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ORIGINAL RESEARCH: *Forages and Feeds*

Influence of corn hybrid, kernel traits, location, and dry rolling or steam flaking on ruminal digestibility in beef cattle

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ABSTRACT

Three trials were conducted to evaluate the effect of corn hybrid, kernel traits, growing location, and dry rolling or steam flaking on DM or starch digestibility or both. Trial 1 used 72 commercially available corn hybrids to evaluate the influence of hybrid on kernel characteristics and their effect on digestibility. Kernel characteristics evaluated were test weight, 1,000-kernel weight, and kernel hardness using the Stenvert hardness test. All analyses were conducted on dry, whole corn samples, and DM digestibility was determined for dry-rolled corn samples. Trial 2 used 12 hybrids to evaluate steam flaking or dry rolling on DM and starch digestibility. Flaking and flaking characterization were conducted at the Department of Grain Science and Industry at Kansas State University. Trial 3 used 132 commercially available corn hybrids grown in 3 separate locations to evaluate the effect of growing location, hybrid, and kernel characteristics on DM digestibility. Hybrids evaluated represented a wide range in relative maturity and, therefore, were separated into similar maturity groups for analysis. Results from trial 1 suggest that softer kernels are more digestible than harder kernels. A 27% difference in DM digestibility was found across hybrids when processed as dry-rolled corn. Results from trial 2 show that steam flaking improved DM digestibility ($P < 0.01$) from 5 to 29% and starch digestibility ($P < 0.01$) from 8 to 36% compared with dry rolling. Results from trial 3 suggest that DM digestibility is affected by corn hybrid ($P < 0.05$) but did not show consistent relationships with kernel characteristics. Our results also suggest that hybrid and growing location may interact, resulting in difficulty separating hybrid differences across locations. Overall, the results of these trials suggest that a softer kernel and a lighter-density flake improve digestibility and that hybrids vary in digestibility.

Key words: corn hybrid, digestibility, dry rolling, steam flaking

INTRODUCTION

Corn grain is the most widely used cereal grain for finishing cattle due to its energy value relative to production costs (Samuelson et al., 2016). Due to this, a large amount of research has evaluated strategies for improving cattle performance when cattle are fed corn. Most scientific research has investigated the influence of processing method (rolling, grinding, flaking, or ensiling) on finishing cattle performance (Barajas and Zinn, 1998; Corona et al., 2005). Less research has focused on corn hybrid or genetic effects on finishing performance, though a few have evaluated the effect of different corn types (dent, flint, genetically enhanced, and waxy) on fiber and DM digestibility (Martin et al., 1999; Akay et al., 2002).

Research has also evaluated the effects of physical and chemical kernel characteristics on digestibility and performance. Jaeger et al. (2006) found kernel characteristics that correlated with G:F. Their study showed that 1,000-kernel weight, the dry weight of 1,000 whole kernels, was positively correlated with G:F (r = 0.81), and Stenvert time to grind, a measure of hardness, was negatively correlated with G:F (r = −0.83). These results suggest that softer kernels with a higher 1,000-kernel weight result in greater feed efficiency when fed as dry-rolled corn (**DRC**).

A few studies have also evaluated the effect of kernel characteristics and processing method on finishing performance. Macken et al. (2003) evaluated 2 endosperm types

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(floury and flinty) fed as either high-moisture or dry-rolled corn. These researchers found that feed efficiency of the floury hybrid was greater when fed as DRC; although, when fed as high-moisture corn, there was no difference in efficiency between the floury and flinty corn. Similarly, Corona et al. (2006) found that less vitreous (flinty) hybrids were more digestible when fed as DRC. However, when these hybrids were processed as steam-flaked corn (**SFC**), no differences in digestibility were observed.

The objectives of this experiment were to identify hybrid effects on kernel characteristics, to evaluate the influence of hybrid and kernel characteristics on DM digestibility, to evaluate the effect of processing on DM and starch digestibility, and to evaluate the effect of growing location on kernel characteristics and DM digestibility.

MATERIALS AND METHODS

Trial 1

Corn grain samples from 72 hybrids, grown in Elkhorn, Nebraska, were collected at harvest (~4.5 kg) and transported to the Animal Science Complex at the University of Nebraska for analysis. At harvest, grain was analyzed for test weight using a Dickey-John grain analysis computer (Model GAC II, Dickey John Corp., Auburn, IL). Also, 1,000-kernel weights were analyzed using a commercial seed counter (Seedburo 801 count-a-pak, Seedburo Equipment Co., Chicago, IL). A representative subsample of approximately 1 kg was taken to conduct further analyses.

All hybrids were analyzed for kernel hardness using the Stenvert hardness test. Analysis was conducted in duplicate because only one sample of each hybrid was received. Twenty-gram samples were ground through a micro hammer mill equipped with a 2-mm screen (Micro Hammer Mill V, Glen Mills Inc., Maywood, NJ; beginning at 3,600 revolutions per minute). Measurements collected were grinding time, reduction in hammer mill speed at maximum grinding power, height (cm) of soft endosperm particles, height (cm) of entire ground sample, and weight of hard endosperm recovered over a US#40 (425-µm) sieve (Pomeranz et al., 1985).

Following the hardness analysis, 24 hybrids were selected for measurement of ruminal in situ digestibility to represent a wide range of kernel weight and hardness. Hybrid samples were ground through a Wiley mill No. 4 (Thomas Scientific, Swedesboro, NJ) to simulate mastication (6.35-mm screen) adapted from the procedure of Simon (2001). A 10-g (as-is) sample of each grain was placed in a 10 × 20 cm Dacron bag (53-µm pore size; Ankom, Fairport, NY) for incubation. Each sample was replicated 6 times per steer for a total of 12 replications per hybrid. The procedure made use of 2 ruminally cannulated crossbred steers (~600 kg of BW) and a 24-h incubation period, which was selected based on the inverse of passage rate assumed to be 4%/h, similar to 3.44%/h (Shain et al., 1999). Steers were fed a finishing diet containing 68.5% DRC, 20% wet corn gluten feed (Sweet Bran, Cargill Inc., Blair, NE), 7.5% alfalfa hay, and 4% supplement (all DM basis).

After removal from the rumen, bags were machine washed with five 3-min cycles, consisting of 1 min of agitation and 2 min of spin. In addition to the incubated bags, 2 bags per sample were not ruminally incubated to account for wash out from the Dacron bags. All bags were then rinsed in distilled water forcing all residues to the bottom, rolled, and placed in a 60°C forced-air oven for 48 h to dry. After drying, bags were removed from the ovens, allowed to cool in desiccators, and weighed to determine the amount of residue left. The residue that remained was divided by the original sample weight, corrected for DM, to determine the extent of DM digestibility (**DMD**) of each hybrid.

Trial 2

Twelve commercially available corn hybrids, which were also from the same test plot as hybrids evaluated in trial 1, were sent to the Department of Grain Science and Industry's Feed Processing Center at Kansas State University, Manhattan, Kansas, to determine hybrid effects on flaking characteristics. Characteristics measured included bulk density at 2 levels [light and heavy, 0.35 kg/L (27 lb/bu) and 0.41 kg/L (32 lb/bu), respectively]; electrical consumption of the steam-flaking motor to determine kilowatt hours per tonne (**kWh/t**); and production rates.

All corn was steam flaked on a Roskamp flaker (Roskamp Champion, Waterloo, IA) equipped with a 25 HP motor and 41 cm × 30 cm rolls at 6.3 grooves/cm (16 grooves/inch). A 30 cm × 38 cm × 183 cm stainless steel steam chamber was used to steam condition all corn before entering the flaking rolls. The feeder was set at a constant rate to facilitate observation of any differences in electrical consumption. For the drive motor, voltage and amperage across each electrical phase was measured using a recording volt-amp meter (Model DM-II Pro, Amprobe, Miami, FL). Electrical consumption was determined by relative (gross) and specific (net) energy. Gross energy was defined as the total amount of energy required while the machine was being used under a load. Net energy was defined as the energy required to operate the machine under a load, minus the energy required to operate the machine empty. Retention time of the corn in the steam chest before flaking was 8 min with a steam conditioning temperature of 98.8°C for all corn hybrids. Upon the completion of flaking, samples were placed in paper feed sacks and allowed to dry and cool to prevent spoilage.

Flaked corn samples (~20 kg) were then transported to the Animal Science Complex at the University of Nebraska to determine hybrid and flaking effects on digestibility. A representative subsample (~2 kg) was taken to run an in situ trial. Flaked corn samples were ground through a Thomas-Wiley mill No. 4 without a screen to simulate mastication according to the procedure of Simon (2001); however, because that procedure was designed for DRC, it was uncertain how accurate this grind was for flakes. With this in mind, we also tested flaked samples whole to identify any possible differences associated with grinding the flakes. Flakes were ground without the screen because we believed that this would give the most accurate representation of particle size change for masticated flakes compared with using the 2-mm screen as in trial 1. The 12 hybrids used in this trial were also used in trial 1, and the samples from trial 1 were run along with the flaked samples to allow for comparisons between DRC and SFC. Also, both the light and heavy density flakes were used allowing for comparisons between the 2 flake densities. The treatment structure for this trial was a 12 × 5 factorial, with 12 hybrids, 5 processing methods (DRC, SFC light, and SFC heavy), and either ground or whole flakes.

A 5-g (as-is) sample of each grain was placed in a 5 × 10 cm Dacron bag (53-μm pore size; Ankom) for incubation. Samples were replicated twice per steer per day, for a total of 8 replications per treatment. The procedure was conducted over a 5-d period, from first bag insertion to final bag removal, using 2 ruminally cannulated Holstein steers (~540 kg of BW), a 24-h incubation time, and a 1-d break between 2 incubation periods. Steers were fed the same finishing diet as in trial 1. Following ruminal incubation, bags were processed as previously described in trial 1.

Starch analysis was conducted on the original and residue samples, and starch disappearance was then calculated. Individual hybrid residues were composited across animals within day for analysis. Samples were ground to pass through a 1-mm screen using a Cyclotec sample mill (Model No. 1093, Foss Tecator, Hoganas, Sweden). Starch determination was conducted using a modified procedure of Fleming and Reichert (1980) and Shetty et al. (1974). This procedure used a calcium chloride solution to disperse the starch granules before complete gelatinization by heat and pressure from autoclaving. Alpha-amylase was used to shorten the starch polymer by cleaving α 1–4 bonds allowing for complete hydrolysis to glucose by amyloglucosidase. Finally, the quantitative yield of glucose from starch was determined by the glucose oxidase-chromogen method and read on a spectrophotometer (SPECTAmax 250, Molecular Devices, Sunnyvale, CA; absorbance of 510 nm), and the amount of starch per sample was determined using a linear regression based on standards (pure corn starch) of known starch content.

Trial 3

A total of 132 commercially available corn hybrids were used in a study designed to identify the effects of corn hybrid and growing location on kernel characteristics, and the effects of hybrid, growing location, and kernel characteristics on digestibility. Hybrids were grown at 3 separate independent research facilities: Ames, Iowa; Waterloo, Nebraska; and Pekin, Illinois. Hybrids were grown in 2 similar, independent field plots. At harvest, an approximately 2.25-kg sample of grain was collected for analysis. A small subsample was sent to a commercial laboratory (Precision Grain Analytics, Greensboro, NC) for near-infrared reflectance (**NIR**) analysis of oil, starch, and protein. The remaining sample was transported to the Animal Science Complex at the University of Nebraska. Once on campus, a representative subsample was taken to conduct further analysis.

The first kernel characteristic measured was the 1,000-kernel weight for each hybrid. Each field replication was analyzed in duplicate for a total of 4 measurements per location per hybrid, resulting in 12 total measurements for each hybrid. This measurement was taken by counting 1,000 whole kernels using a commercial seed counter (Seedburo 801 count-a-pak, Seedburo Equipment Co.). Kernels were then weighed and kernel weight on an air-dry or as-fed basis was recorded. A DM analysis, using 1-g as-is samples dried in a 60°C forced-air oven for 48 h, was conducted on each sample. The kernel weights were adjusted to a DM basis and represented as dry kernel weights.

Following 1,000-kernel weight analysis, all samples were tested for hardness using the Stenvert hardness procedure as previously described. Following the Stenvert hardness test, 30 hybrids were selected for in situ DM digestibility analysis. Hybrids selected for in situ analysis were chosen based on a wide range in kernel weight and hardness as well as hybrids that were also examined in trial 1. Both field replicates within each location of each hybrid were ground using a Thomas-Wiley mill No. 4 to simulate mastication (6.35 mm) adapted from the procedures of Simon (2001). A 5-g (as-is) sample of each sample was placed in a 5 × 10 cm Dacron bag (53-μm pore size; Ankom) for incubation. Samples were replicated twice per animal per day, for a total of 24 replications per hybrid. The procedure was conducted over 2 separate, 2-d periods using 2 ruminally and duodenally cannulated Holstein steers (~560 kg of BW). An incubation time of 22 h was used as adapted from Shain et al. (1999), calculated by taking the 75% mean retention time of an estimated passage rate of 3.44%/h. Steers were fed a finishing diet containing 26.5% DRC, 26.5% high-moisture corn, 35% wet corn gluten feed (Sweet Bran, Cargill Inc.), 7.5% alfalfa hay, and 5% of supplement (all DM basis). Procedures for trial 3 vary slightly from trials 1 and 2 due to being in different years with different resources available. After removal from the rumen, bags were rinsed and dried according the previously stated procedures.

Statistical Analysis

For trial 1, all kernel characteristic data were analyzed using the MIXED procedure of SAS (SAS 9.1, SAS Institute Inc., Cary, NC) with hybrid as a fixed effect. Also, a multiple regression analysis was conducted using the REG procedure to identify physical characteristics that could predict DM digestibility. To evaluate correlations between kernel characteristics and digestibility, the CORR procedure was used with variables including all kernel characteristics of kernel weight, hardness measurements, and digestibility.

For trial 2, DM and starch digestibility data were analyzed using the MIXED procedure of SAS with the model including fixed effects of hybrid, flake density, and grind (either ground or not ground) as well as possible interactions. Steer and day were used as random variables within the model as well. Flaking characteristics were not replicated, and therefore, statistical differences were not analyzed.

For trial 3, all kernel characteristics and digestibility data were analyzed using the MIXED procedure of SAS with hybrid, location, and hybrid × location interactions as fixed effects. Correlations were analyzed using the CORR procedure of SAS, with variables including kernel weight, hardness measurements, NIR data, and digestibility. Hybrids investigated in trial 3 represent a large range in relative maturity (**RM**). The RM is a crop research tool that evaluates the length of time necessary for the corn plant to reach full maturity and is critical for communication of hybrid adaptation to different geographical locations with different growing season lengths. The relative maturity tool also assists in selection of a group of hybrids with diverse maturities as a risk management strategy for planting at a single location. With these variations in RM, we decided the most appropriate analysis for these samples would be to evaluate them within RM groups or a range of RM values that would be considered representative for planting in geographical locations of similar growing-season lengths. Because this decision was made after data collection, correlations with DMD are presented across all hybrids and RM groups rather than separate. Seven RM groups were represented within the entire group of hybrids, but they were grown at locations representing only 1 to 2 different RM maturities, which may be somewhat confounding. The 7 RM groups represented were as follows: an RM of ≤89, an RM of 90 to 96, an RM of 97 to 103, an RM of 104 to 107, an RM of 108 to 112, and an RM of ≥113. These maturity groupings would commonly be planted from north to south as the RM increases, with hybrids from the RM group of ≤89 being planted in the northern United States (North Dakota, as well as northern Minnesota and Wisconsin, for example) and southern Canada and hybrids in the RM group of ≥113 being planted in states such as Missouri and Kansas and south.

A multiyear analysis was conducted using the hybrids tested in trial 1, trial 3, and previous research conducted at the University of Nebraska (unpublished data). Between these 3 data sets, 3 yr worth of data on 12 hybrids and 2 yr of data on 31 hybrids were analyzed for year, hybrid, and hybrid × year effects using the MIXED procedure of SAS. Relationships between kernel characteristics were analyzed using the CORR procedure of SAS. Stepwise regression for prediction of in situ DMD was also conducted on these data. The University of Nebraska's Institutional Animal Care and Use Committee approved all procedures and guidelines before this research.

RESULTS AND DISCUSSION

Trial 1

Hybrid significantly affected all kernel characteristics. A wide range was observed within each kernel trait across hybrid (Table 1). Production-related traits of 1,000-kernel weight and test weight were correlated ($P < 0.05$) with each other and with a few of the Stenvert observations (Table 2). Kernel weight was negatively correlated ($P < 0.01$, r = −0.34) with test weight, indicating that a higher volume weight does not necessarily indicate heavier kernels. Test weight was positively correlated with the Stenvert grind time ($P < 0.01$, r = 0.38), which indicates that a higher volume weight causes the sample to grind slower. In situ DMD is believed to be the best measure of value to the hybrid for finishing cattle other than in vivo measurements. Therefore, kernel traits that correlate with DMD are of primary interest. Test weight was the only kernel trait showing correlation tendency with DMD ($P = 0.07$), but the relationship was not strong (r = −0.38). The linear regression was unable to produce a strong prediction for DMD based on kernel characteristics, with test weight being the only measurement included in the model, producing an $R^2 = 0.14$. The equation was as follows: DMD = 129.51 (±39.35) − 1.29 (±0.67) × test weight.

Research evaluating physical characteristics and their effects on digestibility has found differing results. Philippeau et al. (1999) studied physical traits of corn and their relationship with in situ ruminal starch digestibility. Their study evaluated the physical characteristics of vitreousness, grinding energy, apparent and true densities, specific surface area, and 1,000-grain weight using 8 dent- and 6 flint-type corn hybrids. They also evaluated the rate of DM and starch disappearance using an in situ trial. Though their study did not examine animal performance, they did identify some useful methods to predict starch digestibility, including a strong prediction based on vitreousness ($r^2 = 0.89$). They also found that by combining apparent density and 1,000-kernel weight, they could predict ruminal starch degradation ($R^2 = 0.91$). The results of our study do not completely agree with those of Philippeau et al. (1999) because we did not find a strong relationship between any kernel characteristic and DMD ($R^2 = 0.14$). We did find similar results as far as flintier kernels being less digestible compared with floury kernels. We did not measure vitreousness as was measured by Philippeau et al. (1999), though we did use hardness and our results indicated that the harder or flintier hybrids were less digestible (r = −0.27 for hard percentage and DMD).

Other studies have also found relationships between kernel characteristics, digestibility, and finishing performance. Jaeger et al. (2006) studied 7 commercially available hy-

Table 1. Kernel traits averaged across hybrids

Trait	Mean	Minimum	Maximum	SD	*P*-value
Test weight (kg/L)	0.76	0.72	0.80	0.02	<0.01
Kernel weight[1] (g)	340.6	258.7	407.3	27.4	<0.01
Stenvert hardness test					
Time to grind (s)	6.3	5.0	8.0	0.7	<0.01
RPM[2]	2,442	2,235	2,720	98	<0.01
Soft height[3] (cm)	8.9	7.1	9.5	0.4	<0.01
Total height[4] (cm)	11.1	10.1	11.9	0.4	<0.01
Soft height[5] (%)	80.23	67.94	84.20	2.11	<0.01
Hard[6] (%)	81.64	72.93	89.34	2.81	<0.01
ISDMD[7]	0.538	0.447	0.710	0.06	<0.01

[1]1,000-kernel weight (DM basis).

[2]Lowest revolutions per minute (RPM) recorded; beginning RPM is 3,600.

[3]Height of soft particle column of ground corn sample.

[4]Height of entire column of ground corn sample.

[5]Percentage of soft particle height within the total ground corn column.

[6]Percentage of hard particles remaining on a 425-μm screen after sieving.

[7]ISDMD = ruminal in situ DM digestibility coefficient after 24 h of incubation.

brids fed as DRC in both a finishing and metabolism trial to evaluate kernel characteristic effects. They found strong relationships between kernel characteristics and feed efficiency. They found that 1,000-kernel weight was highly correlated ($P < 0.05$, r = 0.81) with G:F, as was Stenvert time to grind ($P < 0.05$, r = −0.83) and Stenvert soft to coarse particle height ($P < 0.05$, r = 0.83). Their results were similar to some of our results, though we did not use any of these corn hybrids in a finishing trial. Our results from trial 1 show a weak relationship between DMD and 1,000-kernel weight ($P = 0.27$, r = 0.23), Stenvert time to grind ($P = 0.60$, r = −0.11), and Stenvert hard percentage ($P = 0.20$, r = −0.27).

Trial 2

Flaked-corn production rates (kg/h) fluctuated by corn hybrid (Table 3). Although there were differences in production rates, an adjustment was made when calculating kWh/t to accurately assess the effect of hybrid on kWh/t. As previously stated, replications of flaking treatments were not conducted, so statistical differences could not be calculated. Therefore, differences discussed are strictly numerical only. As expected, there was a difference in kWh/t between light and heavy flakes. The steam flaker consumed more electricity as flaking became more rigorous in creating a lighter flake. There also appeared

Table 2. Pearson correlation coefficients between kernel characteristics[1]

Trait	Kern	Test	Grind	RPM	Soht	Totht	SHpct	Hard	ISDMD
Kern	1.00								
Test	−0.34*	1.00							
Grind	0.02	0.38*	1.00						
RPM	−0.10	0.10	0.20	1.00					
Soht	−0.01	−0.45*	−0.58*	−0.18	1.00				
Totht	−0.10	−0.45*	−0.43*	−0.10	0.80*	1.00			
SHpct	0.15	−0.04	−0.27*	−0.15	0.41*	−0.23	1.00		
Hard	0.05	0.22	0.20	0.25*	−0.12	−0.33*	0.32*	1.00	
ISDMD	0.23	−0.38	−0.11	0.01	0.02	0.14	−0.27	−0.27	1.00

[1]Correlations between kernel characteristics used 72 observations, whereas correlations with ISDMD used 24 observations. Kern = 1,000-kernel weight, Test = test weight, Grind = Stenvert time to grind, RPM = revolutions per minute, Soht = Stenvert soft height, Totht = Stenvert total height, SHpct = Stenvert soft height percentage, Hard = Stenvert hard percentage, ISDMD = in situ DM digestibility coefficient.

*Indicates a significant correlation ($P < 0.05$).

Table 3. Flaking characteristics of 12 Golden Harvest (Waterloo, NE) hybrids

	Bulk density (kg/L)		Amperage		Flake production rate (kg/h)	kWh/t[1]	
Hybrid	Light	Heavy	Light	Heavy		Light	Heavy
H-9430Bt	0.34	0.39	17.8	16.7	998	2.45	1.91
H-9485Bt	0.34	0.39	17.9	17.2	916	2.74	2.34
H-9494Bt/RR	0.35	0.39	17.7	16.6	962	2.53	1.92
H-8803Bt	0.34	0.39	18.0	17.0	880	2.89	2.33
H-8906	0.33	0.39	18.3	17.2	998	2.76	2.17
H-8700	0.35	0.39	17.2	16.6	1,061	2.03	1.76
H-9507Bt	0.35	0.40	17.5	16.7	798	2.91	2.38
H-8562	0.36	0.41	17.6	17.1	857	2.76	2.44
H-9164Bt	0.35	0.42	18.1	16.9	880	2.96	2.30
H-9248RR	0.34	0.41	18.1	17.1	948	2.79	2.23
H-9209Bt	0.35	0.39	17.3	16.8	980	2.26	2.01
H-9360Bt	0.35	0.39	17.4	16.7	1,125	2.02	1.69

[1]Kilowatt hours per tonne of electricity consumed during flaking.

to be differences among hybrids within each bulk density treatment. For example, hybrid H-8700 had an electrical consumption of 2.03 kWh/t and hybrid H-9164Bt had an electrical consumption of 2.96 kWh/t, a difference of 0.9 kWh/t. A feedlot with 4 flakers operating at 45 t/h each, operating 16 h/d and 6 d a week, at a $0.07/kW charge would have a potential savings of $1,478.40 per week in electrical costs.

Because grinding flakes had no effect on DMD (data not shown), data were pooled and reported on the basis of bulk density and compared with the DRC samples for each hybrid (Table 4). There was a hybrid × processing interaction ($P < 0.01$) for DMD. The bulk density of the flakes influenced ($P < 0.01$) DMD, with the lighter flakes being more digestible than the heavier flakes. The lighter flakes were also more digestible than the DRC ($P < 0.01$), whereas the heavier flakes were similar to DRC ($P = 0.22$). The second poorest DMD hybrid when fed as DRC (H-9485Bt) turned out to be the best hybrid using a light flake, with a 29% improvement in DMD. The hybrid with the least improvement for light flakes over DRC (H-8562) had a 5% improvement. The range in DMD values for DRC was 10.9 percentage units, whereas the range in DMD for light flakes was 11.8 percentage units.

Coefficients for the extent of starch digestibility of hybrids for DRC and light and heavy flakes are represented in Table 5, with the means being 0.526, 0.665, and 0.538, respectively. A lighter flake resulted in a significantly greater ($P < 0.01$) digestibility compared with DRC and heavy flakes, which were similar ($P = 0.17$). There was a significant hybrid × processing interaction ($P < 0.01$), which was also observed with DMD. The ranking of hybrids from most to least digestible changed somewhat between DM and starch; however, a strong relationship (r = 0.79) between DMD and starch digestibility still existed.

There have been many studies conducted to evaluate differences in digestibility between DRC and SFC. Cooper et al. (2002) evaluated the effects of processing method on starch digestion in finishing cattle. These researchers fed cattle dry-rolled, high-moisture, and steam-flaked corn and collected ruminal, duodenal, and fecal samples for

Table 4. Ruminal in situ DM digestibility coefficients for dry-rolled (DRC) and steam-flaked corn for 12 Golden Harvest (Waterloo, NE) hybrids[1]

Hybrid	DRC[2]	Light flake[3]	Heavy flake[2]
H-9430Bt	0.385	0.495	0.380
H-9485Bt	0.422	0.597	0.454
H-9494Bt/RR	0.434	0.523	0.411
H-8803Bt	0.434	0.543	0.480
H-8906	0.438	0.586	0.468
H-8700	0.439	0.525	0.416
H-9507Bt	0.449	0.564	0.458
H-8562	0.451	0.479	0.384
H-9164Bt	0.452	0.569	0.403
H-9248RR	0.459	0.586	0.412
H-9209Bt	0.475	0.579	0.495
H-9360Bt	0.494	0.569	0.459
Least significant difference	0.060	0.042	0.042

[1]Main effects of hybrid, processing method, and hybrid × processing method.

[2]DRC was not different from heavy flakes, except hybrid H-8562.

[3]Light flakes were different from both DRC and heavy flakes, except hybrid H-8562, which was not different between DRC and light flakes.

Table 5. Ruminal in situ starch digestibility coefficients of dry-rolled (DRC) and steam-flaked corn for 12 Golden Harvest (Waterloo, NE) hybrids[1]

Hybrid	DRC	Light flake	Heavy flake
H-9430Bt	0.482[a]	0.637[b]	0.546[c]
H-9485Bt	0.464[a]	0.687[b]	0.597[c]
H-9494Bt/RR	0.541[a]	0.682[b]	0.524[a]
H-8803Bt	0.533[a]	0.595[b]	0.584[ab]
H-8906	0.540[a]	0.685[b]	0.560[a]
H-8700	0.422[a]	0.662[b]	0.558[c]
H-9507Bt	0.579[a]	0.685[b]	0.480[c]
H-8562	0.524[a]	0.568[a]	0.529[a]
H-9164Bt	0.575[a]	0.739[b]	0.463[c]
H-9248RR	0.553[a]	0.695[b]	0.465[c]
H-9209Bt	0.538[a]	0.692[b]	0.673[b]
H-9360Bt	0.564[a]	0.654[b]	0.476[c]
Least significant difference	0.053	0.045	0.054

[a–c]Means within a row with unlike superscripts differ ($P < 0.05$).

[1]Main effects of hybrid, processing method, and hybrid × processing method.

evaluation of site and extent of starch digestion (Cooper et al., 2002). Cooper et al. (2002) found that SFC resulted in 19% greater ruminal starch digestibility compared with DRC, along with a 3% greater total-tract starch digestibility for SFC compared with DRC. In this experiment, total-tract starch digestibility was not evaluated; however, our ruminal in situ starch results exhibit some similarity to those found by Cooper et al. (2002). Our results indicate a 24% improvement in ruminal starch digestibility for SFC compared with DRC. In a literature review presented by Huntington (1997), a 12% improvement in starch digestibility was seen when feeding SFC compared with DRC.

The influence of flake density on use by finishing cattle has also been evaluated by researchers. Sindt et al. (2006a) studied the influence of tempering moisture, steam time, surfactant addition, and flake density on flaking characteristics. They found that starch availability linearly ($P < 0.01$) increased as flake density decreased from 0.36 to 0.31 kg/L. Flake durability, measured by sieving after tumbling, also increased linearly ($P = 0.02$) as flake density decreased (Sindt et al., 2006a). In another study conducted by Sindt et al. (2006b), the effect of 2 flake densities (0.36 or 0.31 kg/L) on digestibility and finishing performance was evaluated. In both studies by Sindt et al. (2006a,b), a decrease in flake density resulted in an increase ($P < 0.01$) in starch availability. Results from Sindt et al. (2006b) regarding starch availability may explain some of the differences observed in our trial between flake densities, as our higher density flakes resulted in lower DM and starch digestibility compared with the lighter flakes. The results of the second trial by Sindt et al. (2006b) contradict our study because they found no differences between flake densities for ruminal starch digestibility; however, their experiment employed different densities than our study (0.35 and 0.41 kg/L) and digestibility in their study was determined via a marker. Our study also contained the hybrid effect, which may also explain some of the differences observed between our study and these 2 studies.

Another study (Corona et al., 2006) evaluated the effects of steam flaking and kernel characteristics on site and extent of digestion in feedlot cattle. Corona et al. (2006) evaluated 4 dent corn hybrids varying in vitreousness from 55 to 65% to determine the effects of vitreousness on either SFC or DRC. These researchers discovered no interaction between vitreousness and processing method for ruminal digestion; however, they did identify a 14.4% improvement in ruminal starch digestibility for SFC compared with DRC (Corona et al., 2006). This improvement in ruminal starch digestibility was less than the improvement we observed (24%); however, similar patterns were found in both studies. Corona et al. (2006) also noted that more vitreous hybrids were less digestible than less vitreous hybrids when fed as DRC; however, there were no differences in digestibility due to vitreousness when flaked. Our results support this data; the 2 hardest hybrids based on Stenvert analysis from trial 1 showed the greatest improvement for in situ starch digestibility when flaked.

Trial 3

Numerous correlations were observed between kernel characteristics and DMD when we evaluated all hybrids across RM groups. Stenvert time to grind ($P < 0.05$, r = −0.18) and NIR-measured protein content ($P < 0.01$, r = −0. 28) were negatively correlated with DMD, whereas Stenvert soft height ($P < 0.05$, r = 0.17), Stenvert total height ($P < 0.05$, r = 0.15), and NIR-measured starch content ($P < 0.01$, r = 0.24) were positively correlated with DMD.

A significant hybrid × location interaction was observed for almost all kernel characteristics across all RM groups. Kernel characteristics for RM group ≤89 are presented in Table 6. Of the 132 hybrids evaluated, 6 hybrids represented this northernmost RM group. No hybrid from this RM group was selected for the in situ DM digestibility analysis.

Kernel characteristics for RM group 90 to 96 are presented in Table 7. Seventeen hybrids represented this RM group (hybrids commonly grown in North Dakota, northern South Dakota, and central Minnesota and Wisconsin), with 3 hybrids being selected for DMD analysis.

Kernel characteristics for RM group 97 to 103 are presented in Table 8. A total of 25 hybrids represented this RM group, which would include hybrids commonly grown in central South Dakota and southern Minnesota. Five hybrids were selected for DMD analysis from this particular group.

Table 6. Kernel characteristics across hybrids for the relative-maturity group with ≤89 d to maturity

Trait	Mean	Minimum	Maximum	SD	*P*-value Hybrid (H)	*P*-value Location (L)	*P*-value H × L	n[1]
Kernel weight[2] (g)	252.3	227.4	280.2	13.9	<0.01	<0.01	<0.01	6
Stenvert harness test								
Grind time (s)	6.8	5.0	9.0	1.1	0.07	<0.01	0.09	6
RPM[3]	2,427	2,270	2,570	72	<0.01	0.42	<0.01	6
Soft height[4] (cm)	7.9	6.5	9.0	0.6	<0.01	0.21	<0.01	6
Total height[5] (cm)	10.9	9.5	11.9	0.6	<0.01	0.07	<0.01	6
Soft height[6] (%)	72.5	68.0	76.1	1.8	<0.01	0.12	<0.01	6
Hard[7] (%)	72.2	68.3	77.1	1.8	<0.01	0.08	<0.01	6
Near-infrared reflectance (% of DM)								
Oil content	4.2	3.7	4.8	0.4	<0.01	0.01	0.33	6
Protein content	9.9	8.8	10.6	0.4	<0.01	0.50	<0.01	6
Starch content	71.5	69.9	72.5	0.8	<0.01	0.86	0.79	6

[1]Number of hybrids used for analysis.

[2]1,000-kernel weight (DM basis).

[3]Lowest revolutions per minute (RPM) recorded; beginning RPM was 3,600.

[4]Height of soft particle column of ground corn sample.

[5]Height of total column of ground corn sample.

[6]Percentage of soft particles based on column height of ground corn sample.

[7]Percentage of hard particles remaining on 425-μm screen after sieving.

Table 7. Kernel characteristics across hybrids for the relative-maturity group with 90 to 96 d to maturity

Trait	Mean	Minimum	Maximum	SD	*P*-value Hybrid (H)	*P*-value Location (L)	*P*-value H × L	n[1]
Kernel weight[2] (g)	273.7	196.9	325.3	13.9	<0.01	<0.01	<0.01	17
Stenvert hardness test								
Grind time (s)	6.4	5.0	9.0	0.8	<0.01	0.18	<0.01	17
RPM[3]	2,431	2,250	2,660	73	<0.01	0.43	<0.01	17
Soft height[4] (cm)	7.9	6.7	8.8	0.5	<0.01	0.57	<0.01	17
Total height[5] (cm)	10.9	9.5	12.0	0.5	<0.01	0.65	<0.01	17
Soft height[6] (%)	72.7	67.6	77.3	1.6	<0.01	<0.01	<0.01	17
Hard[7] (%)	72.5	66.2	76.9	2.1	<0.01	0.07	<0.01	17
Near-infrared reflectance (% of DM)								
Oil content	4.2	3.4	4.8	0.3	<0.01	0.04	0.30	17
Protein content	9.6	8.4	11.5	0.8	<0.01	<0.01	<0.01	17
Starch content	71.9	69.3	74.2	1.0	0.12	<0.01	0.28	17
ISDMD[8]	0.324	0.235	0.437	0.06	0.12	0.07	0.01	3

[1]Number of hybrids used for analyses.

[2]1,000-kernel weight (DM basis).

[3]Lowest revolutions per minute (RPM) recorded; beginning RPM was 3,600.

[4]Height of soft particle column of ground corn sample.

[5]Height of total column of ground corn sample.

[6]Percentage of soft particles based on column height of ground corn sample.

[7]Percentage of hard particles remaining on 425-μm screen after sieving.

[8]ISDMD = ruminal in situ DM digestibility coefficient after 24 h of incubation.

Kernel characteristics for RM group 104 to 107 are presented in Table 9. Hybrids within this group would be commonly grown in southern South Dakota, as well as northeastern Nebraska and northern Iowa. Twenty-one hybrids represented this RM group, and 5 hybrids from this group were selected for DMD analysis.

Table 10 presents the kernel characteristics for RM group 108 to 112. This RM group would include hybrids commonly grown throughout east central Nebraska, as well as central Iowa, Indiana, and Illinois. Hybrids from this RM group would be most adapted to the 3 growing locations used for this study. Thirty-six hybrids within this RM group were evaluated for physical and chemical kernel characteristics, with 7 hybrids within this group being selected for DMD analysis.

Table 11 presents the kernel characteristics for RM group ≥113. Hybrids within this RM group would commonly be long-season hybrids and would be grown throughout southern Illinois, Missouri, Kansas, Oklahoma, Texas, and other southern and southwestern states. Thirty-eight hybrids from this RM group were evaluated for kernel characteristics, with a total of 10 hybrids being selected for DMD analysis.

As previously discussed, Jaeger et al. (2006) found strong relationships between kernel characteristics and finishing cattle performances. Our results from trial 3 indicated weak relationships between these variables across RM groups. It is important to point out that there are differences between measurements from a finishing trial and an in situ trial because the in situ method uses a small sample size incubated for a small amount of time.

Multiple-Year Analyses

A significant hybrid × year interaction was observed for all kernel characteristics (Table 12). In yr 1, DMD was not analyzed, and in yr 2, test weight was not analyzed. Therefore, values are not presented. Strong correlations were observed between 1,000-kernel weight ($r = 0.64$, $P < 0.01$), Stenvert soft height ($r = 0.74$, $P < 0.01$), Stenvert soft height percentage ($r = 0.83$, $P < 0.01$), and Stenvert hard percentage ($r = 0.82$, $P < 0.01$) with DMD. These correlations suggest those hybrids with greater 1,000-kernel weights and a greater proportion of soft to hard endosperm, analyzed by volume, are more digestible compared with lighter 1,000-kernel weights with a lower proportion of soft to hard endosperm. A poor prediction equation ($R^2 = 0.13$) was observed for DMD by using Stenvert hard percentage. The observed equation was as follows: DMD $= 123.25\ (\pm 44.68) - 0.83\ (\pm 0.54) \times$ Hard %.

Correlations between kernel characteristics and performance in other species have also been explored. Moore et al. (2008a,b) conducted trials evaluating hybrid differences in swine and poultry. Their results indicated that kernel hardness, measured via Stenvert grinding time, affected

Table 8. Kernel characteristics across hybrids for the relative-maturity group with 97 to 103 d to maturity

					P-value			
Trait	Mean	Minimum	Maximum	SD	Hybrid (H)	Location (L)	H × L	n[1]
Kernel weight[2] (g)	273.7	223.1	345.8	22.8	<0.01	<0.01	<0.01	25
Stenvert hardness test								
Grind time (s)	6.4	5.0	8.0	0.7	<0.01	0.08	<0.01	25
RPM[3]	2,428	2,210	2,610	75	<0.01	0.05	<0.01	25
Soft height[4] (cm)	8.0	6.5	9.0	0.4	<0.01	0.32	<0.01	25
Total height[5] (cm)	11.0	9.5	12.1	0.5	<0.01	0.66	<0.01	25
Soft height[6] (%)	72.7	66.0	79.6	1.9	<0.01	0.16	<0.01	25
Hard[7] (%)	72.3	64.9	75.9	1.8	<0.01	0.03	<0.01	25
Near-infrared reflectance (% of DM)								
Oil content	4.3	3.7	4.9	0.3	<0.01	<0.01	<0.01	25
Protein content	10.0	8.9	11.0	0.5	<0.01	<0.01	<0.01	25
Starch content	71.4	69.0	72.7	0.7	<0.01	<0.01	<0.01	25
ISDMD[8]	0.321	0.239	0.411	0.05	<0.01	0.39	<0.01	5

[1]Number of hybrids used for analyses.

[2]1,000-kernel weight (DM basis).

[3]Lowest revolutions per minute (RPM) recorded; beginning RPM was 3,600.

[4]Height of soft particle column of ground corn sample.

[5]Height of total column of ground corn sample.

[6]Percentage of soft particles based on column height of ground corn sample.

[7]Percentage of hard particles remaining on 425-μm screen after sieving.

[8]ISDMD = ruminal in situ DM digestibility coefficient after 24 h of incubation.

Table 9. Kernel characteristics across hybrids for the relative-maturity group with 104 to 107 d to maturity

Trait	Mean	Minimum	Maximum	SD	*P*-value			n[1]
					Hybrid (H)	Location (L)	H × L	
Kernel weight[2] (g)	271.6	203.9	371.7	38.3	<0.01	<0.01	<0.01	21
Stenvert hardness test								
Grind time (s)	6.7	5.0	10.0	1.0	<0.01	0.02	<0.01	21
RPM[3]	2,418	2,280	2,700	74	<0.01	0.18	<0.01	21
Soft height[4] (cm)	7.9	6.5	8.9	0.5	<0.01	<0.01	<0.01	21
Total height[5] (cm)	10.8	9.5	11.9	0.5	<0.01	0.02	<0.01	21
Soft height[6] (%)	72.9	68.4	78.6	1.9	<0.01	0.08	<0.01	21
Hard[7] (%)	72.2	64.4	78.4	2.3	<0.01	0.08	<0.01	21
Near-infrared reflectance (% of DM)								
Oil content	4.2	3.4	5.1	0.4	<0.01	<0.01	0.34	21
Protein content	9.8	8.6	11.3	0.6	<0.01	<0.01	<0.01	21
Starch content	71.7	68.9	73.5	0.8	<0.01	0.41	0.05	21
ISDMD[8]	0.331	0.207	0.397	0.05	0.02	0.02	0.22	5

[1]Number of hybrids used for analyses.
[2]1,000-kernel weight (DM basis).
[3]Lowest revolutions per minute (RPM) recorded; beginning RPM was 3,600.
[4]Height of soft particle column of ground corn sample.
[5]Height of total column of ground corn sample.
[6]Percentage of soft particles based on column height of ground corn sample.
[7]Percentage of hard particles remaining on 425-μm screen after sieving.
[8]ISDMD = ruminal in situ DM digestibility coefficient after 24 h of incubation.

Table 10. Kernel characteristics across hybrids for the relative-maturity group with 108 to 112 d to maturity

Trait	Mean	Minimum	Maximum	SD	*P*-value			n[1]
					Hybrid (H)	Location (L)	H × L	
Kernel weight[2] (g)	287.3	202.2	381.1	31.2	<0.01	<0.01	<0.01	36
Stenvert hardness test								
Grind time (s)	6.7	5.0	9.0	0.9	<0.01	0.17	<0.01	36
RPM[3]	2,417	2,250	2,640	75	<0.01	0.04	<0.01	36
Soft height[4] (cm)	7.9	6.9	9.3	0.5	<0.01	<0.01	<0.01	36
Total height[5] (cm)	10.9	9.8	12.0	0.5	<0.01	<0.01	<0.01	36
Soft height[6] (%)	72.6	67.6	79.1	1.8	<0.01	0.16	<0.01	36
Hard[7] (%)	72.4	66.2	76.9	1.9	<0.01	0.02	<0.01	36
Near-infrared reflectance (% of DM)								
Oil content	4.4	3.4	5.3	0.3	<0.01	<0.01	0.02	36
Protein content	9.6	7.8	11.0	0.6	<0.01	<0.01	<0.01	36
Starch content	71.5	69.5	72.9	0.8	<0.01	0.17	0.66	36
ISDMD[8]	0.334	0.225	0.411	0.05	0.02	0.10	0.08	7

[1]Number of hybrids used for analyses.
[2]1,000-kernel weight (DM basis).
[3]Lowest revolutions per minute (RPM) recorded; beginning RPM was 3,600.
[4]Height of soft particle column of ground corn sample.
[5]Height of total column of ground corn sample.
[6]Percentage of soft particles based on column height of ground corn sample.
[7]Percentage of hard particles remaining on 425-μm screen after sieving.
[8]ISDMD = ruminal in situ DM digestibility coefficient after 24 h of incubation.

Table 11. Kernel characteristics across hybrids for the relative-maturity group with ≥113 d to maturity

Trait	Mean	Minimum	Maximum	SD	*P*-value			n[1]
					Hybrid (H)	Location (L)	H × L	
Kernel weight[2] (g)	302.6	243.3	413.9	30.3	<0.01	<0.01	<0.01	38
Stenvert hardness test								
Grind time (s)	7.3	5.0	11.0	1.2	<0.01	<0.01	<0.01	38
RPM[3]	2,405	2,210	2,700	86	<0.01	0.02	<0.01	38
Soft height[4] (cm)	7.8	6.0	8.9	0.6	<0.01	<0.01	<0.01	38
Total height[5] (cm)	10.7	9.1	11.9	0.6	<0.01	<0.01	<0.01	38
Soft height[6] (%)	72.3	65.3	80.0	2.2	<0.01	0.03	<0.01	38
Hard[7] (%)	71.8	63.6	77.7	2.5	<0.01	<0.01	<0.01	38
Near-infrared reflectance (% of DM)								
Oil content	4.4	3.8	5.3	0.4	<0.01	<0.01	0.56	38
Protein content	9.4	7.9	11.7	0.8	<0.01	<0.01	<0.01	38
Starch content	71.6	69.1	73.7	1.0	<0.01	0.01	0.30	38
ISDMD[8]	0.336	0.225	0.501	0.06	<0.01	<0.01	<0.01	10

[1]Number of hybrids used for analyses.
[2]1,000-kernel weight (DM basis).
[3]Lowest revolutions per minute (RPM) recorded; beginning RPM was 3,600.
[4]Height of soft particle column of ground corn sample.
[5]Height of total column of ground corn sample.
[6]Percentage of soft particles based on column height of ground corn sample.
[7]Percentage of hard particles remaining on 425-μm screen after sieving.
[8]ISDMD = ruminal in situ DM digestibility coefficient after 24 h of incubation.

Table 12. Multiyear analyses across hybrids

Trait	Year			*P*-value			r[1]
	1	2	3	Hybrid (H)	Year (Y)	H × Y	
Test weight (kg/L)	0.76	0.75	NA[2]	<0.01	<0.01	<0.01	−0.20
Kernel weight[3] (g)	320.7	340.7	286.4	<0.01	<0.01	<0.01	0.64*
Stenvert hardness test							
Time to grind (s)	7.8	6.3	6.4	<0.01	<0.01	<0.01	−0.05
RPM[4]	2,870	2,429	2,465	<0.01	<0.01	<0.01	0.17
Soft height[5] (cm)	7.3	8.9	7.9	<0.01	<0.01	<0.01	0.74*
Total height[6] (cm)	10.5	11.0	10.9	<0.01	<0.01	<0.01	0.22
Soft height[7] (%)	69.9	80.3	72.5	<0.01	<0.01	<0.01	0.83*
Hard particles[8] (%)	77.4	82.1	72.9	<0.01	<0.01	<0.01	0.82*
ISDMD[9]	NA	0.544	0.328	<0.01	<0.01	<0.01	NA

[1]Pearson correlation coefficient with in situ DM digestibility coefficient (ISDMD).
[2]NA = not available for yr 3.
[3]1,000-kernel weight (DM basis).
[4]Lowest revolutions per minute (RPM) recorded; beginning RPM was 3,600.
[5]Height of soft particle column of ground corn sample.
[6]Height of total column of ground corn sample.
[7]Percentage of soft particles based on column height of ground corn sample.
[8]Percentage of hard particles remaining on 425-μm screen after sieving.
[9]Ruminal ISDMD coefficient after 24 h of incubation.
*Indicates a significant correlation ($P < 0.05$).

the ADG and intake during the grower phase for swine, whereby softer kernels resulted in an increase in ADG in the early growing phase. For the poultry trial (Moore et al., 2008b), these researchers found that Stenvert grinding time was positively correlated with feed utilization (r = 0.32) for broilers and egg production (r = 0.21) in laying hens. The researchers of these trials concluded that individual kernel traits alone accounted for relatively little variation within many animal production measurements.

APPLICATIONS

The results of this study suggest that kernel characteristics are affected by corn hybrid and that hybrid and kernel characteristics can influence digestibility. Our results from trial 1 indicate that softer kernels, when fed as DRC, are more digestible than harder kernels. Our results from trial 2 suggest that hybrid can affect flaking characteristics and that steam flaking and kernel characteristics may interact. Steam flaking was shown to improve starch digestibility by 24% compared with dry rolling. Results from trial 3 suggest that hybrid, growing location, and year interact and all 3 affect kernel characteristics and digestibility. This interaction is troublesome due to the influence it has on selecting hybrids to perform similarly in different locations. Overall, the results of this study suggest that a softer kernel and a lighter-density flake improve digestibility and that the growing location may interact with hybrid to influence corn utilization by finishing cattle.

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