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Y. K. Chen, A. N. Pell, L. E. Chase and P. Schofield

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# Rate and Extent of Digestion of the Ethanol-Soluble and Neutral Detergent-Insoluble Fractions of Corn Grain

Yuan-Kuo Chen, Alice N. Pell<sup>1</sup>, Larry E. Chase, and Peter Schofield

Department of Animal Science, Cornell University, Ithaca, NY 14853

**ABSTRACT:** The objectives of this study were to partition corn grain into three digestible fractions and to measure the rate of disappearance of these fractions in vitro. Seventeen corn grain samples with varied fiber concentrations were extracted with either 80% ethanol or neutral detergent to obtain estimates of the pool size and digestion kinetics of the A, B1, B2, and C fractions.

The carbohydrate soluble in 80% ethanol averaged only  $2.6 \pm .3\%$  of the DM, although 80% ethanol extracted  $7.1 \pm 1.2\%$  of DM of corn grain. The ethanol-soluble fraction of corn grain contained protein, ether-extractable compounds, and a small amount of ash in addition to carbohydrate. Because of this chemical heterogeneity and because of the small size of the ethanol-soluble fraction, it was not possible to determine the

digestion rate of this fraction by measuring gas production.

The NDF content of the corn grain was  $10.6 \pm .7\%$  of DM and was highly digestible ( $94.6 \pm 1.4\%$ ). The digestible NDF contributed 9.5% of the total gas production from corn grain. Because the size, digestibility, and digestion rate of the digestible NDF fraction varied little among corn grain samples, it is not necessary to routinely analyze the digestion kinetics of the digestible NDF fraction of dried corn grain. An average gas production curve of this fraction can be used as a base to subtract from the total gas production curve to generate the gas production curve of the neutral detergent-soluble fraction for dried, ground corn grain samples.

Key Words: In Vitro, Rumen Gases, Digestion, Maize, Digestibility

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## Introduction

Recent advances in ration balancing include manipulation of protein and energy to increase the quantity and quality of protein and energy delivered to the small intestine (Stern et al., 1994). Chemical and physical forms of carbohydrate, protein, and lipid influence ruminal carbohydrate digestion and microbial growth. Because processing and physical attributes affect digestion kinetics, chemical analyses must be coupled with digestion rates to predict ruminal and animal performance.

In the Cornell Net Carbohydrate and Protein System Model (CNCPS), carbohydrate is divided into four fractions: A (sugars and organic acids), B1 (starch and soluble fiber), B2 (digestible fiber), and C (indigestible residue) (Sniffen et al., 1992). Digestion kinetics for corn have been described with in situ (Odle and Schaefer, 1987; Cerneau and Michalet-Doreau, 1991; Philippeau and Michalet-Doreau, 1997) and with in

vitro gas data (Menke and Steingass, 1988; Opatpatanakit et al., 1994), but digestion kinetics for individual fractions are not available. Because the 1996 Beef NRC (NRC, 1996) and the CNCPS require such information as inputs for ration evaluation, these data are needed.

A gas measurement system was used to study forage digestion kinetics (Pell and Schofield, 1993; Schofield and Pell, 1995). This system and a curve subtraction technique (Schofield and Pell, 1995) have been used to study the neutral detergent-soluble, water-soluble, and ethanol-soluble fractions of forage (Schofield and Pell, 1995; Stefanon et al., 1996; Doane et al., 1997, 1998). Similar approaches were used to analyze starch-rich feeds (Fakhri et al., 1997) and other highly digestible carbohydrate components (Hall et al., 1998).

The goals for this study were to partition corn grain into Fractions A, B1, and B2 and to measure the digestion kinetics of each fraction. The necessity to routinely determine the digestion rates for Fractions A and B2 was assessed.

## Materials and Methods

Samples of 17 different corn hybrids were used in this study. The sample set was selected to provide samples that varied in fiber concentration according

<sup>1</sup>To whom correspondence should be addressed (phone (607) 255-2876; fax: (607) 255-9829; E-mail: ap19@cornell.edu).

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to a laboratory scale wet-milling procedure (Eckhoff et al., 1996). This procedure involves steeping corn grain samples in 2,000 ppm sulfur dioxide and .5% lactic acid solution at 52°C followed by two grinding steps to recover starch and subsequent sieving to fractionate the germ, fiber, and protein (Eckhoff et al., 1996). The mean concentration of fiber obtained using this wet-milling method was 12.7%, with a range from 9.4 to 18.7% (unpublished data, Pioneer Hi-Bred International, Johnston, IA).

All samples were ground through a 1-mm screen in a Wiley mill (model 4, Arthur H. Thomas Co., Philadelphia, PA) prior to analysis. Use of finely ground samples represents a deviation from our normal protocol of grinding grain samples through a 6-mm sieve. This protocol was followed because our goal was to evaluate the rates and extents of digestion of the A and B2 fractions of corn grain, not the starch-containing B1 fraction. Preliminary results showed that the residual NDF was contaminated with starch if coarsely ground corn was used.

#### *NDF Analysis and Preparation*

To avoid starch contamination of the fiber residue, a modified NDF procedure (Van Soest et al., 1991) was used in this study. The NDF concentration of each sample was determined by soaking .5 g of sample in 15 mL of 8M urea plus .1 mL Termamyl (Novo Nordisk, Bagsvaerd, Denmark) overnight, prior to autoclaving the sample in 50 mL of neutral detergent (ND) solution plus .05 mL Termamyl at 105°C for 60 min (Van Soest et al., 1991; Pell and Schofield, 1993). The NDF residue was filtered on tared coarse porosity Gooch crucibles and rinsed with hot water and ethanol. The residue then was rinsed with acetone, dried in a 100°C oven, and weighed.

To obtain the NDF residue for fermentation, the same NDF procedure was used, except that the NDF residue was filtered through a 37- $\mu$ m nylon mesh cloth (Tetko, Briarcliff Manor, NY). Isolated NDF was transferred from the mesh cloth and soaked in 1 M  $(\text{NH}_4)_2\text{SO}_4$  (1 g of fiber to 100 mL of 1 M  $(\text{NH}_4)_2\text{SO}_4$ ) at 39°C overnight to remove the final traces of detergent. The isolated NDF was filtered on nylon mesh again and was washed with hot water, ethanol, and acetone. The NDF residues were dried in a 60°C oven overnight (Pell and Schofield, 1993) and were saved for subsequent fermentation.

#### *Ethanol-Insoluble Residue Analysis and Preparation*

The residue insoluble in 80% EtOH (ethanol-insoluble residue, **EIR**) was determined by continuously stirring .5 g of corn grain sample in 100 mL of 80% EtOH (vol/vol) at room temperature for 4 h and then filtering on tared coarse porosity Gooch crucibles (Shaw and Dickinson, 1984; Henry and Saini, 1989; Hall et al., 1998). The EIR was dried in a 100°C oven, and its

percentage of the total grain was calculated. Twenty milliliters of the 80% ethanol extracts was recovered and evaporated under vacuum to remove ethanol. An equal volume (20 mL) of distilled water was added to redissolve the carbohydrate. An aliquot was analyzed for soluble carbohydrate (soluble CHO) using the anthrone method (Bailey, 1958). Unfractionated corn samples and their EIR were analyzed for crude protein (CP), ether extract, and ash. The Kjeldahl method (AOAC, 1990) was used to determine CP. The concentration of ether-extractable material was determined by extraction with petroleum ether for 72 h in a Soxhlet apparatus (Fisher Scientific, Springfield, NJ). Samples for ash determination were held overnight in a 550°C furnace and then transferred to a 100°C oven for 24 h prior to weighing. The concentration of CP, ether extract, and ash in the ethanol-insoluble fraction was measured directly, and the concentration of these components in the ethanol-soluble fraction was determined by difference.

The ethanol extraction method described above was used to prepare EIR samples for fermentation, except that the EIR was filtered through 37- $\mu$ m nylon mesh cloth (Tetko) and rinsed three times with 80% ethanol. Isolated EIR samples, dried at 60°C, were saved for fermentation.

#### *In Vitro Gas Production*

A mature, nonlactating Holstein cow was fed mixed hay and 1 kg of corn meal per day for 10 d before ruminal fluid was collected. The animal was housed in a tie-stall barn and was cared for following a protocol approved by the Institutional Animal Care and Use Committee. The ruminal fluid, collected 2 to 3 h after the morning feeding, was filtered through four layers of cheesecloth and one layer of glass wool. The filtered ruminal fluid was transferred into a 100-mL serum bottle anaerobically and capped. The ruminal fluid bottle was held at 39°C preceding inoculation.

A preliminary experiment was performed to determine the optimum amount of substrate for fermentation, using a terminal pH of 6.2 as the criterion (Beuvinck and Spoelstra, 1992; Grant and Weidner, 1992). Preliminary experiments showed that 60 mg of either unfractionated corn grain, NDF, or EIR of corn grain maintained the terminal pH above 6.2.

Unfractionated grain, EIR, and ND residues of each corn grain sample (60 mg) were fermented in vitro in 50-mL serum bottles containing 2 mL of ruminal fluid and 8 mL of anaerobic medium. Gas production was measured according to the method of Pell and Schofield (1993), with the modifications described in Schofield and Pell (1995). All anaerobic techniques were similar to those described previously (Pell and Schofield, 1993). The pH was measured at the end of fermentation, and NDF disappearance was determined (Pell and Schofield, 1993).

Voltage changes were recorded every 20 min for 48 h using the Atlantis for Windows (Lakeshore Technologies, Chicago, IL) data acquisition package (Pell and Schofield, 1993). The recorded voltages were converted to gas volumes. Gas volumes, corrected to 760 mm Hg pressure, were calculated to represent production from 100 mg DM of unfractionated corn grain (Pell and Schofield, 1993; Schofield and Pell, 1995).

#### *Experimental Design, Curve Fitting, and Statistical Analysis*

Duplicate samples of each fraction (unfractionated, EIR, and NDF residues) were fermented at the same time in the computerized gas monitoring system (Pell and Schofield, 1993) on a given day, and each sample was fermented on two days using inocula from separate ruminal fluid collections.

To obtain the digestion rate of the A fraction, the gas produced from the fermentation of the EIR was subtracted from the gas of the unfractionated grain at each time point for each of the 144 gas observations. The same approach was used to obtain the digestion rate of Fraction B1, except that the NDF curve was subtracted from the EIR gas production data. For curve subtraction, the gas volume from the EIR and NDF fractions were normalized by multiplying the 100-mg dry substrate values by the corresponding fraction of EIR or NDF in the whole grain. The digestion rate for Fraction B2 was calculated directly from the gas data from the fermentation of the NDF residue (Schofield and Pell, 1995).

To generate the "average" curve for Fraction B2, the amounts of gas produced from fermentation of the NDF residues of each of the 17 grains at each time point were averaged, and the digestion parameters for the resulting curve were determined. The average NDS curve was obtained following the curve subtraction approach outlined above using the average amounts of gas produced from the fermentation of the unfractionated samples and NDF residues. The importance of routine evaluation of Fraction B2 was assessed by using a paired *t*-test to compare the digestion rates of the NDS fraction, calculated using either the observed data for Fraction B2 of each grain sample (observed) or the mean of all 17 samples (average).

For each corn sample, gas production curves were fitted to an exponential equation with discrete lag (Schofield et al., 1994) using the TableCurve program (version 2.0; Jandel Scientific, San Rafael, CA) operating under Microsoft Windows 95 (Schofield et al., 1994). The data used in this curve-fitting exercise included observations from the fermentation of the unfractionated, ND-soluble, and ND-insoluble fractions for each of the 17 corn samples. In addition, the averaged data for the ND-soluble and ND-insoluble fractions were fitted to the exponential model. The criteria used to judge the fit of a given model were the fit statistic (F-values, mean square of regression/mean

square error) and the *t*-values (parameter value/standard error) for each parameter as described previously (Schofield et al., 1994; Stefanon et al., 1996). A larger F-value indicates a better fit of the gas data to the mathematical model. In some situations, it was possible to obtain a higher fit statistic, but the *t*-values of one or more parameters were lowered. A reduced *t*-value indicates that the parameter in question is less well defined. The goal of curve fitting is to generate a good fit with well-defined parameters. Therefore, samples with parameters in which the *t*-value was less than 12 were excluded from the kinetic data set to calculate the mean and standard deviation (Doane et al., 1998).

The means and standard deviations of the pool size estimates of the various fractions, kinetic parameters, total gas yield, and NDF digestibility were calculated using descriptive statistics of Minitab, release 10 for Windows (Minitab, 1994). The kinetic parameters of observed and average ND soluble fractions were compared using a paired *t*-test. The influence of ruminal inoculum collected on different days was removed with this paired comparison.

## Results

### *Carbohydrate Fractions and Gas Production*

The amounts of the various fractions of dried corn grain in this experiment are given in Table 1. Eighty-percent ethanol extracted  $7.1 \pm 1.2\%$  of the DM from corn grain. This fraction included soluble carbohydrate, ether extract, some crude protein, and a trace amount of ash (Table 2). The mean NDF content of the experimental corn samples was  $10.6 \pm .7\%$  as a percentage of DM. The range in NDF concentration (9.0 to 11.2%) was narrower than the range found with the laboratory scale wet-milling procedure (9.4 to 18.7%). When the results from the wet-milling method and the standard NDF procedure were compared using a paired *t*-test, the results from the two methods differed ( $P < .05$ ). The average NDF digestibility of the corn grain after 48 h of fermentation was  $94.6 \pm 1.4\%$ .

The amount of dry matter in Fractions A, B1, B2, and C of the experimental corn grain were  $7.1 \pm 1.2\%$ ,  $82.3 \pm 1.2\%$ ,  $10.0 \pm .6\%$ , and  $.6 \pm .2\%$  of DM, respectively (Table 1). In the 80% ethanol-soluble fraction, only 35.3% of this fraction was true carbohydrate (Table 2). Fraction B1, which was primarily starch, was the largest carbohydrate fraction in corn grain. All the corn samples contained a consistent amount of digestible fiber (B2) with a coefficient of variation of 6.6% that includes both real chemical differences and analytical error. Fraction C was negligible in all samples.

### *Digestion Kinetics and Curve Subtraction*

The digestion kinetics of corn grain and its fractions are given in Table 3. Our attempts to estimate the

Table 1. Fractions and NDF digestibility of corn grains

Sample	Chemical Analysis			Fraction				NDF Dig., % <sup>g</sup>
	80%EIR <sup>a</sup>	s.CHO <sup>b</sup>	NDF	A <sup>c</sup>	B1 <sup>d</sup>	B2 <sup>e</sup>	C <sup>f</sup>	
	----- % of DM -----							
1	91.9	2.3	9.8	8.2	82.0	9.0	.8	92.2
2	90.8	2.4	11.6	9.2	79.3	10.9	.7	93.9
3	92.5	2.7	10.5	7.6	82.0	10.0	.5	95.3
4	94.1	2.1	10.1	5.9	84.0	9.6	.5	94.9
5	93.0	2.8	11.3	7.0	81.7	10.5	.8	93.3
6	91.0	2.7	10.2	9.0	80.8	9.6	.6	94.0
7	94.0	1.9	11.3	6.0	82.7	10.6	.7	93.9
8	92.6	2.6	10.4	7.4	82.1	9.5	.9	91.8
9	93.5	2.4	10.4	6.5	83.2	9.8	.6	94.4
10	92.3	2.7	10.2	7.8	82.0	9.7	.5	95.4
11	94.7	2.3	10.2	5.3	84.4	9.7	.5	94.7
12	94.8	2.4	11.8	5.2	83.0	11.2	.6	94.5
13	91.9	2.9	9.6	8.1	82.3	9.3	.3	96.5
14	94.1	3.2	11.4	5.9	82.7	10.9	.5	95.8
15	93.4	2.8	11.2	6.6	82.2	10.6	.6	94.3
16	92.0	2.8	10.2	8.1	81.8	9.9	.3	97.3
17	93.4	2.7	9.8	6.6	83.6	9.4	.4	96.1
Mean	92.9	2.6	10.6	7.1	82.3	10.0	0.6	94.6
SD	1.2	.3	.7	1.2	1.2	.6	.2	1.4

<sup>a</sup>EIR: 80% ethanol-insoluble residue.

<sup>b</sup>Carbohydrate soluble in 80% EtOH, assayed with the anthrone method (Bailey, 1958).

<sup>c</sup>Fraction A = 100 - 80%EIR.

<sup>d</sup>Fraction B1 = 80%EIR - NDF.

<sup>e</sup>Fraction B2 (digestible fiber) = NDF × NDF digestibility.

<sup>f</sup>Fraction C (indigestible fiber) = NDF × (100 - NDF digestibility)/100.

<sup>g</sup>NDF digestibility was calculated from the NDF disappearance during a 48-h fermentation of isolated NDF; the residue was assayed for NDF (Pell and Schofield, 1993) after fermentation.

digestion rate of Fraction A alone were not successful because the amount of fermentable material in this fraction was too small to permit accurate gas measurements. This is not surprising because the sugar con-

tent of the corn grain samples was only 2.6% of the DM (Table 1). As a result, we combined Fractions A and B1 into the neutral detergent-soluble fraction. For the remainder of this article, we will focus on the digestion kinetics of two pools, the ND-soluble and the ND-insoluble fractions. The gas production curve from the ND-soluble pool, calculated by point-by-point subtraction of the curve of NDF from that of unfractionated corn grain, is shown in Figure 1. When all the data were fitted to the exponential model, the R<sup>2</sup> values for all fits were higher than .99 with no *t*-value of any parameter less than 12, indicating that this model described the data well.

One of the goals of this study was to assess the importance of routine evaluation of the pool size and

Table 2. Composition of the ethanol-soluble fraction of corn grain.

Sample	Soluble carbohydrate <sup>1</sup>	Crude protein	Ether extract	Ash
	----- % of Ethanol-soluble DM -----			
1	36.5	7.4	53.0	3.2
2	39.8	6.9	49.5	3.9
3	40.3	16.0	39.8	3.9
4	29.9	18.4	44.6	7.2
5	33.1	23.3	41.6	2.0
6	27.8	24.5	41.6	6.2
7	35.9	11.4	51.2	1.6
8	35.8	8.2	34.8	21.3
9	38.7	12.6	45.7	3.1
10	35.4	18.1	39.6	6.8
11	35.0	7.4	42.4	15.2
12	30.6	32.0	36.8	.7
13	35.1	15.1	48.4	1.4
14	43.3	11.4	40.6	4.8
15	35.6	10.3	46.9	7.1
16	32.4	17.5	45.6	4.6
17	34.8	16.7	43.8	4.8
Mean	35.3	15.1	43.9	5.7
SD	3.9	6.9	5.0	5.2

<sup>1</sup>Carbohydrate soluble in 80% EtOH, assayed with the anthrone method (Bailey, 1958).

Table 3. Kinetics of gas production from the in vitro fermentation of unfractionated corn grain and its neutral detergent (ND)-soluble and digestible NDF fractions (exponential model)

Parameters	Unfractionated <sup>a</sup>	ND-soluble (A + B1)	Digestible NDF (B2)
V <sub>Final</sub> , mL/100 mg	35.5±1.78	32.0±1.8	3.5±.3
Rate, h <sup>-1</sup>	.15±.03	.16±.03	.11±.01
Lag time, h	2.8±.7	2.8±.7	2.8±.7

<sup>a</sup>Ground samples without further extraction by either 80% ethanol or ND solution.

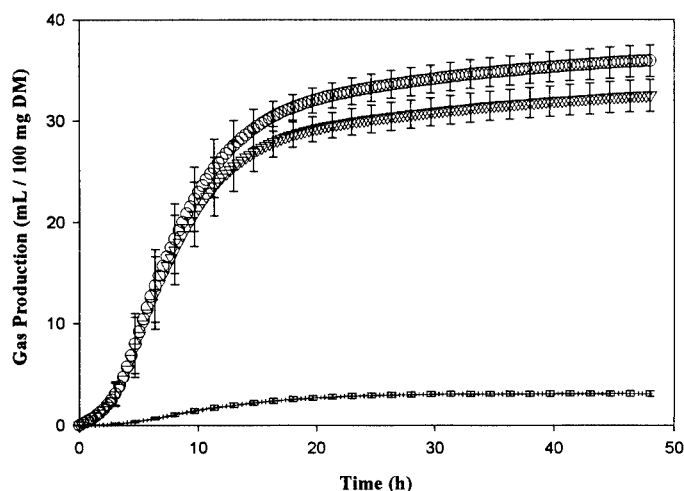


Figure 1. Gas production of unfractionated corn grain (○), digestible NDF fraction (+), and neutral detergent-soluble fraction (▽). Error bars represent  $\pm 1$  SD.

gas yield of the digestible NDF fraction. To achieve this, either the average ( $\text{Gas}_{\text{unfractionated}} - \text{Gas}_{\text{average ND-insoluble}}$ ) or the observed ( $\text{Gas}_{\text{unfractionated}} - \text{Gas}_{\text{actual ND-insoluble}}$ ) gas production from the ND-insoluble fraction was used to calculate the gas produced from the ND-soluble fraction. The digestion parameters of the resulting curves were compared (Table 4). There was no difference between the parameters obtained using the observed or average gas production curves of the ND-soluble fraction. The pool size, gas yield, and digestion kinetics of the digestible NDF fraction were similar among the corn grain samples (Table 3).

## Discussion

### Carbohydrate Fractions and Digestion Kinetics of Corn Grain

Extraction with aqueous ethanol removed ash, ether extract, crude protein, and low molecular weight carbohydrates (Table 2). This finding agrees with previous studies (Theander and Westerlund, 1986; Hall et

al., 1998). The ethanol-soluble fraction was primarily organic matter with a trace amount of ash (Table 2). In corn grain, most of the low molecular weight carbohydrate is composed of sugars (Watson, 1987). Watson (1987) reported that the average sugar content of seven midwestern hybrids of dent corn was 1.9% (dry matter basis) and that of corn grain purchased on the open market was 2.6%. Cone et al. (1989) reported that the sugar content of corn grain was less than 2%. In the present study, the 80% ethanol-soluble carbohydrate assayed with the anthrone method was 2.6% of dry matter (Table 1). The composition of the 80% ethanol-soluble fraction was not homogeneous (Table 2). We recommend that Fractions A and B1 should be combined as one pool for dried corn samples to determine rates of digestion. In the CNCPS, Fraction A was calculated by subtracting starch from the nonstructural carbohydrate (NSC) content (Sniffen et al., 1992), and the feed library indicated that 90% of the NSC in dried corn grain was starch. Fraction A estimated from this calculation was 7.7%. Although the 7.7% obtained using the CNCPS and the 7.1% obtained from 80% EtOH extraction are in agreement, both of these approaches overestimate the carbohydrate in Fraction A unless they are corrected for protein, ether extract, and ash.

Odle and Schaefer (1987) and Cerneau and Michalet-Doreau (1991) reported that the NDF content of corn grain was 10.8 and 10.1%, respectively. These values are close to the 10.6% (Table 1) found in this study and the NRC (1996) value of  $10.8 \pm 3.6\%$ . In contrast, Watson (1987) and Herrera-Saldana et al. (1990) reported that NDF values for corn grain were 9.5 and 9.3%, respectively. The variation of NDF content in different studies may result from different hybrids, growing conditions, and environmental factors or from incomplete removal of starch during the NDF analysis. We used 8 M urea and heat-stable amylase as recommended by Van Soest et al. (1991) to avoid this problem.

Most studies with corn grain have reported the digestibility of dry matter or starch in the rumen or in the total digestive tract (Herrera-Saldana et al., 1990; Cerneau and Michalet-Doreau, 1991; Philippeau and Michalet-Doreau, 1997). Information on the NDF digestibility of corn grain is limited. The NDF digestibility measured in the current study was consistently high ( $94.6 \pm 1.4\%$ ). The CV for the gas yield of Fraction B2 (Table 3) was 8.6%.

Opatpatanakit et al. (1994) incubated several varieties of corn grains in vitro for 7 h and reported an average accumulated gas production of 13.8 mL/100 mg DM (range 12.7 to 15.9 mL/100 mg DM). This result is close to the gas yield of 16.2 mL/100 mg DM that we measured at 7 h in the current study (Figure 1). The accumulated gas volume reported by Menke and Steingass (1988) using 92 mg DM of maize meal also was consistent with the gas yield observed in this study. Because there was little variation in gas produc-

Table 4. Comparison of kinetic parameters for the neutral detergent (ND)-soluble fraction using observed or averaged data during curve subtraction

Parameter	ND soluble (average <sup>a</sup> )	ND soluble (observed <sup>b</sup> )	SEM	P-value
Digestion rate	.159	.158	.034	.980
Gas yield	32.05	32.04	1.78	.991
Lag time	2.81	2.81	.68	.978

<sup>a</sup>Average gas yield curves of ND-soluble fraction were estimated by subtracting the average digestible NDF curve from the curves of the unfractionated grain.

<sup>b</sup>Observed gas curves of ND-soluble fraction were calculated by curve subtraction between observed gas yield curves of unfractionated grain and its digestible NDF.

tion of Fraction B2, the variation in gas production of corn grain can be attributed primarily to the ND-soluble (A + B1) fraction (Figure 1).

Most of the earlier studies on digestion kinetics were conducted using in situ methods (Odle and Schaefer, 1987; Herrera-Saldana et al., 1990; Cerneau and Michalet-Doreau, 1991; Philippeau and Michalet-Doreau, 1997). Odle and Schaefer (1987) reported that the maximum degradation rate for ground corn grain was  $.024 \text{ h}^{-1}$  when rumen ammonia concentration was varied. Cerneau and Michalet-Doreau (1991) and Herrera-Saldana et al. (1990) described their in situ DM disappearance data using a single-pool exponential equation. Respective values reported for the DM degradation rate and percentage of rapidly degraded fraction of ground corn grain were  $.043 \text{ h}^{-1}$  and 28.2% (Cerneau and Michalet-Doreau, 1991) and  $.047 \text{ h}^{-1}$  and 18.6% (Herrera-Saldana et al., 1990). Philippeau and Michalet-Doreau (1997) found a similar degradation rate for mature corn grain ( $.043 \text{ h}^{-1}$ ) and a higher rate ( $.19 \text{ h}^{-1}$ ) for immature grain. Data obtained using the in situ technique had a very low carbohydrate degradation rate and a small rapidly degraded pool compared with our findings. The difference may result from different curve fitting models, different particle size, or microbial contamination in the in situ study.

In the CNCPS feed library (version 3.0), the degradation rates of Fractions A, B1, and B2 of ground corn grain are 300, 35, and  $6\% \text{ h}^{-1}$ , respectively (Sniffen et al., 1992). In our study with finely ground corn, Fractions A and B1 were combined, and the exponential degradation rates of the combined A + B1 fraction and Fraction B2 were 15.9 and  $10.5\% \text{ h}^{-1}$ , respectively. Reliance on feed library values would have resulted in a large overestimation of the degradation rate of Fraction A + B1. This would have led to an overestimation of ruminally available carbohydrate in diets in which corn grain was a major component.

The small variation in pool size (CV = 6.6%), digestibility (CV = 1.5%), and gas production (CV = 8.6%) from the digestible NDF fraction of 17 different corn hybrids suggests that routine measurement of the B2 digestion rate is not necessary. When a gas production curve of the unfractionated corn grain (dried and ground) sample is available, the curve of the ND-soluble fraction can be obtained by point-by-point subtraction of the average gas production curve of digestible NDF fraction reported here from that of the unfractionated sample.

### Implications

The gas yield of Fraction A in corn grain is small. This fraction should be combined with Fraction B1 when rates of digestion are measured using gas production. The neutral detergent fiber (NDF) content of dried corn grain and the gas yield from NDF seem relatively constant across several grain hybrids. The digestion kinetics of the neutral detergent soluble frac-

tion of corn grain can be obtained by subtracting the average gas production curve for the digestible NDF fraction from that of the unfractionated corn grain (dried, ground). By using this approach, the information required for the Beef NRC, and CNCPS programs for diet evaluation can be obtained.

### Literature Cited

- AOAC. 1990. Official Methods of Analysis (15th Ed.). Association of Official Analytical Chemists, Arlington, VA.
- Bailey, R. W. 1958. The reaction of pentoses with anthrone. *Biochem. J.* 68:669–672.
- Beuvink, J.M.W., and S. F. Spoelstra. 1992. Interactions between substrate, fermentation end-products, buffering systems and gas production upon fermentation of different carbohydrates by mixed rumen microorganisms in vitro. *Appl. Microbiol. Biotechnol.* 37:505–509.
- Cerneau, P., and B. Michalet-Doreau. 1991. In situ starch degradation of different feeds in the rumen. *Reprod. Nutr. Dev.* 31:65–72.
- Cone, J. W., W. Cline-Theil, A. Malestein, and A.T.V. Klooster. 1989. Degradation of starch by incubation with rumen fluid. A comparison of different starch sources. *J. Sci. Food Agric.* 49:173–183.
- Doane, P. H., A. N. Pell, and P. Schofield. 1997. The effect of preservation method on the neutral detergent soluble fraction of forages. *J. Anim. Sci.* 75:1140–1148.
- Doane, P. H., A. N. Pell, and P. Schofield. 1998. Ensiling effects on the ethanol fractionation of forages using gas production. *J. Anim. Sci.* 76:888–895.
- Eckhoff, S. R., S. K. Singh, B. E. Zehr, K. D. Rausch, E. J. Fox, A. K. Mistry, A. E. Haken, Y. X. Niu, S. H. Zoh, P. Buriak, M. E. Tumbleson, and P. L. Keeling. 1996. A 100-g laboratory corn wet-milling procedure. *Cereal Chem.* 73:54–57.
- Fakhri, S., A. R. Moss, D. I. Givens, and E. Owen. 1997. Comparison of four in vitro gas production methods to study rumen fermentation kinetics of starch rich feeds. *Proc. Br. Soc. Anim. Sci.* p 196 (Abstr.).
- Grant, R. J., and S. J. Weidner. 1992. Digestion kinetics of fiber: Influence of in vitro buffer pH varied within observed physiological range. *J. Dairy Sci.* 75:1060–1068.
- Hall, M. B., A. N. Pell, and L. E. Chase. 1998. Characteristics of neutral detergent-soluble fiber fermentation by mixed ruminal microbes. *Anim. Feed Sci. Technol.* 70:23–39.
- Henry, R. J., and H. S. Saini. 1989. Characterization of cereal sugars and oligosaccharides. *Cereal Chem.* 66:362–365.
- Herrera-Saldana, R. E., J. T. Huber, and M. H. Poore. 1990. Dry matter, crude protein, and starch degradability of five cereal grains. *J. Dairy Sci.* 73:2386–2393.
- Menke, K. H., and H. Steingass. 1988. Estimation of the energetic feed value obtained from chemical analysis and in vitro gas production using rumen fluid. *Anim. Res. Dev.* 28:7–55.
- Minitab. 1994. Minitab Reference Manual, Release 10 for Windows. Minitab Statistical Software. Minitab Inc., State College, PA.
- NRC. 1996. Nutrient Requirements for Beef Cattle (7th Ed.). National Academy Press, Washington, DC.
- Odle, J., and D. M. Schaefer. 1987. Influence of rumen ammonia concentration on the rumen degradation rates of barley and maize. *Br. J. Nutr.* 57:127–138.
- Opatpatanakit, Y., R. C. Kellaway, I. J. Lean, G. Annison, and A. Kirby. 1994. Microbial fermentation of cereal grains in vitro. *Aust. J. Agric. Res.* 45:1247–1263.
- Pell, A. N., and P. Schofield. 1993. Computerized monitoring of gas production to measure forage digestion in vitro. *J. Dairy Sci.* 76:1063–1073.
- Philippeau, C., and B. Michalet-Doreau. 1997. Influence of genotype and stage of maturity of maize on rate of ruminal starch degradation. *Anim. Feed Sci. Technol.* 68:25–35.
- Schofield, P., and A. N. Pell. 1995. Measurement and kinetic analysis of the neutral detergent-soluble carbohydrate fraction of legumes and grasses. *J. Anim. Sci.* 73:3455–3463.

- Schofield, P., R. E. Pitt, and A. N. Pell. 1994. Kinetics of fiber digestion from in vitro gas production. *J. Anim. Sci.* 72:2980–2991.
- Shaw, J. R., and D. B. Dickinson. 1984. Studies of sugars and sorbitol in developing corn kernels. *Plant Physiol.* 75:207–211.
- Sniffen, C. J., J. D. O'Connor, P. J. Van Soest, D. G. Fox, and J. B. Russell. 1992. A Net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. *J. Anim. Sci.* 70:3562–3577.
- Stefanon, B., A. N. Pell, and P. Schofield. 1996. Effect of maturity on digestion kinetics of water-soluble and water-insoluble fractions of alfalfa and brome hay. *J. Anim. Sci.* 74:1104–1115.
- Stern, M. D., G. A. Varga, J. H. Clark, J. L. Firkins, J. T. Huber, and D. L. Palmquist. 1994. Evaluation of chemical and physical properties of feeds that affect protein metabolism in the rumen. *J. Dairy Sci.* 77:2762–2786.
- Theander, O., and E. A. Westerlund. 1986. Studies on dietary fiber. 3. Improved procedures for analysis of dietary fiber. *J. Agric. Food Chem.* 34:330–336.
- Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74:3583–3597.
- Watson, S. A. 1987. Structure and Composition. In: S. A. Watson and P. E. Ramstad (Ed.) *Corn: Chemistry and Technology*. pp 53–82. American Association of Cereal Chemists, St. Paul, MN.

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