Forage Quality of Maize Genotypes Selected for Extreme Fiber Concentrations

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ABSTRACT

An understanding of the factors and relationships affecting whole-plant digestibility is needed to improve the nutritional quality of maize (*Zea mays* L.) forage. The objectives of this study were to: (i) determine the ranges among 24 maize genotypes for fiber composition and digestibility of stover and whole-plant forage, and (ii) determine the relationships between fiber composition and digestibility. Twenty-four $S_{0.1}$ families (S_0-derived families in S_1) exhibiting a range in neutral detergent fiber (NDF) and lignin at mid-flower, were testcrossed to two commercial inbred lines (FR23 and LH74) to form two groups of F_1 hybrids. A third experimental group was created by self-pollinating the $S_{0.1}$ families to form $S_{0.2}$ families. These germplasms were evaluated in three Wisconsin environments. Ranges in $S_{0.2}$ family means for fiber and digestibility were: NDF, 439 to 582 g kg^{-1} for the whole plant and 579 to 654 g kg^{-1} for the stover; and in vitro true digestibility (IVTD), 714 to 820 g kg^{-1} for the whole plant and 689 to 757 g kg^{-1} for the stover. Narrower ranges were observed among LH74 and FR23 testcrosses. For $S_{0.2}$ families, correlation coefficients for stover IVTD with stover NDF and lignin were −0.76 and −0.85, respectively. Correlation coefficients for whole-plant IVTD with stover IVTD and lignin of $S_{0.2}$ families were 0.44 and −0.49, respectively. The results of this study show that (i) significant variation exists for nutritional quality traits of the stover and whole-plant forage and (ii) stover quality is an important factor influencing whole-plant nutritional quality within the germplasm studied.

FORAGE MAIZE DIGESTIBILITY is influenced by both grain content and stover digestibility (Deinum and Bakker, 1981; Hunt et al., 1992; Vattikonda and Hunter, 1983). The future genetic improvement of maize silage quality will most likely focus on stover composition and digestibility (Deinum and Struik, 1989; Dolstra and Medema, 1990). Broad ranges exist for NDF, ADF, and lignin of the stover, within and between maize populations (Beeghly, 1990). Sufficient genetic variation may exist for improving the nutritional value of maize used for silage.

Hunt et al. (1992) evaluated six commercial maize hybrids to determine the extent of variation for nutritional quality and found differences among commercial hybrids for both stover and whole-plant tissues. Hybrids with equal grain yield can have large differences in nutritive value. Therefore, selection criteria for silage hybrids should include whole-plant grain content and stover fiber content.

Elevated concentrations of NDF, ADF, lignin, and silica in maize stover are positively correlated with resistance to second generation European corn borer (ECB) (*Ostrinia nubilalis*, Hubner) (Buendgen et al., 1990; Coors, 1987, 1988). Five cycles of S_1 selection for first and second generation ECB resistance in the BS9(CB) population were accompanied by increases in NDF, ADF, lignin, and ash concentrations in the leaf sheath and stalk (Buendgen et al., 1990). Because maize breeders often screen inbreds for ECB resistance, this may decrease whole-plant nutritive value of such germplasm when used for silage.

Two maize populations, WFISIHI and WFISILO, were developed at the Univ. of Wisconsin to study the effects of cell wall composition on insect resistance (Buendgen et al., 1990). The populations were created to express extreme fiber and lignin concentrations. They are, therefore, likely to be useful in examining relationships between fiber composition and digestibility characteristics in stover and whole-plant forage.

The focus of the current research is to evaluate selected genotypes from three populations [WFISIHI, WFISILO, and BS9(CB)] for fiber composition and digestibility of stover and whole-plant forage. The objectives of this study were to: (i) determine the ranges that exist among these genotypes for fiber composition and digestibility of stover and whole-plant tissue harvested as forage, and (ii) determine the relationships between fiber composition and digestibility, both within and between stover and whole-plant tissues.

MATERIALS AND METHODS

Germplasm

Germplasm used in this study originates from three maize populations: BS9(CB)C2, WFISILO, and WFISIHI. The BS9(CB) synthetic was developed at Iowa State Univ. as the base population for S_1 recurrent selection to improve both first- and second-generation ECB resistance (Russell and Guthrie,

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Abbreviations: ADF, acid detergent fiber; CP, crude protein; CWD, cell wall digestibility; ECB, European corn borer; IVTD, in vitro true digestibility; NDF, neutral detergent fiber; NIRS, near-infrared reflectance spectroscopy.

1982). Second-cycle (C2) germplasm from BS9(CB) was used for this experiment.

Populations WFISILO (Wisconsin fiber silica low) and WFISIHI (Wisconsin fiber silica high) were developed at the Univ. of Wisconsin-Madison to be low and high, respectively, in NDF, lignin, and silica concentrations of the leaf sheath. Each population was developed from a wide array of germplasm previously described by Buendgen et al. (1990).

One-hundred $S_{0.1}$ families of each population were evaluated for NDF and lignin concentrations of leaf sheath and stalk tissue at mid-flower in 1988. Based on these analyses, eight $S_{0.1}$ families per population were selected for this study. Four families were selected on the basis of high NDF and lignin concentrations; four families, low NDF and lignin concentrations. Therefore, within each population there are two subpopulations, "hi" and "lo", each composed of four families. The $S_{0.1}$ families selected from WFISIHI generally had highest concentrations of fiber components, and those from WFISILO had the lowest concentrations for stalk and leaf sheath tissue. Generally, families from BS9 were intermediate between the other two populations. The WFISIHI-hi subpopulation had the highest concentrations of fiber components, while WFISILO-lo had the lowest concentrations.

In 1989, the 24 $S_{0.1}$ families were testcrossed to two commercial inbreds, FR23 and LH74, to form two experimental groups of F_1 hybrids. At least 10 plants from each $S_{0.1}$ were used to make the testcrosses. A third experimental group was created by selfing at least 10 plants from each $S_{0.1}$ family to form bulk $S_{0.2}$ families. Testcross and $S_{0.2}$ families were evaluated to determine how fiber composition and digestibility traits are passed from partially inbred lines to hybrids.

Field Experiments

The FR23 and LH74 hybrid trials and $S_{0.2}$ family trials were treated as three independent field experiments. This was done for two reasons. First, we wanted to evaluate the $S_{0.2}$ families without competition from the more vigorous testcrosses. Second, LH74 and FR23 inbred testers have different maturities, so forage harvests of the two sets of testcrosses were expected to take place at different times.

Forage trials were conducted to evaluate the germplasm for fiber composition and digestibility of the stover and whole-plant dry matter. These trials were grown for each experimental group at Madison and Arlington, WI, in 1990 and at Madison in 1991. Soil type at both locations is Plano silt loam (fine-silty, mixed mesic Typic Arguidoll). The experimental design for all trials was a randomized complete block with three replications.

Trials were machine-planted in two-row plots 5.5 m long with 0.76 m between rows. Final plant population was approximately 57 400 plants ha^{-1}. In 1991, trials involving $S_{0.2}$ families were double planted with jab planters and thinned to 57 400 plants ha^{-1}. This was done to alleviate problems of thin stands that occurred for several $S_{0.2}$ families in 1990. Plots were fertilized according to soil tests. For annual weed control, preplant incorporated applications of atrazine (6-chloro-N-ethyl-N-(1-methylethyl)-1,3,5-triazine-2,4-diamine, 2.8 kg ha^{-1}) and alachlor (2-chloro-N-(2,6-diethylphenyl)-N-(methoxymethyl) acetamide, 2.2 kg ha^{-1}) were applied in 1990 and cyanazine (2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2yl] amino]-2-methylpropanenitrile 2.2 kg ha^{-1}) and alachlor (2.2 kg ha^{-1}) in 1991. Rotary hoeing, cultivating, and hand weeding were used as necessary to aid weed control.

The trials were harvested when approximately 75% of the plots had a milk-line rating of 1/2 or lower (Crookston and Kurle, 1988). Before harvest, the ears were removed from one row of each plot; this row was harvested as stover and the second row as whole-plant forage. Plots were harvested with a single-row, tractor-drawn, forage chopper. Stalks were cut 18 cm above the ground. Chopped plant matter was collected in a barrel, weighed, emptied onto a tarp,, and mixed by hand. An approximate 1-kg subsample of stover and whole-plant tissue was collected from each plot and dried at 60 °C for 1 wk. These samples were used for laboratory analysis of quality traits.

Laboratory Procedures

Identical laboratory procedures were conducted separately for samples collected in 1990 and 1991. In both years, studies were conducted on four groups of samples: (i) whole-plant samples from FR23 and LH74 testcrosses, (ii) stover samples from FR23 and LH74 testcrosses, (iii) whole-plant samples from $S_{0.2}$ families, and (iv) stover samples from $S_{0.2}$ families.

Dried stover and whole-plant samples were ground with a hammer mill and reground with a UDY cyclone mill (UDY Corp., Boulder, CO) to pass a 1-mm screen. All samples were scanned on a Pacific Scientific 51A near infrared reflectance spectrophotometer (Pacific Scientific, Silver Spring, MD). Separate calibration sets were selected in 1990 and 1991 for each of the four groups of samples. Each calibration set contained 20% of the samples from that particular group.

Samples from each calibration set were analyzed for NDF, ADF, permanganate lignin, in vitro true digestibility (IVTD), and crude protein. A 0.5-g sample was used for sequential detergent analysis to determine NDF, ADF, and permanganate lignin (Goering and Van Soest, 1970). A modification to the NDF procedure was the treatment of samples with 0.1 mL of alpha-amylase (Sigma Chemical Co., St. Louis, MO, no. A-3306) during refluxing and again during sample filtration (Van Soest et al., 1991; Wiersma et al., 1993). Total N was determined using the micro-Kjeldahl method. Crude protein was calculated by multiplying total N by 6.25.

A 0.25 g sample was used to determine IVTD by a modification of the method described by Goering and Van Soest (1970). The 48-h fermentation was performed in centrifuge tubes according to Marten and Barnes (1980); however, buffer and mineral solutions described by Goering and Van Soest (1970) were used. Undigested residue was refluxed in neutral detergent solution with alpha-amylase, as described above. Neutral detergent dissolves bacterial debris and only undigested plant residue remains. Therefore, IVTD is expected to give higher digestibilities than in vitro dry matter digestibility procedures such as the Tilley and Terry method. Schmid et al. (1975) reported a strong association ($r = 0.85$), between IVTD and the Tilley and Terry method.

Using modified partial least squares, near infrared prediction equations were developed for NDF, ADF, lignin, IVTD, and crude protein (Shenk and Westerhaus, 1991). Cell wall digestibility (CWD) for each sample was calculated using NDF and IVTD (Van Soest, 1982). Criteria used to select prediction equations were high coefficients of multiple determination and low standard errors of calibration and cross validation. Coefficients of multiple determination (R^2) exceeded 0.9 in most cases, and standard errors of calibration (SEC) and cross validation (SECV) were generally less than 3% and 4%, respectively, of the predicted trait mean. The primary exception was lignin concentration, which tended to have lower R^2 and higher SEC and SECV than other traits.

Statistical Analysis

Analyses of variance were calculated by considering each year-location combination as a separate environment. Replications and environments were considered random effects and families or testcrosses were considered fixed effects. Degrees of freedom for families or testcrosses were partitioned into single degree of freedom contrasts to make comparisons between populations, subpopulations within populations, and genotypes within subpopulations.

For testcross experiments, mean values combined across environments were generated for populations, subpopulations, and testcrosses. Least significant differences (LSDs) ($P < 0.05$)

Table 1. Mean values of forage composition traits from maize stover, for populations and subpopulations of $S_{0.2}$ families averaged from three environments. The range among 24 $S_{0.2}$ families is also shown.

	NDF†	ADF‡	Lignin	IVTD§	CP¶	CWD#
	g kg^{-1}					
Population $\bar{x}$						
BS9	613	302	32	725	86	553
WFISIHI	631	315	37	703	89	530
WFISILO	617	305	32	724	87	555
Subpopulation $\bar{x}$						
BS9-hi	624	308	34	713	89	541
BS9-lo	603	296	30	737	82	565
WFISIHI-hi	637	319	39	692	91	518
WFISIHI-lo	624	311	35	714	87	543
WFISILO-hi	624	307	33	711	88	538
WFISILO-lo	610	302	31	737	86	571
Range among families						
high	654	323	42	757	99	589
low	579	282	27	689	65	502
LSD (0.05)						
populations	7	3	2	6	ns	8
subpopulation	10	5	3	8	4	11
families	20	10	5	17	7	23
CV%	2.0	3.0	9.1	1.5	7.0	2.6

† NDF = neutral detergent fiber.
‡ ADF = acid detergent fiber.
§ IVTD = *in vitro* true digestibility.
¶ CP = crude protein.
# CWD = cell wall digestibility.

were computed for comparisons between populations, subpopulations, and genotypes. Because of missing plots in the $S_{0.2}$ family trials, least square means combined across environments were generated for populations, subpopulations, and families. Approximate LSDs were calculated for all comparisons in $S_{0.2}$ trials. Phenotypic correlations among traits were computed within each experiment. All discussions of significance refer to $P < 0.05$.

RESULTS AND DISCUSSION

Growing conditions were favorable for maize in all environments. Cool and wet conditions in May 1990 delayed planting at Madison. In contrast, May 1991 was dry and warm, which resulted in earlier planting at Madison. Above-average temperatures in May and June of 1991 stimulated early growth and resulted in early harvest dates for all trials. As a result of these different environmental conditions, significant genotype × environment interactions were observed for numerous traits within all trials. The effect of the interaction was a change in magnitude across environments. In general, a significant change in the ranking of genotypes did not occur; therefore, means combined across environments are presented.

Stover Composition

In $S_{0.2}$ and testcross trials, differences were generally found among populations and subpopulations for cell wall components (NDF, ADF, and lignin) and digestibilities (IVTD and CWD) (Tables 1 and 2). Populations did not differ for crude protein in any trial and only within the $S_{0.2}$ trial were differences found among subpopulations.

The differences among populations and subpopulations were very similar between trials. When differences existed, population WFISIHI had the highest concentrations of cell wall components and lowest digestibilities in all three trials. Populations WFISILO and BS9 were similar for most traits. Among subpopulations, WFISIHI-hi had the highest concentrations of cell wall components and lowest digestibilities. However, in the testcross trials, WFISIHI-hi was not consistently higher than all other subpopulations for cell wall components. In all trials, either BS9-lo or WFISILO-lo had the lowest cell wall concentrations and highest digestibilities. They generally did not differ from each other.

Within populations, the "hi" subpopulations generally had higher concentrations of cell wall components and lower digestibilities than corresponding "lo" subpopulations. This was consistent across all three trials; however, differences were not always significant.

The $S_{0.1}$ families selected for these experiments ex-

Table 2. Mean values of forage composition traits from maize stover, for populations and subpopulations of FR23 and LH74 testcrosses averaged from three environments. Ranges among 24 FR23 and 24 LH74 testcrosses are also shown.

	FR23 testcrosses						LH74 testcrosses					
	NDF†	ADF‡	Lignin	IVTD§	CP¶	CWD#	NDF	ADF	Lignin	IVTD	CP	CWD
	g kg^{-1}											
Population $\bar{x}$												
BS9	629	333	40	705	63	531	623	324	35	706	65	529
WFISIHI	636	340	40	698	62	527	636	335	36	696	65	524
WFISILO	625	332	39	709	61	536	620	323	35	707	65	528
Subpopulation $\bar{x}$												
BS9-hi	638	336	39	700	63	530	633	331	36	700	66	528
BS9-lo	620	329	40	709	63	532	613	318	34	712	64	531
WFISIHI-hi	640	344	40	692	63	521	642	339	37	690	66	518
WFISIHI-lo	631	337	40	704	60	533	630	331	36	703	63	530
WFISILO-hi	631	337	40	702	62	529	619	323	35	703	66	521
WFISILO-lo	619	328	37	716	60	543	621	322	34	711	64	535
Range among testcrosses												
high	647	349	43	723	72	544	649	343	37	729	72	541
low	600	315	36	686	57	514	588	299	33	687	58	509
LSD (0.05)												
populations	9	5	ns	4	ns	3	8	5	ns	4	ns	4
subpopulations	12	8	2	6	ns	4	11	7	2	6	ns	5
testcrosses	24	15	3	11	6	8	21	14	ns	12	6	10
CV%	2.6	3.3	9.0	1.2	9.0	1.6	2.2	3.4	8.7	1.3	6.9	1.6

† NDF = neutral detergent fiber. ‡ ADF = acid detergent fiber. § IVTD = *in vitro* true digestibility. ¶ CP = crude protein.
# CWD = cell wall digestibility.

Table 3. Phenotypic correlation coefficients (n = 24) among maize stover and whole-plant forage composition traits for $S_{0.2}$ families.

	Stover					Whole-plant					
	ADF†	Lignin	IVTD‡	CP§	CWD¶	NDF	ADF	Lignin	IVTD	CP	CWD
Stover:											
NDF#	0.93**	0.49**	−0.76**	−0.24	−0.42*	−0.01	0.07	0.20	0.10	−0.26	0.18
ADF		0.65**	−0.83**	−0.10	−0.57**	0.06	0.20	0.35	−0.03	−0.15	0.02
Lignin			−0.85**	0.35	−0.86**	0.28	0.44*	0.69**	−0.49*	0.29	−0.57**
IVTD				−0.26	0.91**	−0.38	−0.48*	−0.69**	0.44*	−0.14	0.39
CP					−0.51**	0.57**	0.61**	0.62**	−0.60**	0.77**	−0.52**
CWD						−0.54**	−0.63**	−0.83**	0.68**	−0.37	0.66**
Whole-plant:											
NDF							0.97**	0.78**	−0.88**	0.34	−0.61**
ADF								0.87**	−0.89**	0.40	−0.65**
Lignin									−0.89**	0.53**	−0.81**
IVTD										−0.51*	0.91**
CP											−0.58*

*,** significant at the 0.05 and 0.01 probability levels, respectively. † ADF = acid detergent fiber.
‡ IVTD = *in vitro* true digestibility. § CP = crude protein. ¶ CWD = cell wall digestibility. # NDF = neutral detergent fiber.

pressed a broad range in NDF of the stalk (158 g kg^{-1}) and leaf sheath (136 g kg^{-1}) (Beeghly, 1990). Among $S_{0.2}$ families, a smaller range of 75 g kg^{-1} for NDF of stover tissue was observed (Table 1). Ranges for IVTD were 68 and for CWD were 87 g kg^{-1}. Dolstra and Medema (1990) reported ranges of 239 g kg^{-1} for IVTD and 180 g kg^{-1} for CWD of stalk tissue in a study of 20 diverse inbred lines; however, these ranges were likely exaggerated due to large maturity differences among inbreds.

Ranges observed in the testcross trials were narrower than those observed among $S_{0.2}$ families. This was expected due to the use of a common parent within each testcross trial. For example, among 24 LH74 testcrosses the range for NDF was 61 g kg^{-1}; IVTD, 42 g kg^{-1}; and CWD, 32 g kg^{-1} (Table 2). Similar ranges were found among FR23 testcrosses. These ranges are smaller than previous observations among commercial hybrids. Vattikonda and Hunter (1983) reported an 80 g kg^{-1} range for stover in vitro dry matter digestibility (IVDMD) among 28 commercial hybrids. Hunt et al. (1992) reported a range of 138 g kg^{-1} for NDF among six commercial hybrids.

Across $S_{0.2}$ and testcross trials, increased concentrations of stover cell wall components were generally associated with decreases in stover IVTD and CWD (Tables 3 and 4). Acid detergent fiber had the strongest associations with IVTD and CWD. In general, for $S_{0.2}$ and testcross trials, NDF and lignin had slightly stronger associations with CWD than NDF. This indicates that although CWD is associated with cell wall concentration (NDF), it is more strongly associated with cell wall composition and, particularly, lignification. Crude protein was not consistently correlated with cell wall components and digestibility traits in any trial.

Whole-Plant Composition

In $S_{0.2}$ and FR23 trials, differences were found among populations and subpopulations for all traits (Tables 5 and 6). Among populations in the LH74 trial, differences were found for IVTD and CWD, while among subpopulations, differences existed for all traits except crude protein (Table 6). When differences existed within a trial, WFISIHI generally had the highest cell wall concentrations and lowest digestibilities. It also had the highest crude protein in the FR23 trial. Population WFISILO had higher digestibilities than BS9 in the $S_{0.2}$ trial, otherwise they generally did not differ.

Among subpopulations WFISILO-lo had the lowest cell wall concentrations and highest digestibilities. However, in testcross trials, WFISILO-lo was not consis-

Table 4. Phenotypic correlation coefficients (n = 24) among maize stover and whole-plant forage composition traits for FR23 testcrosses (above diagonal) and LH74 testcrosses (below diagonal).

	Stover						Whole-plant					
	NDF†	ADF‡	Lignin	IVTD§	CP¶	CWD#	NDF	ADF	Lignin	IVTD	CP	CWD
Stover:												
NDF		0.90**	0.28	−0.84**	−0.05	−0.42*	0.10	0.07	0.06	−0.48*	−0.14	−0.56**
ADF	0.96**		0.43*	−0.91**	−0.14	−0.63**	0.09	−0.08	0.17	−0.50*	0.10	−0.59**
Lignin	0.68**	0.73**		−0.39	−0.31	−0.37	0.42*	0.43*	0.54*	−0.48*	0.00	−0.26
IVTD	−0.88**	−0.94**	−0.78**		−0.15	0.84**	−0.13	−0.08	−0.20	0.65**	−0.06	0.76**
CP	−0.39	−0.42*	−0.10	0.23		−0.27	−0.03	−0.14	−0.02	−0.22	0.18	−0.31
CWD	−0.44*	−0.59**	−0.64**	0.81**	−0.02		−0.09	−0.04	−0.26	0.61**	−0.22	0.75**
Whole-plant:												
NDF	−0.04	−0.02	0.09	−0.07	0.13	−0.17		0.97**	0.73**	−0.69**	0.24	0.07
ADF	−0.04	0.01	0.09	−0.09	0.09	−0.22	0.97**		0.77**	−0.61**	0.25	0.14
Lignin	0.07	0.21	0.26	−0.35	0.03	−0.58**	0.62**	0.65**		−0.62**	0.29	−0.11
IVTD	−0.11	−0.16	−0.39	0.37	−0.39	0.56**	−0.66**	−0.63**	−0.58**		−0.11	0.68**
CP	−0.47*	−0.41*	−0.10	0.25	0.68**	−0.10	−0.02	0.04	0.15	−0.27		0.09
CWD	−0.16	−0.20	−0.41*	0.40	−0.37	0.53**	0.19	0.20	−0.08	0.61**	−0.36	

*,** significant at the 0.05 and 0.01 probability levels, respectively. † NDF = neutral detergent fiber. ‡ ADF = acid detergent fiber.
§ IVTD = *in vitro* true digestibility. ¶ CP = crude protein. # CWD = cell wall digestibility.

Table 5. Mean values of composition traits from maize whole-plant forage, for populations and subpopulations of $S_{0.2}$ families averaged over three environments. The range among 24 $S_{0.2}$ families is also shown.

	NDF†	ADF‡	Lignin	IVTD§	CP¶	CWD#
	g kg⁻¹					
Population x̄						
BS9	514	239	24	771	92	555
WFISIHI	541	256	27	751	93	539
WFISILO	512	238	21	786	90	582
Subpopulation x̄						
BS9-hi	520	244	25	765	93	550
BS9-lo	508	235	22	776	91	559
WFISIHI-hi	543	258	29	746	94	532
WFISIHI-lo	539	253	25	756	93	545
WFISILO-hi	544	250	24	761	90	559
WFISILO-lo	481	226	18	811	90	606
Range among families						
high	582	275	32	820	100	624
low	439	208	15	714	82	509
LSD (0.05)						
populations	9	5	1	7	2	10
subpopulations	12	6	2	10	3	14
families	27	13	4	20	5	28
CV%	3.9	4.0	10.1	1.9	4.3	3.0

† NDF = neutral detergent fiber.
‡ ADF = acid detergent fiber.
§ IVTD = *in vitro* true digestibility.
¶ CP = crude protein.
# CWD = cell wall digestibility.

tently higher or lower than several other subpopulations. When differences existed within a population, the "lo" subpopulation had lower cell wall concentrations and higher crude protein and digestibilities.

Ranges among all 24 $S_{0.2}$ families were 143 g kg^{-1} for NDF, 106 g kg^{-1} for IVTD, and 115 g kg^{-1} for CWD (Table 5). It is unusual that these ranges were greater than those observed for stover tissue traits. Generally, ranges in whole-plant traits are less than ranges of stover traits because of the dilution effect of grain. However, some $S_{0.2}$ families had very low grain yields (Wolf et al., 1994); therefore, whole-plant tissue was essentially composed of stover, which distorted ranges observed for whole-plant traits.

Ranges for testcross whole-plant traits were less than 50% of those observed in the $S_{0.2}$ trials. Among 24 LH74 testcrosses, ranges were 60 g kg^{-1} for NDF, 28 g kg^{-1} for IVTD, and 43 g kg^{-1} for CWD (Table 6). Similar results were observed among FR23 testcrosses. Vattikonda and Hunter (1983) reported a range of 50 g kg^{-1} for whole-plant digestibility, while Allen et al. (1990) reported ranges of 91 g kg^{-1} for NDF, 47 for IVTD, and 72 for CWD among commercial hybrids. Unlike the $S_{0.2}$ trials, whole-plant ranges in the testcrosses were similar to the ranges for stover. This is probably because grain yield was relatively more consistent across testcrosses than $S_{0.2}$ families.

For the $S_{0.2}$ trial, relationships between cell wall components and digestibilities were similar to those observed for stover. In both FR23 and LH74 testcrosses, IVTD was negatively correlated with cell wall components, but not CWD. Allen et al. (1991) also reported high correlations of IVTD with NDF ($r = 0.73$, $P < 0.01$) and NDF ($r = -0.79$, $P < 0.01$) in whole-plant forage.

The rankings of populations and subpopulations in testcrosses were similar to those observed for $S_{0.2}$ trials. This was true for stover and whole-plant forage. These similarities are supported by correlations between composition traits of $S_{0.2}$ families and testcrosses (Table 7). Therefore, within this study, hybrid performance is related to performance of partially inbred families for composition traits.

Relationships between Stover and Whole-Plant Composition

In the $S_{0.2}$ and testcross trials, no consistent correlations existed between cell wall components of the stover and whole plant (Tables 2 and 4). In general, increased stover digestibilities were associated with increased whole-

Table 6. Mean values of composition traits from maize whole-plant forage, for populations and subpopulations of FR23 and LH74 testcrosses averaged over three environments. Ranges among 24 FR23 and 24 LH74 testcrosses are also shown.

	FR23 testcrosses						LH74 testcrosses					
	NDF†	ADF‡	Lignin	IVTD§	CP¶	CWD#	NDF	ADF	Lignin	IVTD	CP	CWD
	g kg⁻¹											
Population x̄												
BS9	414	202	21	821	75	568	420	203	19	815	76	560
WFISIHI	426	207	22	813	78	562	429	206	20	811	77	559
WFISILO	416	203	20	823	76	575	425	205	19	818	77	571
Subpopulation x̄												
BS9-hi	417	203	21	818	74	563	421	203	18	813	75	556
BS9-lo	412	201	21	824	77	573	420	203	19	817	77	564
WFISIHI-hi	426	207	22	811	78	558	426	205	19	810	78	555
WFISIHI-lo	425	207	21	815	77	565	431	207	20	812	76	563
WFISILO-hi	422	204	21	817	76	567	439	211	20	810	77	567
WFISILO-lo	410	201	20	829	76	583	412	199	18	825	77	575
Range among testcrosses												
high	436	212	22	834	80	588	452	215	20	830	83	582
low	395	192	18	807	70	548	392	187	18	802	73	539
LSD (0.05)												
populations	7	4	1	3	1	7	ns	ns	ns	3	ns	8
subpopulations	10	5	1	4	2	10	11	6	1	4	ns	12
testcrosses	19	10	2	8	4	21	22	11	1	8	4	24
CV %	4.1	4.4	6.0	1.0	5.0	3.0	4.0	4.3	5.7	1.1	4.7	3.4

† NDF = neutral detergent fiber. ‡ ADF = acid detergent fiber. § IVTD = *in vitro* true digestibility. ¶ CP = crude protein.
# CWD = cell wall digestibility.

Table 7. Correlation coefficients for maize stover and whole-plant forage composition traits of $S_{0.2}$ families correlated with the combined mean of FR23 and LH74 testcrosses.

Trait†	Stover	Whole-plant
NDF	0.61**	0.83**
ADF	0.65**	0.73**
Lignin	0.40	0.58**
IVTD	0.74**	0.85**
Crude Protein	0.53**	0.49*
CWD	0.72**	0.62**

*,** significant at the 0.05 and 0.01 probability levels respectively.
† NDF = neutral detergent fiber.
ADF = acid detergent fiber.
IVTD = *in vitro* true digestibility.
CWD = cell wall digestibility.

plant digestibilities. In the LH74 trial, though, stover IVTD was not correlated with whole-plant IVTD or CWD. Vattikonda and Hunter (1983) reported strong correlations between stover and whole-plant digestibilities (r = 0.7 to 0.8), which exceeded those reported here. Cell wall digestibility of the whole plant should reflect stover CWD because grain has a very low cell wall concentration. This relationship is shown by the significant correlation between whole-plant and stover CWD in all trials.

For the S_2 trial, whole-plant IVTD and CWD were negatively correlated with stover lignin (Table 2). In the FR23 testcrosses, stover concentrations of both ADF and lignin were negatively correlated with IVTD of the whole plant, while only stover ADF was correlated with CWD of the whole plant (Table 4). In the LH74 trial, the only significant association between stover cell wall components and whole-plant digestibility was a negative correlation between stover lignin and whole-plant CWD.

In testcross and $S_{0.2}$ family trials, NDF and CWD were highly correlated with IVTD for stover and whole-plant fractions. Lower correlations of NDF with CWD indicated that composition of the NDF fraction influenced digestibility independent of NDF concentration. An important factor in the composition of the NDF fraction appeared to be lignin. Increased stover lignin was generally associated with decreased stover and whole-plant digestibilities in all trials.

CONCLUSION

Differences in stover and whole-plant cell wall composition and digestibility among populations and subpopulations were consistent across testcross and $S_{0.2}$ family trials. As expected, WFISIHI generally had higher concentrations of cell wall components and lower digestibility. Differences between WFISILO and BS9 varied across traits and trials. Within populations, the "hi" subpopulation generally had higher concentrations of cell wall components and lower digestibilities.

Ranges observed for nutritional quality traits of both stover and whole-plant forage were significant in most cases, but not considered large when compared to ranges reported in previous studies. Within testcross trials, ranges were smaller or comparable to those previously reported among commercial hybrids. This was not surprising because a common parent was used within each testcross.

Stover quality was found to be an important factor influencing whole-plant nutritional quality. Improvements in stover quality will be attained by decreasing cell wall concentration and increasing cell wall digestibility. Lignin is an important factor limiting cell wall digestibility. However, decreasing cell wall and lignin concentrations may have unfavorable consequences, such as increased lodging and susceptibility to European corn borer. For corn used specifically as forage, these negative effects may not be severe because it is harvested earlier than corn for grain. Our findings indicate that future efforts to improve whole-plant digestibility should concentrate on stover digestibility.

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