

Type of corn endosperm influences nutrient digestibility in lactating dairy cows

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ABSTRACT

An experiment was conducted to evaluate the effect of type of corn endosperm on nutrient digestibility in lactating dairy cows. Near-isogenic variants of an Oh43 × W64A normal dent endosperm hybrid carrying *floury-2* or *opaque-2* alleles were grown in spatial isolation in field plots and harvested as dry shelled corn. Six ruminally cannulated, multiparous Holstein cows (67 ± 9 d in milk at trial initiation) were randomly assigned to a replicated 3×3 Latin square design with 14-d periods; the first 11 d of each period were for diet adaptation followed by 3 d of sampling and data collection. Treatment diets that contained dry rolled vitreous-, floury-, or opaque-endosperm corn [33% of dry matter (DM)], alfalfa silage (55% of DM) and protein-mineral-vitamin supplement (12% of DM) were fed as a total mixed ration. The percentage vitreous endosperm was zero for floury and opaque endosperm corns and $64 \pm 7\%$ for the vitreous corn. Prolamin protein content of floury and opaque endosperm corns was 30% of the content found in vitreous corn. Degree of starch access and in vitro ruminal starch digestibility measurements were 32 and 42% greater on average, respectively, for floury and opaque endosperm corns than for vitreous corn. Dry matter and starch disappearances after 8-h ruminal in situ incubations were, on average, 24 and 32 percentage units greater, respectively, for floury and opaque endosperm corns than for vitreous corn. Ruminal pH and acetate molar percentage were lower, propionate molar percentage was greater, and acetate:propionate ratio was lower for cows fed diets containing floury and opaque endosperm corns than for cows fed vitreous corn. In agreement with laboratory and in situ measurements, total-tract starch digestibility was 6.3 percentage units greater, on average, for cows fed diets containing floury and opaque endosperm corns than vitreous corn. Conversely, apparent total-tract neutral

detergent fiber (NDF) digestibility was lower for cows fed diets containing floury and opaque endosperm corns compared with vitreous corn. The type of endosperm in corn fed to dairy cows can have a marked effect on digestion of starch and NDF. Feeding less vitreous corn increased starch digestion but decreased NDF digestion.

Key words: corn, digestibility, lactating cow, starch

INTRODUCTION

Starch in corn grain is a major source of energy in dairy cattle diets. Total-tract digestibility of corn starch by dairy cows was highly variable ($n = 83$, mean = 90.6%, SD = 7.4%, and range = 30%) among experiments in the literature review of Firkins et al. (2001). Accounting for this variation were conservation method (high-moisture > dry corn), processing method (ground > rolled corn; steam flaked > steam rolled > dry rolled corn), and particle size (fine ground > rolled or cracked dry corn).

Kernel vitreousness, the ratio of vitreous to floury endosperm, has been used to assess the type of corn endosperm (Ngonyamo-Majee et al., 2008a,b). Increased kernel vitreousness reduced ruminal in situ corn starch degradation (Philippeau and Michalet-Doreau, 1997; Correa et al., 2002; Ngonyamo-Majee et al., 2008b). Kernel vitreousness was lower and ruminal in situ starch degradation was greater for dry corn with floury or opaque endosperm than with normal dent endosperm (Ngonyamo-Majee et al., 2008a,b). Taylor and Allen (2005a) reported greater ruminal and total-tract starch digestibilities in ruminally and duodenally cannulated lactating dairy cows for floury (3% vitreousness) versus normal dent (67% vitreousness) endosperm dry corn.

Our objective was to use near-isogenic variants of corn hybrid Oh43 × W64A carrying *floury-2* and *opaque-2* alleles found to reduce vitreousness and increase ruminal in situ starch degradation (Ngonyamo-Majee et al., 2008a,b) to evaluate the effect of type of corn endosperm on nutrient digestibility in lactating dairy cows.

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Table 1. Ingredient and nutrient composition of the diets

Item	TMR ¹		
	ISO	FL	OP
Ingredient, % of DM			
Alfalfa silage ²		55.0	
Rolled shelled corn		33.0	
Soybean meal-48%		9.6	
Tallow		0.48	
Calcium carbonate		0.50	
Sodium bicarbonate		0.53	
Magnesium oxide		0.13	
Mg-K-S ³		0.05	
Sodium chloride		0.17	
Trace mineral salt ⁴		0.33	
Vitamin premix ⁵		0.17	
Selenium 0.02%		0.04	
	ISO	FL	OP
Nutrient ^{6,7} (DM basis)			
OM, %	86.3 ± 0.8	86.3 ± 0.7	86.8 ± 1.2
CP, %	19.7 ± 0.2	19.7 ± 0.9	19.5 ± 0.7
NDF, %	31.0 ± 3.9	29.8 ± 2.3	29.9 ± 3.2
Starch, %	20.8 ± 1.2	18.5 ± 0.4	18.9 ± 1.1

¹Treatments were dry rolled shelled corn from either W64A × OH43 (ISO), W64A × OH43 *fl2/fl2* (FL), or W64A × OH43 *o2/o2* (OP) varieties fed in TMR.

²DM = 42.7 ± 3.2%; CP = 19.2 ± 2.9%; NDF = 46.0 ± 5.5%.

³Dynamate (11% Mg, 18% K, 22% S; The Mosaic Co., Plymouth, MN).

⁴88% NaCl; 0.002% Co; 0.2% Cu; 0.012% I; 0.18% Fe; 0.8% Mn; 0.006% Se; 1.4% Zn.

⁵Vitamin A 3,300,000 IU/kg; vitamin D 1,100,000 IU/kg; vitamin E 11,000 IU/kg.

⁶Orts-adjusted diet nutrient composition.

⁷DM content of TMR 46.7% ± 5.6.

MATERIALS AND METHODS

The experimental corn hybrid varieties were W64A × OH43 (ISO), W64A × OH43 *fl2/fl2* (FL), and W64A × OH43 *o2/o2* (OP). All varieties were planted in 0.75-ha plots at University of Wisconsin Arlington Research Station (Arlington, WI) at a density of 59,000 plants/ha. The FL and OP plots were planted in 1-km spatial isolation of the ISO plot to prevent cross-pollination to preserve endosperm properties associated with the recessive alleles. Each field plot was combine harvested as shelled corn after field drying to approximately 20% moisture, and then each lot of corn was air-dried at low temperature (<32°C) in storage bins to approximately 14% moisture at Wisconsin Foundation Seeds (Arlington, WI). Percentage vitreous endosperm, determined as described by Correa et al. (2002), was zero for both FL and OP kernels and 64 ± 7% for ISO kernels. Before the feeding trial was conducted, each lot of corn was processed using a stationary roller mill (A. O. Smith Corp., Milwaukee, WI) with the roll clearance set at 1 mm and bagged.

Six ruminally cannulated, multiparous Holstein cows (638 ± 5 kg of BW and 67 ± 9 DIM at trial initiation)

were randomly assigned to a replicated 3 × 3 Latin square design with 14-d periods; the first 11 d of each period were for diet adaptation followed by 3 d for sampling and data collection. All experimental procedures were approved by the Research Animal and Resource Center of the College of Agriculture and Life Sciences, University of Wisconsin–Madison. Experimental diets contained ISO, FL, or OP dry rolled corn (33% of diet DM) and alfalfa silage (55% of diet DM) along with soybean meal, tallow, and mineral-vitamin ingredients. With these ingredient constraints set, diets were formulated to meet or exceed NRC (2001) CP and macromineral concentration guidelines for early lactation cows. Trace minerals and vitamins were supplemented to meet or exceed NRC (2001) guidelines. Ingredient and nutrient composition of the experimental diets are presented in Table 1. Diets were formulated to contain 18.5% CP (DM basis) so that RDP was not limiting for ruminal digestion. The orts-adjusted diets contained 19.5 to 19.7% CP (DM basis), however, because the alfalfa silage and soybean meal fed during the trial were both higher in CP than the values used for the pretrial formulations.

Cows were housed in tie-stalls and milked twice daily in a parlor with yield recorded at each milking for each cow. Milk samples were collected from each cow at each milking on the last 3 d of each period and analyzed for fat, true protein, lactose, and MUN concentrations using infrared analysis (AgSource Milk Analysis Laboratory, Menomonie, WI). Cows were fed individually a TMR at 6-h intervals daily for 5% refusals with the amounts fed and refused recorded once daily. The alfalfa silage DM content was determined weekly with the as-fed proportions of alfalfa silage, respective treatment corns, and the protein-mineral-vitamin concentrate adjusted as necessary to maintain the desired DM proportions of these ingredients in the TMR.

The treatment corns and TMR sampled daily during each sampling period and alfalfa silage and concentrate sampled weekly throughout the trial were dried at 60°C for 48 h in a forced-air oven to determine DM content, ground to pass a 1-mm Wiley mill (Arthur H. Thomas, Philadelphia, PA) screen, and composited by period for the following analyses at a commercial feed testing laboratory (Dairyland Laboratories Inc., Arcadia, WI): OM (ashing at 600°C for 2 h), CP (AOAC, 1995), NDF using α-amylase and sodium sulfite (Van Soest et al., 1991), and starch (Ehrman, 1996; YSI Biochemistry Analyzer, YSI Inc., Yellow Springs, OH). Separate samples of the treatment corns were composited by period, left undried and unground, and sent to commercial feed testing laboratories for analyses as follows: mean particle size (MPS) determined at Dairyland Laboratories Inc. (Arcadia, WI) by dry sieving using a

Tyler Ro-Tap Shaker Model RX-29 (Mentor, OH) and sieves with apertures of 2,360, 1,700, 1,180, 850, 600, 425, 300, 212, 150, 106, 75, and 53 μm plus bottom pan, and calculated using a log normal distribution (Waldo et al., 1971); degree of starch access (Blasel et al., 2006) and prolamin protein (Larson and Hoffman, 2008) determined at the University of Wisconsin-Madison Soil and Plant Analysis Laboratory (Marshfield, WI); 7-h *in vitro* ruminal starch digestibility determined at Cumberland Valley Analytical Services Inc. (Maugansville, MD). The Cumberland Valley Analytical Services *in vitro* ruminal starch digestibility procedure was as follows: corn grain ground to pass a 2-mm screen in a Udy Cyclone Mill (Udy Corp., Fort Collins, CO); 1.0-g samples weighed into 125-mL Erlenmeyer flasks, reducing (2 mL) and buffer (40 mL) solutions added to the flasks, and O_2 purged from the flasks with CO_2 ; rumen fluid from 3 mid-lactation, ruminally cannulated dairy cows fed a corn silage-alfalfa silage based TMR combined, strained through nylon mesh, and 20 mL added to each flask; flasks maintained in a 40°C water bath under CO_2 for 7 h and then removed from the water bath and refrigerated overnight; residue remaining in the flasks analyzed for starch using thermo-stable amylase incubation followed by glucose analysis with an Astoria auto-analyzer (Astoria-Pacific Int., Clackamas, OR).

Fecal grab samples were collected from each cow twice daily to cover 0400, 0800, 1200, 1600, 2000, and 2400 h time points over the 3-d sampling period. Ort samples were collected from each cow daily during the 3-d sampling period. Fecal and ort samples were dried and ground as described previously and composited by cow within period; composite samples were analyzed for DM, OM, CP, NDF, and starch as described previously.

Ruminal fluid was collected from each cow immediately before the 0600 h feeding and at 2, 4, 8, and 16 h after that feeding on the first 2 d of each sampling period. Samples were collected from 5 sites within the ventral rumen via the cannula using a metal filter probe. The fluid was immediately filtered through 2 layers of cheesecloth, and pH was measured (Cardy Twin pH meter Model 2103-A, Spectrum Technologies Inc., Plainfield, IL). Duplicate 1-mL strained rumen fluid samples were acidified in 20 μL of 50% H_2SO_4 solution, and immediately frozen in microfuge tubes until VFA analysis. After thawing, the rumen fluid was centrifuged at $10,000 \times g$ for 3 min. Then, 0.6 mL of supernatant was added to 0.12 mL of 25% metaphosphoric acid and allowed to stand at room temperature for 30 min. The sample was centrifuged again at $10,000 \times g$ for 3 min. The supernatant was transferred to a gas-liquid chromatography vial for analysis on a Perkin

Elmer Autosystem gas chromatograph (Perkin Elmer Instruments, Shelton, CT) using a 1.8-m column (Supelco, Bellefonte, PA) packed with 4% Carbowax 20M 80/120 Carbopack B-DA with an oven temperature of 160°C and a nitrogen flow rate of 24 mL/min. Separate duplicate 1-mL strained rumen fluid samples were acidified in 20 μL of 50% TCA solution and immediately frozen in microfuge tubes until prepared and analyzed for ammonia-N as described by (Bal et al., 2000).

Dacron bags (10 \times 15cm, $52 \pm 5 \mu\text{m}$ pore size, R102 Marvelaire White, Balson Erlanger, New York, NY) containing approximately 5 g (as-fed basis and not reground) of the same treatment corn being fed to the incubation cow were inserted via the cannula in weighted nylon-mesh laundry bags positioned in the ventral rumen at the 0600 h feeding and at 1400 h for 16- and 8-h incubations, respectively (all bags were removed at 2200 h), on the last day of each sampling period to determine ruminal DM and starch disappearance for the treatment corns. Triplicate bags were used for each treatment at each incubation time. Immediately upon removal from the rumen, bags were immersed in ice water until washing. Zero-hour bags were not inserted ruminally, but were soaked in tepid tap water for 30 min. All bags were washed using cold water for 2 cycles in a commercial washing machine (Cherney et al., 1990), dried at 60°C for 72 h, and weighed to determine the amount of DM remaining in the bags for calculation of ruminal DM disappearance percentages. Triplicate bag residues were then composited, ground, and analyzed for starch content as described previously to determine the amount of starch remaining in bags for calculation of ruminal starch disappearance percentages.

Total-tract nutrient digestibilities were determined using 120-h indigestible NDF as an internal marker. Following completion of the Latin square, the 6 cows remained on a TMR consisting of the same DM proportions of alfalfa silage, protein-mineral-vitamin concentrate, and a corn mixture composed equally of the 3 treatment corns for 2 wk. Composite fecal, ort, and TMR samples were incubated ruminally in Dacron bags in triplicate for 120-h during the last 5 d of the 2-wk feeding period. *In situ* Dacron bag procedures were as described previously. The NDF content of the bag residues was determined in triplicate using α -amylase and sodium sulfite (Van Soest et al., 1991) and an Ankom²⁰⁰ Fiber Analyzer (Ankom Technology, Fairport, NY). Total-tract nutrient digestibilities were calculated from 120-h indigestible NDF and nutrient concentrations in the orts-adjusted diet and feces.

Data were analyzed as a replicated Latin square using the PROC MIXED procedure (SAS Institute, 2004). The model included square, period, and treatment as fixed effects; cow within square was a random effect.

Table 2. Laboratory evaluation of the experimental corn varieties¹

Item	ISO	FL	OP
DM, % as fed	87.4 ± 0.2	86.9 ± 0.3	86.0 ± 0.3
CP, % of DM	10.4 ± 0.1	10.8 ± 0.2	10.2 ± 0.2
Starch, % of DM	69.2 ± 0.4	62.9 ± 0.7	67.5 ± 1.5
Mean particle size, μm	1,792 ± 125	1,394 ± 116	1,456 ± 160
Vitreousness, %	64 ± 7	0	0
Prolamin protein			
% of DM	7.50 ± 0.52	2.80 ± 0.17	1.73 ± 0.06
% of CP	72.2 ± 6.0	26.2 ± 1.9	17.4 ± 0.7
% of starch	10.8 ± 0.8	4.5 ± 0.3	2.6 ± 0.1
Degree of starch access ²			
% starch	53.5 ± 1.5	69.4 ± 1.3	71.5 ± 1.8
In vitro ruminal starch digestibility ³			
7-h, % starch	62 ± 2	91 ± 2	85 ± 4

¹Treatments were dry rolled shelled corn from W64A × OH43 (ISO), W64A × OH43 *fl2/fl2* (FL), and W64A × OH43 *o2/o2* (OP) varieties.

²University of Wisconsin–Madison Soils and Forages Analysis Lab, Marshfield, WI.

³Cumberland Valley Analytical Services Inc., Maugansville, MD.

Ruminal data were analyzed with time as repeated measures using the first-order autoregressive covariance structure that provided the best fit according to Sawa's Bayesian information criterion. Degrees of freedom were calculated using the Kenward-Roger option. Pre-planned contrasts were included to compare ISO versus FL and OP, and FL versus OP. The least squares mean statement was used to determine treatment means. Statistical significance and trends were considered at $P \leq 0.05$ and $P \geq 0.06$ to $P < 0.10$, respectively.

RESULTS AND DISCUSSION

Results of analysis of the experimental corn hybrid varieties are presented in Table 2. The treatment corns were of similar DM and CP content. The FL corn contained approximately 6 percentage units less starch than ISO. The starch content for OP was more variable than for ISO (SD 1.5 vs. 0.4%).

Despite similar mechanical processing of the treatment corns, MPS was lower for FL and OP corns compared with ISO. Taylor and Allen (2005a) reported that MPS was lower for floury compared with vitreous corn (1,377 vs. 1,594 μm) fed in their trial despite similar mechanical processing for both types of corn. The magnitude of the endosperm effect on processed dry corn MPS was similar for both experiments; 20% lower MPS on average for FL and OP than ISO in our trial and 14% lower MPS for floury compared with vitreous corn in the trial of Taylor and Allen (2005a). Reduced MPS of dry corn has been shown to increase total-tract digestibility of starch by dairy cows (Knowlton et al., 1998), but with greater reductions in MPS (64 vs. 14 and 20%) and at lower MPS (618 μm vs. 1,377 and 1,394 μm) when comparing MPS for that trial to MPS from our trial and the trial of Taylor and Allen (2005a).

Allen et al. (2008) evaluated floury versus vitreous dry corn and fine versus medium particle size in a factorial experiment; total-tract digestibility of starch by dairy cows was greater for floury than for vitreous corn but was unaffected by fineness of grind. From the foregoing discussion, we suggest that differences in MPS between the experimental corns in our study had much less effect on the results than did differences in kernel vitreousness or prolamin protein content.

Percentage vitreous endosperm was zero for both FL and OP kernels and 64 ± 7% for ISO kernels. Taylor and Allen (2005a) reported greater ruminal and total-tract starch digestibilities in lactating dairy cows for floury (3% vitreousness) versus normal dent (67% vitreousness) endosperm dry corn. Prolamin protein concentrations, expressed as percentages of DM, CP, and starch, for FL and OP, on average, were reduced by 70% relative to the concentrations found for ISO. Highly vitreous corn types contain higher concentrations of prolamin proteins than floury or opaque corn types (Hamaker et al., 1995; Larson and Hoffman, 2008). Starch granules in the corn endosperm are surrounded by hydrophobic prolamin proteins, which are slowly degraded (McAllister et al., 1993). Degree of starch access and in vitro ruminal starch digestibility were 32 and 42% greater, respectively, for the average of FL and OP compared with ISO. Kernel vitreousness, prolamin proteins, degree of starch access, and in vitro ruminal starch digestibility measurements appeared to agree for the comparison of FL and OP, on average, to ISO.

The lactation performance of cows fed the experimental diets is presented in Table 3; these results should be interpreted with caution because of the relatively short duration of the experimental periods. Dry matter intake and milk yield averaged 25.6 and 45.2 kg/d, re-

Table 3. Effect of corn endosperm type on least squares means for DMI, milk production, and feed efficiency¹

Item	ISO	FL	OP	SEM	<i>(P <)</i>	
					ISO vs. FL, OP	FL vs. OP
DMI, kg/d	26.4	25.3	25.2	0.9		NS ²
Milk yield, kg/d	44.0	45.1	46.4	2.5		NS
4% FCM, kg/d	40.1	41.0	42.1	2.5		NS
Milk fat, %	3.38	3.42	3.36	0.14		NS
Milk fat, kg/d	1.50	1.53	1.57	0.11		NS
Milk protein, %	2.63	2.77	2.68	0.03	0.01	0.09
Milk protein, kg/d	1.16	1.23	1.24	0.07	NS	NS
MUN, mg/dL	18.1	18.3	17.3	0.8		NS
Feed efficiency kg of milk/kg of DMI	1.69	1.76	1.85	0.14		NS

¹Treatments were dry rolled shelled corn from W64A × OH43 (ISO), W64A × OH43 *fl2/fl2* (FL), and W64A × OH43 *o2/o2* (OP) varieties fed in TMR.

²Not significant ($P > 0.10$).

spectively, for the trial and were unaffected ($P > 0.10$) by treatment. Milk protein percentage was greater ($P < 0.01$) for cows fed FL and OP than for cows fed ISO, and tended to be greater ($P < 0.09$) for FL than for OP. Milk protein yield, however, was unaffected ($P > 0.10$) by treatment. The relatively low milk protein and high MUN concentrations that were observed across treatments were likely related to relatively high alfalfa silage and CP contents and low starch content of the experimental diets (refer to Table 1; NRC, 2001). Furthermore, the relatively low milk percentages across treatments may have been related to the lack of diet formulation for RUP and amino acids (NRC, 2001). Greater milk protein percentage for cows fed FL and OP compared with ISO could have resulted from greater ruminal starch digestibility increasing microbial protein production (NRC, 2001).

Ruminal fermentation parameters of cows fed the experimental diets are presented in Table 4. Ruminal pH and acetate molar percentage were lower ($P < 0.01$), propionate molar percentage was greater ($P < 0.01$), and acetate:propionate ratio was lower ($P < 0.01$) for cows fed FL and OP compared with cows fed ISO. Taylor and Allen (2005b) reported similar effects of a floury endosperm type on ruminal pH and acetate:propionate ratio when fed to lactating dairy cows. Molar percentage of ruminal butyrate was greater ($P < 0.05$) for cows fed FL and OP compared with cows fed ISO, and tended to be greater ($P < 0.07$) for FL than for OP. The concentration of ruminal ammonia nitrogen tended to be lower ($P < 0.10$) for cows fed FL and OP than for cows fed ISO. Hour of sampling relative to feeding affected ($P < 0.001$) ruminal pH, VFA, and ammonia nitrogen, but there were no hour × treatment interactions ($P > 0.10$). Ammonia nitrogen concentrations in

rumen samples obtained 4 h after the morning feeding, however, were affected ($P < 0.04$) by treatment (ISO = 15.6, FL = 9.7, and OP = 11.7 mg/dL). Ruminal fermentation parameters were indicative of greater ruminal starch digestibility (Allen, 1997) for FL and OP.

Results for ruminal in situ DM and starch disappearance from Dacron bags for the experimental corns are presented in Table 5. Zero-hour washout losses of DM and starch from the bags were 8 to 9 percentage units greater ($P < 0.01$) for FL and OP, on average, than for ISO; differences were most likely related to the reduced particle size for FL and OP because of the loss of fine particles through bag pores. Washout loss of starch was greater ($P < 0.001$) for FL than for OP even though the washout loss of DM was similar for these 2 types of corn; we have no explanation for this observation. Dry matter and starch disappearances after 8-h ruminal incubations were 24 and 32 percentage units greater ($P < 0.001$), respectively, for the average of FL and OP compared with ISO. Corresponding ruminal DM and starch disappearances were 18 to 20 percentage units greater after 16-h than after 8-h incubations. After 16-h ruminal incubations, disappearances of DM and starch were, on average, 20 and 28 percentage units greater ($P < 0.001$), respectively, for FL and OP than for ISO. Differences ($P < 0.05$) between FL and OP for 16-h DM and 8-h starch disappearances were minor (approximately 6 percentage units). These observations were similar to those of Taylor and Allen (2005a), who reported greater ruminal starch digestibility using ruminally and duodenally cannulated lactating dairy cows for floury than for vitreous corn.

Total-tract apparent nutrient digestibilities in cows fed the experimental diets are presented in Table 6. Starch digestibility was, on average, 6.3 percentage

Table 4. Effect of corn endosperm type on ruminal pH, VFA molar percentages, and ammonia nitrogen least squares means for samples obtained immediately before the morning feeding and then at 2, 4, 8, and 16 h postfeeding¹

Item	ISO	FL	OP	SEM	<i>(P <)</i>	
					ISO vs. FL, OP	FL vs. OP
pH ²	6.62	6.46	6.53	0.05	0.01	NS ³
Total VFA, ² mM	87.8	88.8	90.7	4.2	NS	NS
VFA, ² molar %						
Acetate	64.5	62.3	63.1	0.6	0.01	NS
Propionate	18.4	19.6	19.6	0.4	0.01	NS
Butyrate	11.9	13.1	12.3	0.4	0.05	0.07
Others ⁴	5.2	5.1	5.1	0.2	NS	NS
Acetate:propionate ²	3.51	3.21	3.30	0.08	0.01	NS
Ammonia nitrogen, ⁵ mg/dL	13.6	11.1	12.5	1.2	0.10	NS

¹Treatments were dry rolled shelled corn from W64A × OH43 (ISO), W64A × OH43 *fl2/fl2* (FL), and W64A × OH43 *o2/o2* (OP) varieties fed in TMR.

²Hour effect ($P < 0.001$) but no ($P > 0.10$) hour × treatment interaction.

³Not significant ($P > 0.10$).

⁴Iso-butyrate, 2-methyl butyrate, iso-valerate, and valerate.

⁵Hour effect ($P < 0.001$), no ($P > 0.10$) hour × treatment interaction, and effect of treatment ($P < 0.04$) at 4-h slice (ISO = 15.6, FL = 9.7, and OP = 11.7 mg/dL).

units greater ($P < 0.001$) for cows fed diets containing FL and OP than for cows fed ISO. Observed in vivo starch digestibility differences coincide with observed differences between the FL and OP versus ISO for vitreousness, prolamin protein content, degree of starch access, in vitro ruminal starch digestibility, and ruminal in situ DM and starch disappearances. The magnitude of the total-tract starch digestibility differences for cows fed diets containing ISO versus FL or OP was likely moderated by postruminal compensatory starch digestion (Taylor and Allen, 2005a). Taylor and Allen (2005a) reported ruminal and total-tract starch digestibilities to be 16 and 5 percentage units greater, respectively, for cows fed diets containing floury com-

pared with vitreous corn. Differences in laboratory and in situ measurements defining starch digestibility were small between FL and OP; likewise, no differences ($P > 0.10$) in total-tract nutrient digestibilities for cows fed diets containing these types of corn were observed. Digestibility of NDF was 5.8 percentage units lower ($P < 0.001$), on average, for cows fed diets containing FL and OP than for cows fed ISO. The reduction in total-tract NDF digestibility may have been related to greater ruminal starch digestibility for FL and OP influencing ruminal pH and VFA (Allen, 1997). A reduction in hindgut NDF digestion (Firkins, 1997) could also partially explain the reduced total-tract NDF digestibility observed in our study, but we collected no data

Table 5. Effect of corn endosperm type on least squares means for ruminal in situ corn DM and starch disappearance from Dacron bags¹

Item	ISO	FL	OP	SEM	<i>(P <)</i>	
					ISO vs. FL, OP	FL vs. OP
DM disappearance, %						
0-h	17.1	24.3	24.9	2.4	0.01	NS ²
8-h	38.7	60.7	64.4	2.4	0.001	NS
16-h	59.6	75.8	82.2	2.4	0.001	0.05
Starch disappearance, %						
0-h	9.5	24.9	11.8	2.9	0.01	0.001
8-h	34.7	69.6	63.3	2.9	0.001	0.05
16-h	57.3	85.7	85.2	2.9	0.001	NS

¹Treatments were dry rolled shelled corn from W64A × OH43 (ISO), W64A × OH43 *fl2/fl2* (FL), and W64A × OH43 *o2/o2* (OP) varieties fed in TMR. Added to the Dacron bags for in situ disappearance measurements were the ISO, FL, and OP corn as fed without further processing.

²Not significant ($P > 0.10$).

Table 6. Effect of corn endosperm type on least squares means for total tract apparent nutrient digestibilities^{1,2}

Item	ISO	FL	OP	SEM	<i>(P <)</i>	
					ISO vs. FL, OP	FL vs. OP
	————— % Digestibility —————					
DM	73.1	73.6	73.4	0.6	NS ³	NS
OM	73.6	75.3	75.1	0.8	0.06	NS
CP	74.6	75.1	74.6	0.6	NS	NS
NDF	60.3	55.1	54.0	1.4	0.001	NS
Starch	89.6	95.1	96.6	1.5	0.001	NS

¹Treatments were dry rolled shelled corn from W64A × OH43 (ISO), W64A × OH43 *fl2/fl2* (FL), and W64A × OH43 *o2/o2* (OP) varieties fed in TMR.

²Determined using 120-h indigestible NDF as an internal marker.

³Not significant ($P > 0.10$).

to evaluate this premise. The potential for a negative associative effect of greater starch digestibility on NDF digestibility warrants further study in dairy cows fed corn of varying endosperm composition. Because treatment effects on starch and NDF digestibilities were opposing and apparent CP digestibility was unaffected ($P > 0.10$), total-tract DM and OM digestibilities were largely unaffected by treatment except for OM digestibility, which tended to be greater ($P < 0.06$) by 1.6 percentage units for FL and OP compared with ISO.

CONCLUSIONS

In agreement with laboratory and in situ measurements, total-tract starch digestibility was greater for diets fed to lactating dairy cows that contained floury and opaque corns compared with a diet that contained vitreous corn. In contrast, apparent total-tract NDF digestibility was lower for diets containing the floury and opaque corns. Type of corn endosperm influenced starch and NDF digestibility in lactating dairy cows. The potential for a negative associative effect of greater starch digestibility on NDF digestibility warrants further study in dairy cows fed corn of varying endosperm composition.

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