to 0.096 h^{-1} ..."

inbreds (r = 0.31). Additionally, digestibility of stems at silking and physiological maturity were also weakly correlated (r = 0.40). Thus, these results suggest that selection could be made at the time of normal silage harvest using either the whole plant or stover. These weak correlations suggest the possibility of modifying digestibility and cell-wall constituents of plant parts independently of each other.

From half to two-thirds of the variability in stem digestibility was accounted for by variation in NDF concentration (Lundvall et al. 1994). Equations relating these two variables were:
Silking:
$y = 123 - 1.05x$ $r^2 = 0.54$,
Physiological maturity:
$y = 122 - 1.11x$ $r^2 = 0.67$,
where y equals in vitro digestibility and x equals NDF concentration. Lignin/NDF in a multiple regression with NDF explained an additional 13 to 17% of the variation in stem digestibility. NDF and lignin/NDF, however, accounted for only 31% of the variability in leaf digestibility.

In further evaluation of the stems harvested at silking, we found only a weak relationship between cell-wall polysaccharide degradation and a multiple regression model of principal components associated with cell-wall lignification (Jung and Buxton 1994). As Jung and Buxton note in these proceedings, the relationship between fiber digestibility and lignin concentration is often low when genetic materials of a common maturity are compared. This has caused us to plan experiments to evaluate several inbreds for variation in the influence of structural and anatomical features on digestibility of stems.

Rate of Digestion

In other work with these inbred samples, rate of digestion of the potentially digestible NDF among the inbreds varied from 0.026 to 0.096 h^{-1} (Hintz, Mertens, Buxton, and Jung, unpublished). Although brown midrib inbreds are thought to be superior to normal lines for digestibility, we found normal inbreds that equaled or exceeded the brown midrib lines for both extent and rate of fiber digestion. These results suggest that improving digestibility of corn stalks by selecting within agronomically superior inbreds without incorporation of undesirable agronomic characteristics associated with the brown midrib trait should be possible. Brown-midrib plants usually have a lower yield and more lodging than normal plants. We found genotype *x* year effects for both extent and rate of fiber digestion, which suggests that multiple environments will be required to accurately characterize these inbreds for digestion parameters.

The resources and amount of work required when in vitro digestion analysis is used has been a factor limiting development of corn lines with improved digestion kinetics. Near infrared reflectance spectroscopy (NIRS) has been used to estimate other forage quality traits. We found NIRS to be more accurate in predicting extent of digestion than in predicting rate of digestion (Hintz, Mertens, Buxton, and Jung, unpublished). The accuracy was sufficient, however, that we believe NIRS can be used for initial screening of corn lines. We also found digestion of potentially digestible fiber at 24 h was highly correlated with rate of fiber digestion (r=0.87). Thus, it may also be possible to identify corn inbreds with fast digestion rates with few in vitro analyses. Depending

Table 2.
In vitro dry matter disappearance (IVDMD), neutral detergent fiber (NDF), and lignin/NDF of parental inbred forage maize lines (Redfearn, Buxton, Hallauer, and George, unpublished).

	IVDMD		Neutral detergent fiber		Lignin/NDF	
Inbred	Stover	Whole-plant	Stover	Whole-plant	Stover	Whole-plant
	% DM				% NDF	
B57	55.4	65.7	67.2	54.2	7.7	7.0
R227	54.5	64.8	67.2	55.2	7.6	6.7
NC258	59.5	63.7	60.8	56.2	7.2	7.2
Mo17	56.7	64.8	66.7	54.2	7.0	6.9
N28	54.4	60.8	64.1	58.7	7.5	7.2
B94	51.9	65.3	67.9	53.7	8.0	7.3
NC272	53.7	61.6	68.4	59.6	6.9	6.6
B52	51.2	57.8	67.0	60.0	8.1	7.6
B64	51.9	59.7	67.5	60.5	8.1	7.5
NC262	54.8	62.4	65.7	56.7	7.1	6.9
B79	54.9	65.0	65.4	54.4	7.6	7.3
LAN496	57.7	68.2	70.1	56.2	6.0	5.9
LSD (0.05)	2.1	1.9	2.2	2.5	0.6	0.6

Table 3.
In vitro dry matter disappearance (IVDMD), neutral detergent fiber (NDF), and lignin/NDF of hybrid forage maize lines (Redfearn, Buxton, Hallauer, and George, unpublished).

	IVDMD		Neutral detergent fiber		Lignin/NDF	
Hybrid	Stover	Whole-plant	Stover	Whole-plant	Stover	Whole-plant
	% DM				% NDF	
B57xNC258	52.3	63.2	68.4	53.2	7.9	7.8
R227xB94	52.2	65.0	69.5	52.1	7.4	6.8
N28xMo17	51.2	66.0	70.1	50.0	7.8	7.6
NC272xB52	50.5	61.3	68.3	56.0	8.0	7.5
B64xNC262	48.9	63.1	71.3	53.2	7.8	7.1
B79xLAN496	49.5	66.4	72.7	51.1	7.0	6.0
B57xB52	51.6	62.2	69.1	54.4	7.2	7.0
NC258xNC272	53.4	63.0	66.9	53.7	7.7	7.2
B79xMo17	52.6	66.0	70.7	51.3	7.1	6.8
N28xNC262	49.4	61.2	70.6	55.4	8.3	7.4
B64xB94	50.1	63.2	71.8	54.4	7.6	7.1
R227xLAN496	51.9	63.9	71.7	54.3	6.9	5.9
LSD (0.05)	1.9	2.2	2.1	2.7	0.6	0.5

upon the heritability of these traits and the impact that heterosis has on the progeny of superior inbred lines, it should be possible to genetically improve the fiber digestibility of corn hybrids.

High heritabilities have been reported for most forage quality traits in corn (Coors et al., 1994). These authors concluded that corn inbreds should be evaluated for forage quality characteristics rather than estimating general combining ability effects of forage quality parameters in testcross evaluations. They further suggest that the emphasis in hybrid testing should be for grain yield, maturity, and lodging resistance.

Developing Improved Hybrids

We developed 12 single-cross hybrids from 12 of the inbreds described by Lundvall et al. (1994). Six inbreds were selected for high digestibility and six were selected for low digestibility. Each inbred was used twice as parents. Three hybrids were developed by crossing two inbreds with high digestibility and three were developed by crossing two inbreds with low digestibility. The remaining six hybrids were developed by crossing high digestibility inbreds with low digestibility inbreds.

Forage quality characteristics of stover and whole plants were subsequently measured on the inbreds and hybrids when the plants were near physiological maturity. Grain and stover yield were also measured (Redfearn, Buxton, Hallauer, and George, unpublished). Variation for in vitro digestibility, NDF, and lignin/NDF was greater for stover and whole-plant forage of the inbreds than for the hybrids (Tables 2 and 3). Whole-plant forage had more variation than stover, except NDF of the inbreds. The range in inbred stover digestibility was 8.3 percentage units, whereas the range for whole-plant forage was 10.4 percentage units (Table 2). This compares with ranges of 4.5 and 5.2 percentage units for stover and whole-plant forage, respectively, in the hybrids (Table 3).

Significant correlations existed between mid-parent values and derived hybrids for in vitro digestible dry matter (IVDDM) and NDF concentration in both whole plants and in stover (Fig. 1). The correlations were higher in whole plants than in stover.

In the stover, indigestible NDF of the hybrids ranged from 20.4 (NC258 x NC272) to 22.3% (B64 x B94 and B79 x LAN496) of dry matter and that in the inbreds from 15.9 (NC258) to 20.7% (B94). The ratio of NDF digestibility at 24 h to that at 96 h (an index for rate of fiber digestion) ranged from 0.77 (LAN496) to 0.83 (NC258) in the inbreds and 0.73 (B64 x NC262 and B79 x LAN496) to 0.79 (NC258 x NC272) in the hybrids. While these differences are not as large as the differences in digestion rate found for stem bases, they show potential for improving digestion rate in the total stover. They also show agreement between inbred and hybrid characteristics.

NDF concentration explained less than 40% of the variation in stover digestibility of both the inbreds and hybrids in this study. However, NDF concentration explained 62% of the variation in inbred whole plants and 78% in hybrid whole plants. The consistently negative relationship between fiber concentration and digestibility suggests that reduction in NDF concentration can be an effective means for initially improving digestibility of corn stover.

We are presently evaluating a large number of single-cross hybrids to learn if the negative relationship between digestibility and fiber concentration continues to be important. We are also evaluating these hybrids for variation in rate and extent of fiber digestion with the goal of using some of them in a feeding trial to examine the importance of fiber digestion rate vs. extent of digestion. Until now little experimental evidence has been available concerning the relative importance of each.

Because reduction in cell-wall characteristics can also affect agronomic performance, caution must be exercised not to reduce cell-wall concentration below critical levels. This may be especially important for fiber levels in sheaths for European corn borer resistance. To make greater improvements in digestibility of the stover, more targeted improvements will likely be necessary as discussed by Jung et al. in these proceedings. Because dual use of corn for grain production and for forage will continue to be important, we believe that successful new hybrids used for forage will require high grain yields plus improved forage quality characteristics. There may be much potential for further improvements in forage quality traits of U.S. hybrids by developing breeding programs with this goal.

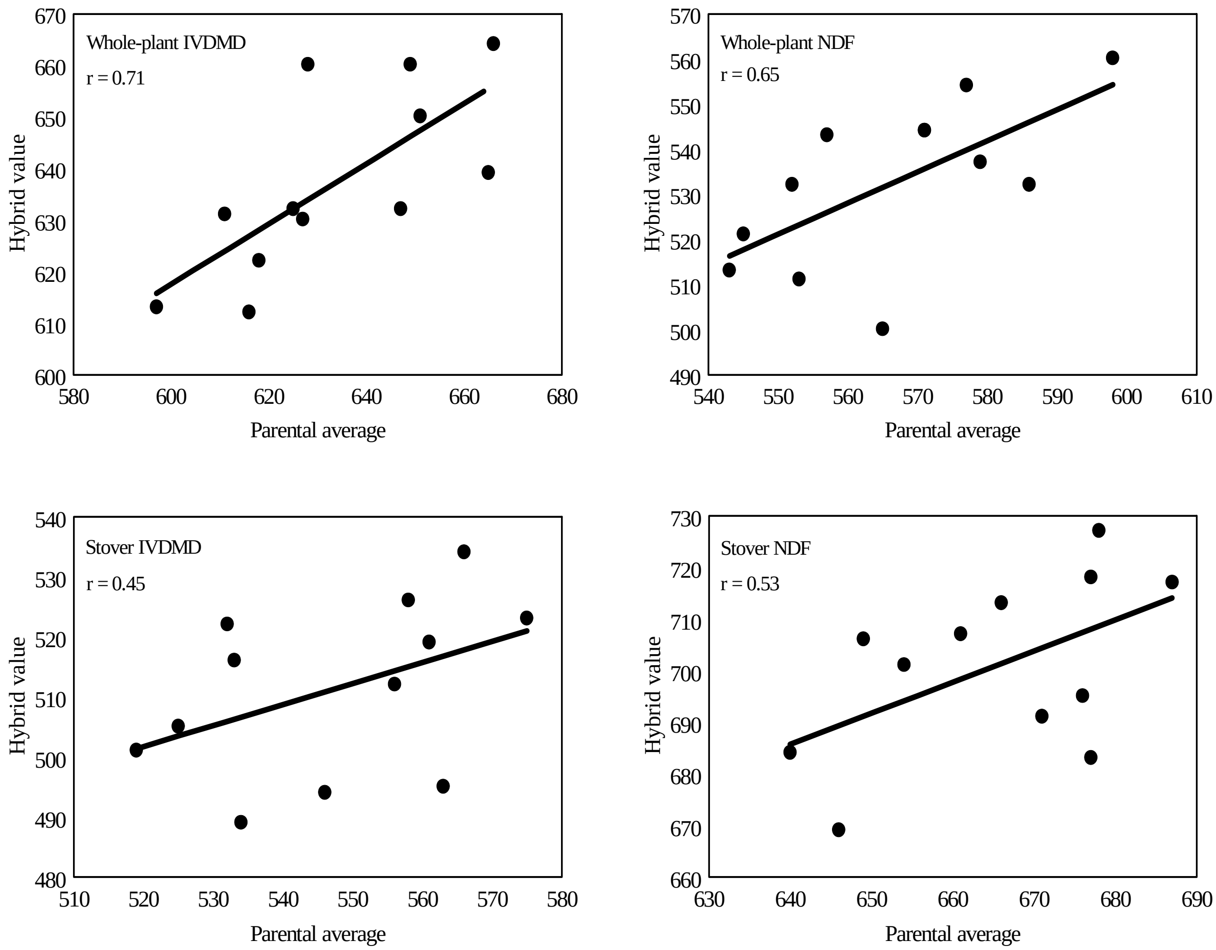

Figure 1. Whole-plant and stover IVDMD and NDF comparisons of inbred parental averages and derived hybrid values.

References

Albrecht, K.A., M.J. Martin, W.A. Russell, W.F. Wedin, and D.R. Buxton. 1986. Chemical and in vitro digestible dry matter composition of maize stalks after selection for stalk strength and stalk-rot resistance. Crop Science. 26:1051-1055.

Allen, M.S., and D.R. Mertens. 1987. Evaluating constraints on fiber digestion by rumen microbes. Journal of Nutrition 118:261-170.

Buendgen, M.R. J.G. Coors, A.W. Grombacher, and W.A. Russell. 1990. European corn borer resistance and cell wall composition of three maize populations. Crop Science 30:505-510.

Buxton, D.R., and M.D. Casler. 1993. Environmental and genetic effects on cell-wall composition and digestibility. *In* H.G. Jung, D.R. Buxton, R.D. Hatfield, and J. Ralph, eds., Forage Cell Wall Structure and Digestibility, pp. 685-714. ASA, CSSA, and SSSA, Madison, WI.

Buxton, D.R., D.R. Mertens, and D.S. Fisher. 1996. Forage quality and ruminant utilization. *In* L.E. Moser, D.R. Buxton, and M.D. Casler, eds., Cool-Season Forage Grasses, pp. 229-266. ASA, CSSA, and SSSA, Madison, WI.

Buxton, D.R., K.P. Vogel, M.D. Casler, and K.J. Moore. 1995. Field survival of perennial forages divergently selected for digestibility. *In* Agronomy Abstracts, p. 163. American Society of Agronomy, Madison, WI.

Coors, J.G., P.R. Carter, and R.B. Hunter. 1994. Silage corn. *In* A.R. Hallauer, ed., Specialty Corns, pp. 305-340. CRC Press, Boca Raton, FL.

Irlbeck, N.A., J.R. Russell, A.R. Hallauer, and D.R. Buxton. 1993. Nutritive value and ensiling characteristics of maize stover as influenced by hybrid maturity and generation, plant density and harvest date. Animal Feed Science and Technology 41:51-64.

Jung, H.G., and M.S. Allen. 1995. Characteristics of plant cell walls affecting intake and digestibility of forages by ruminants. Journal of Animal Science. 73:2774-2790.

Jung, H.G., and D.R. Buxton. 1994. Forage quality variation among maize inbreds: Relationships of cell-wall composition and in-vitro degradability for stem internodes. Journal of the Science of Food and Agriculture 66:313-322.

Jung, H.G., and D.A. Deetz. 1993. Cell wall lignification and degradability. *In* H.G. Jung, D.R. Buxton, R. D. Hatfield, and J. Ralph, eds., Forage Cell Wall Structure and Digestibility, pp. 315-346. ASA, CSSA, and SSSA, Madison, WI.

Lundvall, J.P., D.R. Buxton, A.R. Hallauer, and J.R. George. 1994. Forage quality variation among maize inbreds: In vitro digestibility and cell-wall components. Crop Science 34:1672-1678.

Russell, J.R., N.A. Irlbeck, A.R. Hallauer, and D.R. Buxton. 1992. Nutritive value and ensiling characteristics of maize herbage as influenced by agronomic factors. Animal Feed Science and Technology 38:11-24.

Wilson, J.R., and D.R. Mertens. 1995. Cell wall accessibility and cell structure limitations to microbial digestion of forage. Crop Science 35:251-259.