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CASE STUDY: Laboratory Evaluation of Corn Grain and Silage Digestibility

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ABSTRACT

The primary objective of this trial was to compare commercially available laboratory assays for assessing starch digestibility of dry (DC) and high-moisture (HMC) corn and corn silage (WPCS) using samples from 22 dairy farms. In addition, in vitro NDF digestibility (IVNDFD) in WPCS was measured at 2 incubation times (24 and 48 h). Dry matter contents of HMC and WPCS were 73.7 ± 3.7% and 35.8 ± 4.7%, respectively. The r-value from multiple regression of degree of starch access (DSA) on DM content and mean particle size for HMC was 0.78 (P < 0.0001). Dry matter content was negatively (r = –0.66) correlated (P < 0.05) to a modified in vitro ruminal plus intestinal starch degradation assay (MIVSD-RI) in HMC, but MIVSD-RI was not related (P > 0.10) to mean particle size for either HMC or dry corn. For WPCS, DSA was positively but not highly (r = 0.43) correlated (P < 0.05) with kernel processing score. The MIVSD-RI of WPCS varied minimally (98.0 ± 1.1% of starch) and was greater than DSA (93.7 ± 2.3% of starch). Average 24-h IVNDFD was 19 percentage units lower than average 48-h IVNDFD for WPCS. The r-value from regression of 24-h IVNDFD on 48-h IVNDFD was only 0.57 (P < 0.05). More comparative research of assays designed to assess starch and NDF digestibility and further research to validate results relative to in vivo digestibility data is needed. Additionally, more research on the relationship of 24- to 48-h IVNDFD and to NDF digestion and DMI is needed.

Key words: starch, fiber, digestibility, in vitro

INTRODUCTION

Starch, supplied by dry (**DC**) or high-moisture (**HMC**) corn and corn silage (**WPCS**), is an important source of energy in dairy cattle diets. The digestibility of cornstarch can be quite variable (Owens et al., 1986; Nocek and Tamminga, 1991). Although in vivo digestion studies have been useful for elucidating factors that influence starch digestibility by ruminants, such trials cannot be used to assess the extent of variation in starch digestibility across feed mills or farms.

Laboratory methods to assess the variation across WPCS samples for starch digestibility include sieving to measure the percentage of starch that passes through a 4.75 mm sieve (kernel processing score, **KPS**; Ferreira and Mertens, 2005; Mertens, 2005), enzymatic starch recovery from unground samples (degree of starch access, **DSA**; Blasel et al., 2006), and ruminal in situ or ruminal-fluid in vitro degradation of coarsely ground samples either with or without subsequent determination of in vitro enzymatic digestion of the incubation residue (modified in vitro starch degradation, **MIVSD**; Sapienza, 2002). For DC and HMC samples, DSA and MIVSD along with sieving to determine mean particle size (**MPS**) and measuring density of flaked corn have been employed. Work to compare results from the various assays now available has been limited.

In vitro NDF digestibility (**IVNDFD**) can influence DMI and milk production (Oba and Allen, 1999). Several commercial feed testing laboratories offer wet chemistry IVNDFD measurements for WPCS. The NRC (2001) recommended use of 48-h incubation for NDF digestibility appraisal to use in the NRC (2001) model. Although earlier incubation time points are preferred by the industry, little work has compared NDF digestibility values measured after different incubation time points.

Our objectives were to 1) compare selected assays available through commercial feed testing laboratories to predict starch digestibility in DC, HMC, and WPCS, and 2) compare IVNDFD in WPCS measured after 24- and 48-h incubations.

MATERIALS AND METHODS

Dry corn, HMC, and WPCS samples were obtained from feed inventories from 22 dairy farms during 2 sep-

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arate farm visits in June and July 2006. Corn silage samples were collected from all farms and 7 of the farms had 2 open silos that were sampled (n = 29). The number of farms contributing DC (n = 11) and HMC (n = 16) samples varied depending upon whether these ingredients were fed. Sample numbers by storage structure were as follows: DC — upright bin (n = 5) and flat storage (n = 6); HMC — upright silo (n = 9), silo bag (n = 2), and bunker silo (n = 5); WPCS — upright silo (n = 3), silo bag (n = 4), bunker silo (n = 17), and drive-over pile (n = 5). The farms were located in southern (n = 17), central (n = 2), and northeast (n = 2) Wisconsin and in northern Illinois (n = 1).

Ten grab samples were taken from various areas of the exposed face of the feed in the storage structure and then combined to make a large sample. This sample was mixed thoroughly and reduced to a volume of 1 L. These final samples were then placed in plastic sample bags and either mailed immediately to Dairyland Laboratories Inc. (**DLI**; Arcadia, WI) or frozen until they could be mailed for analyses. The samples from the 2 separate visits to individual farms were analyzed separately at the laboratory, and data were then averaged by storage unit within farm for presentation and analysis; the data presented herein represents variation among the farms and should not be interpreted as variation among the individual samples or analytical error.

Dry corn and HMC samples were analyzed for DM, CP, NDF, ADF, fat, and ash at DLI using near infrared spectroscopy (NIRS; ash was determined using both NIRS and total combustion at 500°C for 2 h). Energy values for DC and HMC samples were calculated using summative equations (Weiss et al., 1992). Corn silage samples were analyzed for DM, pH, CP, neutral detergent insoluble CP, NDF, ADF, lignin, fat, and ash at DLI using NIRS; ADL (Goering and VanSoest, 1970) and ash (total combustion at 500°C for 2 h) were determined using both NIRS and wet chemistry methods. Energy and milk per ton values for WPCS samples were calculated using both MILK2000 (Shaver et al., 2001a,b; Schwab et al., 2003) and MILK2006 (Shaver et al., 2006) equations. For DC, HMC, and WPCS samples, starch was measured at DLI by using wet chemistry methods as part of the DSA procedure (Blasel et al., 2006). Particle size of DC and HMC samples were determined by dry sieving at DLI using Tyler Ro-Tap Shaker Model RX-29 (Mentor, OH) and sieves with 2,360, 1,700, 1,180, 850, 600, 425, 300, 212, 150, 106, 75, and 53 mm apertures plus bottom pan. Mean particle size was calculated using a log normal distribution (Waldo et al., 1971). Corn silage particle size distributions were determined at DLI as part of the procedure for KPS (Mertens, 2005) using a Ro-Tap shaker. The WPCS KPS (Mertens, 2005) and corn grain and WPCS DSA (Blasel et al., 2006) procedures were performed at DLI. The data from the DSA assay presented herein are the estimated starch digestibility values calculated from the starch recoveries in the DSA procedure using the following equation: starch digestibility$_{DSA}$, % of starch = 78.6 + (0.1928 × DSA starch recovery, % of starch). Corn grain and WPCS samples were sent by DLI to Sapienza Analytica, LLC (Johnston, IA) for determination of MIVSD (Sapienza, 2002) as follows: samples were dried in 62°C forced-air oven to a consistent weight, ground through 6-mm Wiley Mill screen, and placed in Dacron bags incubated for 12 h in flasks filled with mixed rumen fluid from 4 cows using 8 replicates per sample; 4 replicates then were incubated in pepsin plus pancreatic enzymes for 8 h (Calsamiglia and Stern, 1995). The disappearance values were then added together to estimate ruminal plus intestinal starch degradation. The data from the MIVSD assay presented herein are classified as modified in vitro ruminal starch degradation (**MIVSD-R**) and modified in vitro ruminal plus intestinal starch degradation (**MIVSD-RI**). Corn silage samples were sent by DLI to the University of Wisconsin-Madison Soil and Plant Analysis Laboratory (Marshfield, WI) for 24- and 48-h IVNDFD determinations according to Goering and Van Soest (1970). Descriptive statistics, correlation coefficients, and regressions were determined using SAS (2001).

RESULTS AND DISCUSSION

Descriptive statistics (average, standard deviation, minimum, and maximum) are presented in the tables.

The nutrient composition of DC, HMC, and WPCS samples are presented in Table 1. Presented in Table 2 are particle size data and results from laboratory assays assessing starch digestibility for DC and HMC. Mean particle size was lower and percentage passing a coarse sieve (#16; 1,180 μ) was higher for DC than HMC. The MPS and the percentage passing a coarse sieve data had a high negative correlation ($P < 0.05$) for both DC (r = –0.94) and HMC (r = –0.96), indicating that the percentage passing the #16 sieve was a good predictor of MPS. Variation in MPS of HMC was extensive, with two-thirds of the HMC samples falling between 1,250 and 2,000 μ and with minimum and maximum values of 950 and 2,500 μ, respectively. This is likely due to the varying types of processing used for HMC on these farms and also the variation in DM content when processed. The average MPS of HMC samples ground through a hammer mill was 1,208 μ, whereas samples processed through a roller mill averaged 1,780 μ. There was no relationship ($P > 0.10$) between MPS and the DM content of HMC samples. As expected (Blasel et al., 2006), DSA had a high negative correlation ($P < 0.05$) with MPS (r = –0.72) for HMC. But, DSA was not correlated ($P > 0.10$) to either MPS or the percentage passing a coarse sieve for DC. This may have been related to the MPS range for DC vs. HMC samples (642 vs. 1,531 μ) or the relatively small number of DC samples (n = 11) in

Table 1. Nutrient composition of dry and high-moisture corn and corn silage samples measured using near infrared spectroscopy (NIRS), except for ash, which was measured using both NIRS and total combustion methods, lignin (corn silage only), which was measured using both NIRS and acid detergent lignin (Goering and Van Soest, 1970) methods, and starch, which was measured using wet chemistry during the degree of starch access procedure (Blasel et al., 2006)

Item	Units	Average	SD	Minimum	Maximum
Dry corn					
NIRS DM	% as fed	85.3	1.2	83.7	87.2
NIRS CP	% of DM	9.5	0.5	9.0	10.7
NIRS NDF		9.9	1.1	8.4	12.2
NIRS ADF		4.0	0.4	3.4	4.8
Starch		66.2	1.8	62.6	68.2
NIRS fat		3.9	0.5	3.2	5.1
NIRS ash		1.4	0.1	1.2	1.6
Total combustion ash		1.3	0.1	1.1	1.5
TDN_{maint}[1]		87.4	0.4	86.6	88.0
$NE_{l3\times}$[2]	Mcal/kg DM	2.02	0.02	2.00	2.05
High-moisture corn					
NIRS DM	% as fed	73.7	3.7	67.6	81.3
NIRS CP	% of DM	9.3	0.5	8.2	10.5
NIRS NDF		7.5	1.1	5.6	9.2
NIRS ADF		3.3	0.5	2.3	4.0
Starch		67.4	1.7	64.9	71.6
NIRS fat		3.9	0.4	2.8	4.7
NIRS ash		1.4	0.1	1.2	1.5
Total combustion ash		1.3	0.1	1.0	1.5
TDN_{maint}		88.4	0.5	87.4	89.1
$NE_{l3\times}$[2]	Mcal/kg DM	2.05	0.02	2.02	2.07
Corn silage					
NIRS DM	% as fed	35.8	4.7	29.9	51.9
NIRS pH		3.9	0.2	3.5	4.2
NIRS CP	% of DM	8.5	0.6	7.1	9.5
NIRS NDICP[3]		1.4	0.1	1.1	1.5
NIRS NDF		40.6	2.8	34.1	46.3
NIRS ADF		25.0	2.0	20.1	28.5
NIRS lignin		3.4	0.3	2.7	4.0
Acid detergent lignin		3.1	0.4	2.5	4.1
Starch		31.6	3.6	25.5	37.8
NIRS fat		3.6	0.3	3.2	4.2
NIRS ash		3.8	0.3	3.3	4.5
Total combustion ash		4.1	1.0	2.4	7.6

[1]TDN_{maint} = TDN at maintenance level of energy intake.

[2]$NE_{l3\times}$ = NE_l at 3× maintenance level of energy intake.

[3]NDICP = neutral detergent insoluble CP.

this data set. Dry matter content of HMC was negatively (r = –0.50) correlated ($P < 0.05$) to DSA in HMC. The r-value from multiple regression of DSA on DM content and MPS for HMC samples was 0.78 ($P < 0.0001$). This supports the data of Blasel et al. (2006), which showed that the DSA assay was sensitive to both particle size and moisture content of HMC. Dry matter content was negatively (r = –0.66) correlated ($P < 0.05$) to both MIVSD-R and MIVSD-RI in HMC. For HMC, correlations ($P < 0.05$) between MIVSD-R and MPS or the percentage passing a coarse sieve were only –0.39 and –0.43, respectively, and MIVSD-RI was unrelated ($P > 0.10$) to particle size. For DC, the MIVSD parameters were unrelated ($P > 0.10$) to particle size. This was not surprising because samples were ground to pass through a 6-mm screen prior to performing the in vitro starch degradation assays. Degree of starch access was unrelated ($P > 0.10$) to the MIVSD parameters in HMC, but was positively (r = 0.71) correlated ($P < 0.05$) to MIVSD-RI in DC. It is unclear why DSA was re-

Table 2. Particle size data and results from assays to assess starch digestibility for dry and high-moisture corn samples[1]

Item	Units	Average	SD	Minimum	Maximum
Dry corn					
Mean particle size	μ	670	180	407	1,049
Passing #16 sieve	% as fed	69.1	13.8	41.5	91.4
DSA	% of starch	96.4	3.4	86.9	98.9
MIVSD-R		64.3	9.3	48.7	74.3
MIVSD-RI		86.2	5.9	72.9	96.3
High moisture corn					
Mean particle size	μ	1629	377	955	2486
Passing #16 sieve	% as fed	25.0	11.7	4.7	54.9
DSA	% of starch	94.9	2.8	89.1	98.1
MIVSD-R		73.1	9.3	58.9	93.4
MIVSD-RI		87.9	8.4	74.3	98.6

[1]DSA = degree of starch access; MIVSD-R = modified in vitro ruminal starch degradation; MIVSD-RI = modified in vitro ruminal plus intestinal starch degradation.

lated to MIVSD-RI but not MIVSD-R. The MIVSD-RI values were low for both HMC and DC relative to published total tract starch digestibility values from in vivo experiments (Owens and Zinn, 2005), which may partially be explained by lack of measurement of hindgut fermentation with the MIVSD procedure (Owens et al., 1986).

Particle size data and results from assays to assess starch digestibility for WPCS are presented in Table 3. Particle size data are presented as the percentage of DM retained on 4.75- and 1.18-mm screens and the pan. On average, approximately equal parts DM were retained on the 4.75- and 1.18-mm screens with 11.2 ± 4.9% retained on the pan. Mertens (2005) suggested optimum, average, and poor KPS values of ≥ 70%, < 70% and ≥ 50%, and < 50% of starch passing through a 4.75 mm screen, respectively. Only 10% of the samples were in the optimum processing category. This agrees with Visser (2005) who reported only 10% and 7% of the samples from data sets of 252 and 55 WPCS samples, respectively, were in the optimum processing category. The consistently low percentage of samples categorized as optimally processed by the KPS procedure suggests that requiring ≥ 70% of starch passing through a 4.75-mm screen for designation as optimum kernel processing may be too rigid. It is also possible that viscous starch retained on coarse fiber particles may inappropriately reduce the starch that passes through a 4.75-mm screen or KPS for some samples (P. C. Hoffman, unpublished data). Kernel processing was categorized as poor (< 50% of starch passing through a 4.75-mm screen) in 35% of the samples. This agrees closely with the Visser (2005) in

Table 3. Particle size data and results from assays to assess starch digestibility for corn silage samples[1,2]

Item	Units	Average	SD	Minimum	Maximum
Remaining on coarse screen	% of DM	47.1	9.4	22.0	61.0
Remaining on medium screen		41.7	5.3	31.5	53.5
Remaining on pan		11.2	4.9	7.0	28.5
KPS	% of starch passing 4.75-mm screen	54.4	12.7	32.0	88.0
DSA	% of starch	93.7	2.3	90.1	97.2
MIVSD-R		89.7	5.4	75.8	98.8
MIVSD-RI		98.0	1.1	96.1	99.5

[1]Sieving was done using the Tyler Ro-Tap Shaker Model RX-29 Ro-tap: coarse screens were ≥ 4.75 mm, medium screens had openings < 4.75 mm and > 1.18 mm, and the pan retained material that passed through the 1.18 mm screen.

[2]KPS = kernel processing score; DSA = degree of starch access; MIVSD-R = modified in vitro ruminal starch degradation; MIVSD-RI = modified in vitro ruminal plus intestinal starch degradation.

which 37% of the WPCS samples were in the poor processing category when averaged across the 2 sample sets evaluated in that report. There was variation in DSA of WPCS; two-thirds of the samples fell between 91% and 96% of starch. There was also variation in MIVSD-R of WPCS; two-thirds of the samples fell between 84% and 95% of starch. The DSA and MIVSD-R average values of 94% and 90% of starch, respectively, may have been lower, and possibly the variation wider, had the WPCS samples evaluated not been in the silos for 8 months or more because starch digestibility has been shown to increase over time in storage (Newbold et al., 2006). The MIVSD-RI values varied minimally (98.0 ± 1.1% of starch). Higher MIVSD-RI values for WPCS than HMC (refer to Table 4) was not unexpected because WPCS is normally harvested at an earlier stage of kernel maturity than HMC, and the kernels in some WPCS samples may be processed finer than HMC. Degree of starch access was positively ($r = 0.43$) correlated ($P < 0.05$) to KPS. The KPS was unrelated ($P > 0.10$) to the MIVSD parameters. The lack of a KPS relationship with MIVSD parameters is likely due to samples being ground to pass through a 6-mm screen prior to performing the MIVSD procedure. Whole-plant corn silage DM content was unrelated ($P > 0.10$) to DSA and the MIVSD parameters.

Corn silage TDN, NE_L, and milk per ton values calculated using MILK2000 (regression for starch digestibility) and MILK2006 (regression, KPS, DSA, and MIVSD-RI) are presented in Table 4. As expected, average NE_l and milk per ton values were lower when using MILK2006 than when using MILK2000 due to changes in model equations (Shaver, 2006). The MILK2006 WPCS evaluation model (Shaver et al., 2006) allows spreadsheet users the option of using regression or inputting results from assays to assess starch digestibility (KPS, DSA, or in vitro) to calculate TDN, NE_l, and milk per ton. Differences in average TDN, NE_l, and milk per ton values and their variance estimates within MILK2006 when using regression, KPS, DSA, or MIVSD-RI for starch digestibility were minimal for this sample set. Further, sample rank correlations between regression and KPS, DSA, or MIVSD-RI methods of calculating starch digestibility were highly positive ($P < 0.05$) for NE_l ($r = 0.81$ to 0.92) and milk per ton ($r = 0.82$ to 0.93) values.

The MILK2006 WPCS evaluation model (Shaver et al., 2006) allows spreadsheet users the option of inputting 48-, 30- or 24-h IVNDFD data to calculate TDN, NE_l, and milk per ton. Corn silage DM digestibility and IVNDFD values measured with wet chemistry using 24- and 48-h ruminal in vitro incubations are presented in Table 5. Variation in 48-h IVNDFD

Table 4. Corn silage $TDN_{1\times}$,[1] $NE_{l3\times}$,[2] and milk per ton and calculated using MILK2000 and MILK2006 corn silage evaluation models[3,4]

Item	Method	Units	Average	SD	Minimum	Maximum
$TDN_{1\times}$						
MILK2000	Regression	% DM	75.9	0.8	72.9	76.2
MILK2006	Regression		74.5	1.0	71.3	75.1
	KPS		73.8	1.3	69.7	75.1
	DSA		73.7	0.7	72.6	74.8
	MIVSD-RI		74.9	0.3	74.3	75.1
$NE_{l3\times}$						
MILK2000	Regression	Mcal/kg DM	1.74	0.07	1.65	1.87
MILK2006	Regression		1.58	0.04	1.50	1.69
	KPS		1.58	0.07	1.45	1.67
	DSA		1.56	0.04	1.47	1.67
	MIVSD-RI		1.61	0.04	1.47	1.69
Milk per ton						
MILK2000	Regression	kg/ton DM	1,791	100	1,650	2,006
MILK2006	Regression		1,575	72	1,426	1,708
	KPS		1,551	77	1,392	1,699
	DSA		1,547	74	1,408	1,694
	MIVSD-RI		1,590	69	1,412	1,707

[1]$TDN_{1\times}$ = TDN at maintenance level of energy intake.

[2]$NE_{l3\times}$ = NE_l at 3× maintenance level of energy intake.

[3]All calculations were done using 48-h in vitro NDF digestibility data. Regression equation from Schwab et al. (2003).

[4]KPS = kernel processing score; DSA = degree of starch access; MIVSD-RI = modified in vitro ruminal plus intestinal starch degradation.

Table 5. Corn silage DM- and NDF-digestibilities (DMD and NDFD) measured with wet chemistry using 24- and 48-h ruminal in vitro incubations, and the impact of 48-h vs. 24-h in vitro NDF digestibility measurements on corn silage milk per ton calculated using the MILK2006 corn silage evaluation model[1]

Item	Incubation	Units	Average	SD	Minimum	Maximum
In vitro						
DMD	48-h	% of DM	85.7	2.3	82.0	90.6
	24-h		78.0	2.9	72.3	86.0
NDFD	48-h	% of NDF	64.6	5.1	53.5	76.4
	24-h		45.6	6.4	33.3	63.1
Milk per ton						
MILK2006	48-h	kg/ton DM	1,575	72	1,425	1,708
	24-h		1,529	85	1,259	1,659

[1]All milk per ton calculations were done using starch digestibility regression equation for processed corn silage (Schwab et al., 2003).

was extensive, with two-thirds of the samples falling between 60 and 70% of NDF and with minimum and maximum values of 54% and 76% of NDF, respectively. The average 24-h IVNDFD was 19 percentage units lower than the average 48-h IVNDFD (46% vs. 65% of NDF). But, the r-value from regression of 24-h IVNDFD on 48-h IVNDFD presented in Figure 1 was only 0.57 ($P < 0.05$). For wet chemistry lignin expressed as a percent of DM, data were negatively (r = –0.32) correlated ($P < 0.05$) with 48-h IVNDFD, but unrelated ($P > 0.10$) to 24-h IVNDFD. For NIRS lignin expressed as a percent of DM, data were unrelated ($P > 0.10$) to 48- or 24-h IVNDFD. When either wet chemistry or NIRS lignin data were expressed as a percent of NDF, data were negatively (r = –0.49 and –0.28) correlated ($P < 0.05$) with 48- and 24-h IVNDFD, respectively. The NRC (2001) equations were used to calculate NDF digestibility using NDF, lignin, and neutral detergent insoluble CP concentrations. The resultant calculated NDF digestibility data were positively but not highly correlated (Figure 2; r = 0.53 and 0.30; $P < 0.05$) with 48- and 24-h IVNDFD, respectively. These correlations were similar when NIRS instead of wet chemistry lignin data were used to calculate NDF digestibility. Results from this relatively small WPCS sample set show that 24-h IVNDFD was less related to lignin than 48-h IVNDFD, with a weak relationship between the time points. The use of 48- or 24-h IVNDFD data within the MILK2006 spreadsheet (Shaver et al., 2006) had minimal impact on the milk per ton estimates, though the average milk per ton was 46 kg lower and the standard deviation 13 kg greater when using 24-h rather than 48-h IVNDFD data (refer to Table 5). Further, the sample rank correlation for milk per ton estimates calculated using 24- or 48-h IVNDFD was only 0.64 ($P < 0.05$). This suggests that although differences in the milk per ton values between the 2 time points were small, the choice of incubation time point for IVNDFD measurement may influence sample rankings for this quality index. More research on the utility and impact of 24- vs. 48-h in IVNDFD measurements is needed.

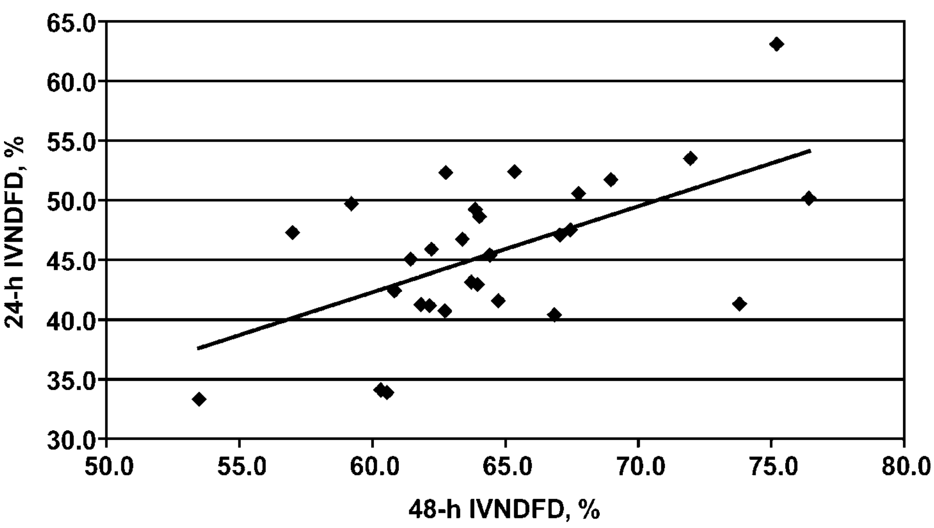

Figure 1. Regression of 24-h in vitro NDF digestibility (IVNDFD) vs. 48-h IVNDFD for the 29 corn silage samples. Y = 0.7187x – 0.0082; r = 0.57.

IMPLICATIONS

Variation in processing characteristics of corn grain and silage fed on dairy farms in the Upper Midwest is extensive. Recent advances in assays designed to assess starch digestibility

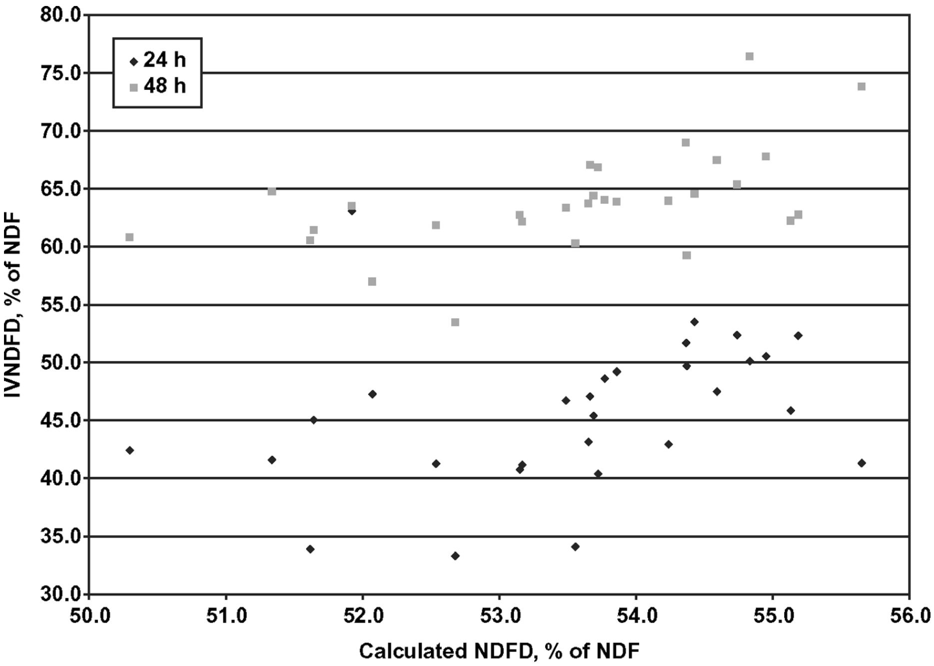

Figure 2. Regression of NDF digestibility (NDFD) calculated as recommended in NRC (2001) vs. 24-h in vitro NDF digestibility (IVNDFD; r = 0.30) and 48-h IVNDFD (r = 0.53) for the 29 corn silage samples.

of corn grain and silage and fiber digestibility of corn silage can aid our diagnostic evaluation of these feeds in the laboratory. However, more comparative research of the assays designed to assess starch digestibility and research to validate their results relative to in vivo digestibility data is needed before these assays can be used with confidence. Further, more research on the impact of 24- vs. 48-h IVNDFD measurements on corn silage energy content and DMI predictions and milk per ton estimates is needed. The poor correlations between IVNDFD measurements and NDF digestibility calculated as recommended in NRC (2001) raises concern about which values are more appropriate for calculating the energy value of corn silage.

LITERATURE CITED

Blasel, H. M., P. C. Hoffman, and R. D. Shaver. 2006. Degree of starch access: An enzymatic method to determine starch degradation potential of corn grain and corn silage. J. Anim. Feed Sci. Technol. 128:96.

Calsamiglia, S., and M. D. Stern. 1995. A three-step in vitro procedure for estimating intestinal digestion of protein in ruminants. J. Anim. Sci. 73:1459.

Ferreira, G., and D. R. Mertens. 2005. Chemical and physical characteristics of corn silages and their effects on in vitro disappearance. J. Dairy Sci. 88:4414.

Goering, H. K., and P. J. Van Soest. 1970. Forage Fiber Analyses (Apparatus, Reagents, Procedures, and Some Applications). Agric. Handbook No. 379. p. 8. ARS-USDA, Washington, DC.

Mertens, D. R. 2005. Particle size, fragmentation index, and effective fiber: Tools for evaluating the physical attributes of corn silages. In Proc. Four-State Dairy Nutr. and Mgmt. Conf. MWPS-4SD18. p. 211 Dubuque, IA.

Newbold, J. R., E. A. Lewis, J. Lavrijssen, H. J. Brand, H. Vedder, and J. Bakker. 2006. Effect of storage time on ruminal starch degradability in corn silage. J. Dairy Sci. 89(Suppl. 1):190. (Abstr.)

Nocek, J. E., and S. Tamminga. 1991. Site of digestion of starch in the gastrointestinal tract of dairy cows and its effects on milk yield and composition. J. Dairy Sci. 74:3598.

NRC. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

Oba, M., and M. S. Allen. 1999. Evaluation of the importance of the digestibility of neutral detergent fiber from forage: Effects on dry matter intake and milk yield of dairy cows. J. Dairy Sci. 82:589.

Owens, F. N., and R. A. Zinn. 2005. Corn grain for cattle: Influence of processing on site and extent of digestion. Proc. Southwest Nutr. Conf. Phoenix, AZ.

Owens, F. N., R. A. Zinn, and Y. K. Kim. 1986. Limits to starch digestion in the ruminant small intestine. J. Anim. Sci. 63:1634.

Sapienza, D. 2002. Pioneer tripartite method: Linking nutrient content to availability. In Proc. 64th Cornell Nutr. Conf. p. 27. East Syracuse, NY.

SAS. 2001. SAS/STAT Software. Release 8.02. SAS Inst. Inc., Cary, NC.

Schwab, E. C., R. D. Shaver, J. G. Lauer, and J. G. Coors. 2003. Estimating silage energy value and milk yield to rank corn hybrids. Anim. Feed Sci. Technol. 109:1.

Shaver, R. D. 2006. Corn silage evaluation: The MILK2006 update. In Proc. 41st Pacific Northwest Anim. Nutr. Conf. p. 71. Vancouver, Canada.

Shaver, R., J. Lauer, J. Coors, and P. Hoffman. 2006. MILK2006 Corn Silage: Calculates TDN-1x, NEL-3x, Milk per ton, and Milk per acre. milk2006corn silagev1.xls http://www.uwex.edu/ces/dairynutrition/spreadsheets.cfm Accessed Sep. 10, 2007.

Shaver, R., J. Lauer, J. Coors, E. Schwab, and P. Hoffman. 2001a. University of Wisconsin Corn Silage Evaluation System – MILK2000 version 7.54 Excel spreadsheet. http://www.uwex.edu/ces/forage/pubs/milk2000.xls. Accessed May 1, 2007.

Shaver, R., D. Undersander, E. Schwab, P. Hoffman, J. Lauer, D. Combs, and J. Coors. 2001b. Milk2000: Combining Yield and Quality into a Single Term. http://www.uwex.edu/ces/forage/pubs/milk2000.htm Accessed May 1, 2007.

Visser, B. 2005. Forage density and fermentation variation: A survey of bunkers, piles and bags across Minnesota and Wisconsin dairy farms. In Proc. Four-State Dairy Nutr. & Mgmt. Conf. MWPS-4SD18. p. 233. Dubuque, IA.

Waldo, D. R., L. W. Smith, E. L. Cox, B. T. Weinland, and H. L. Lucas. 1971. Logarithmic normal distribution for description of sieved forage materials. J. Dairy Sci. 54:1465.

Weiss, W. P., H. R. Conrad, and N. R. St. Pierre. 1992. A theoretically-based model for predicting total digestible nutrient values of forages and concentrates. Anim. Feed Sci. Technol. 39:95.