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Waxy corn as a replacement for dent corn for lactating dairy cows

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Abstract

Waxy and dent corn starch differences were compared in diets of early lactating dairy cows. Thirty multiparous Holsteins averaging 568 ± 76 kg body weight (BW) and 50 ± 24 d in lactation were randomly assigned at two locations to three treatments to evaluate: (1) the extent to which replacing dent corn in the diet with recently developed waxy hybrids affects milk yield and composition; and (2) to document changes in the concentration of blood and ruminal metabolites of dairy cattle fed waxy corn compared to dent corn. A 3 × 3 Latin square design was used to test the treatments: control, (100% dent corn in grain mix), dent + waxy (50% dent and 50% waxy corn in grain mix), and waxy corn (100% in grain mix). Total mixed rations (TMR) formulated to be isonitrogenous at 17.2% crude protein and isocaloric at 1.72 Mcal net energy for lactation per kg of DM, were fed twice daily to individual cows in Calan gates (North Dakota State University Dairy Research Center) or in tie stalls (University of Minnesota, Crookston Dairy Research Center) for 15 weeks. Rumen, blood and milk samples were collected during the fifth week of each period. Ruminal acetate, isobutyrate, isovalerate and total volatile fatty acid (VFA) concentrations were lower ($P < 0.05$) when waxy corn was added to the diet. Serum urea nitrogen and milk fat percentage were decreased ($P < 0.05$) in rations where the grain concentrate was comprised of waxy corn. Blood glucose and insulin concentrations were unchanged ($P > 0.05$) by treatment. There was no difference in milk yield or total milk solids indicating similar lactational performance among treatments using waxy and dent corn. © 1998 Elsevier Science B.V.

Keywords: Waxy corn; Amylopectin; Starch; Dairy; Ruminant

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1. Introduction

The rapid development of waxy corn hybrids for the food industry has increased its availability as a feed source for livestock. It has been suggested that its structural composition could improve weight gain and feed utilization in beef cattle (Johnston and Anderson, 1992). However, there is limited data supporting anecdotal evidence of an improved performance response in milk production by dairy cattle.

Differences in animal performance have been attributed to structural changes in corn endosperm (Huntington, 1997). Amylose is a linear polymer of several thousand glucose residues linked by α (1,4) bonds. Amylopectin consists mainly of α (1,4) linked glucose residues, but is a branched molecule with α (1,6) branched points every 24 to 30 glucose residues. Nearly 100% of the starch in waxy corn is amylopectin, compared with common corn starch which is approximately 73% amylopectin and 27% amylose (Brown et al., 1984). Starch digestibility characteristics associated with amylopectin may alter ruminal fermentation characteristics (Braman et al., 1973; Streeter et al., 1991; Kotarski et al., 1992; Wester et al., 1992), and both milk yield and composition (Nocek and Tamminga, 1991) are affected by changes in the concentrations of the volatile fatty acids (VFA), propionate and acetate.

Considering the economic importance of optimal milk production and the currently limited research concerning the affects of waxy corn on ruminal fermentation, this study was designed to compare the affects of different starch sources on the performance of lactating dairy cows. The objectives were: (1) to determine the extent to which waxy corn affects milk yield and composition; and (2) to document changes in the concentration of blood and ruminal metabolites of dairy cattle fed waxy corn compared to dent corn.

2. Materials and methods

2.1. Experimental design

Thirty multiparous Holstein cows, fifteen cows at two locations (North Dakota State University, Fargo, and University of Minnesota, Crookston), were assigned to a 3×3 Latin square design. Treatments consisted of three rations of equal crude protein (17.2% CP) and energy (1.72 Mcal/kg) (National Research Council, 1989) which contained: control, (100% dent corn in grain mix), dent + waxy (50% dent and 50% waxy corn in grain mix), and waxy corn (100% in grain mix) on dry matter basis (Table 1). Concentrates were pelleted for uniformity. Completely blended rations of concentrate and forage were fed twice a day and fed throughout three 5-week periods. Observations, measures and sample collections were made during the fifth week of each feeding period.

2.2. Feed processing

Corn, soybean meal, beet pulp, vitamins, and minerals were incorporated into a 6.25 mm diameter pellet processed in a California Pellet Mill, Hy-Flow Model™. Meal was

Table 1
Ingredients and chemical composition of experimental rations for Holstein cows

Composition	Waxy corn, %		
	0	50	100
% Dry matter			
Formulated levels			
Crude protein	17.2	17.2	17.2
Acid detergent fiber	19.0	19.0	19.0
Neutral detergent fiber	25.0	25.0	25.0
Net energy for lactation (Mcal/kg)	1.72	1.72	1.72
Blended ingredients[a]			
Alfalfa hay	23.7	23.7	23.7
Alfalfa haylage	15.8	15.8	15.8
Sunflower seed	4.0	4.0	4.0
Concentrate (pellet)	56.5	56.5	56.5
% Concentrate			
Dent corn	52.0	26.0	0.0
Waxy corn	0.0	26.0	52.0
Soybean meal, 44%	12.8	12.8	12.8
Beet pulp	26.8	26.8	26.8
Constant ingredients[b]	8.4	8.4	8.4
% Dry matter			
Chemical analysis			
Dry matter	74.5	74.7	75.2
Crude protein	17.1	17.1	16.7
Lipid	3.6	3.6	3.6
Acid detergent fiber	23.5	25.2	24.1
Neutral detergent fiber	32.6	37.0	36.6
Calcium	1.20	1.21	1.19
Phosphorous	0.54	0.56	0.57

[a] Forage to concentrate ratio = 40:60.
[b] The 8.4% constant ingredients consisted of 2.0% molasses, 2.3% dicalcium phosphate, 1.6% trace mineralized salt (NaCl 95%), 1.6% sodium bicarbonate, 0.45% magnesium oxide, 0.45% Zinpro and vitamin A and D to supply 3200 IU/kg and 300 IU/kg, respectively.

conditioned using low pressure steam at 0.94 kg cm^{-2} to achieve 61.5 to 66.4°C prior to pellet pressing. Retention time for meal conditioning was approximately 8 to 10 s at an estimated 16 to 17% moisture.

2.3. Sample collection and analysis

Production responses were accessed by monitoring total dietary dry matter intake and milk yield. Sampling routine was standardized for both locations. Complete blended rations were fed twice daily in amounts to ensure a 5 to 10% weigh back, with intakes recorded daily using an electronic feeding gate system (American Calan, Northwood, NH) or individual compartments in a feed manger. Total mixed rations (TMR) and individual feed components (including pelleted feed) were sampled prior to the beginning of the feeding trial and during the fifth week of each of the three feeding periods.

Feed refusals, weighing approximately 1 kg/cow, were sampled during a three-consecutive day period of the same week. A subsample of the 3-day composite was made for each of the experimental (cow) units for analysis. Individual feed components, TMR and feed refusals were analyzed for dry matter (DM), crude protein (CP), ether extract, ash, calcium (Ca), and phosphorous (P) according Association of Official Analytical Chemists (1990) procedures. Acid detergent fiber (ADF) and neutral detergent fiber (NDF) were determined by methods of Goering and Van Soest (1970). Starch intake was estimated for corn only, based on the modal value of 72% DM of Huntington (1997).

Milk, blood and rumen fluid samples were collected during the fifth week of each of the three experimental feeding periods. Milk samples were taken from 4 consecutive milkings and composited; milk was analyzed for total protein (Kjeldahl), casein, fat (Babcock) and total solids using standard Association of Official Analytical Chemists (1990) procedures. Milk urea nitrogen (MUN) was determined using procedures described by Roseler et al. (1993) and Sigma Chemical (procedure 535). Milk weights were recorded daily. Blood samples were withdrawn via coccygeal vein 3 h post feeding at the end of each experimental period, centrifuged at $1500 \times g$ at 4°C for 20 min, and the serum was analyzed for glucose (Sigma Chemical; procedure 510), insulin (Diagnostic Products; CAC radioimmunoassay kit), total protein (Biuret method, Oser, 1965); and urea nitrogen (Sigma Chemical; procedure 640). Rumen fluid was similarly extracted 3-h post feeding via stomach pump. All samples were transported to the laboratory on wet ice. Rumen fluids were acidified using metaphosphoric acid (25% wt./vol.) according to Erwin et al. (1961) after determining pH and frozen until ammonia (Sigma Chemical; modified procedure 640) and further analysis were conducted. These samples were prepared for VFA determination (Baumgardt, 1964; Fritz and Schenk, 1979) and gas chromatographic analysis with the following conditions: column setting, 30 M $\times$ 0.32 mM Superox-FA (0.3 μM film) (Alltech Associates); detector, 250°C; injector, split at 250°C; and carrier gas, helium at 15 psi (68 cm/s).

2.4. Statistical method

The data were analyzed using SAS System for Linear Models (SAS® User's Guide: Statistics, 1988). The model was tested using the terms: location, treatment, treatment by location, period (location), group (location) and cow (group by location), where group represented five cows assigned to each of the six group–location combinations in the experiment. The error term to test for location and group (location) was cow (group by location). All means are reported as least square means. Differences were considered significant at $P < 0.05$. Details of the analysis of variance are in Table 2.

3. Results and discussion

3.1. Ration composition

Dietary treatments were formulated to be of the same composition except for the substitution of waxy for dent corn. All concentrates were prepared by the feed mill on

Table 2
Combined analysis of variance for two 3×3 latin squares for lactation trial

Source of variation	Degrees of freedom
Location	1
Treatment	2
Location by treatment	2
Period (location)	4
Group (location)	4
Cow (location by group)[a]	21
Error[b]	46

[a]Used as the error term for location and group (location).
[b]Used as the error term for treatment, location by treatment, period (location) and cow (location by group).

the North Dakota State University campus for both locations. Only the forages differed, and thus were unique to location inventory. Diets from both locations had similar percentages of DM, CP, lipid, ADF, Ca, and P (Table 2). All samples of TMR, however, had higher NDF than intended, partially attributable to the variation in fiber content of the ground alfalfa hay used at each site (40% vs. 53% NDF).

3.2. Milk production

The cows in the 100% waxy corn treatment had a higher dry matter intake (DMI) ($P < 0.05$) and estimated starch intake ($P < 0.05$) than the control and dent + waxy groups as shown in Table 3. The higher intake of DM resulted in a slightly lower energy efficiency calculation ($P > 0.05$). There were no differences among treatments in actual milk yield or yields adjusted for fat corrected milk (3.5% FCM) or solids corrected milk (SCM) (Table 4).

Table 3
Least square means for intake and feed efficiency of Holstein cows

Item	Waxy corn, %			
	0	50	100	SEM[1]
Intake				
Dry matter (kg/d)	22.02[a]	21.84[a]	22.80[b]	0.290
Starch (kg/d)[2]	4.13[a]	4.10[a]	4.28[b]	0.055
Efficiency[3]				
Energy	86.31	86.28	83.46	1.520
Protein	28.59	29.33	28.85	0.347

[1]Standard error of the mean, where $n = 10$ animals per treatment.
[2]Estimated starch content in the diet from corn (Huntington, 1997).
[3]Efficiency expressed as: energy = fat corrected milk (kg)/net energy (Mcal); protein = [milk protein (kg) × 100]/feed protein (kg).
[a,b]Means within a row without common superscripts differ ($P < 0.05$).

Table 4
Least square means for milk yield and milk composition of Holstein cows

Item	Waxy corn, %			
	0	50	100	SEM[1]
Milk yield (kg / d)				
Actual	36.0	36.4	36.4	0.438
3.5% Fat corrected milk	33.0	32.0	32.9	0.492
Solids corrected milk	37.2	36.4	37.3	0.510
Milk composition (%)				
Protein	3.00	3.02	3.02	0.020
Casein	2.02	2.03	2.00	0.022
Fat	3.01[a]	2.75[b]	2.91[a,b]	0.090
Total solids	11.68	11.54	11.67	0.086

[1]Standard error of the mean, where $n = 10$.
[a,b]Means within a row without common superscripts differ ($P < 0.05$).

Nearly 100% of the starch in waxy corn is amylopectin while typical dent corn contains starch that is about 27% amylose and 73% amylopectin (Brown et al., 1984). In addition, starch granules from different sources have widely different susceptibilities to glucoamylase hydrolysis (Kimura and Robyt, 1995). Since amylopectin is more easily broken down under laboratory conditions when compared with amylose, it was expected that the starch composed of amylopectin in waxy corn would be digested more quickly by the cow, reflecting differences in efficiency and milk yield.

3.3. Milk composition and rumen VFA

The dent + waxy corn treatment group had less milk fat than either the control or 100% waxy corn groups (Table 4). Total VFA concentrations were decreased in the cows on both diets with waxy corn, but only the individual VFA measures of acetate, isobutyrate and isovalerate were significantly different from the control (Table 5).

There is little that can be accomplished by management or nutrition to increase normal milk fat, but many factors may cause a reduction in individual milk components (Linn, 1988). With exceptions, feeding effects on milk fat percent can be related to changes in rumen function. Milk fat is closely related to propionate production ($r^2 = 0.84$) (McCullough, 1966), and it is adversely affected when ruminal propionate constitutes greater than 25 mol.% of the total ruminal VFA (Davis, 1978). Although the milk fat was lower than typical for the research herd at the time of this experiment, the molar ratio of acetate:propionate was greater than 2.5 which is considered optimal for maintenance of milk fat.

Propionate increases plasma concentrations of glucose and insulin (Palmquist and Conrad, 1971; Sutton et al., 1985) and thereby milk fat. It was anticipated that an increase in propionic acid would promote the synthesis of glucose which is one of the limiting nutrients in the biosynthesis of milk. However, we found no differences in actual or fat corrected milk yield in cows among dietary treatments. These data suggest

Table 5
Least square means for rumen VFA concentration, pH, ammonia, milk urea nitrogen, and blood serum metabolites of Holstein cows

Item	Waxy corn, %			
	0	50	100	SEM[1]
Rumen VFA (mM)				
Acetate (A)	75.33[a]	68.03[b]	68.43[a,b]	2.562
Propionate (P)	29.43	27.60	27.71	1.129
Butyrate	16.55	15.20	15.39	0.549
Isobutyrate	1.76[a]	1.54[b]	1.67[a,b]	0.059
Valerate	4.55	4.21	4.23	0.162
Isovalerate	2.74[a]	2.38[b]	2.58[a,b]	0.088
Total	130.36	118.96	120.01	4.189
A:P ratio	2.62	2.53	2.56	0.065
pH	6.27	6.36	6.40	0.056
Ammonia (mg/dl)	15.14	14.77	14.37	1.427
Milk				
Urea nitrogen (mg/dl)	12.18	11.62	11.95	0.242
Serum				
Insulin (μU/ml)	21.07	18.46	19.12	1.446
Glucose (mg/dl)	67.65	69.52	69.17	0.717
Urea nitrogen (mg/dl)	15.39[a]	14.51[b]	14.76[b]	0.201
Total protein (g/dl)	8.27[a]	8.20[a,b]	8.07[b]	0.056

[1]Standard error of the mean, where $n=10$.
[a,b]Means within a row without common superscripts differ ($P<0.05$).

that the increase in the dietary substitution of waxy corn was not sufficient under the conditions of this experiment to bring about a significant metabolic response.

3.4. Blood parameters

The levels of waxy corn in the diet did not affect serum insulin or glucose, but total serum protein and serum urea nitrogen were lower ($P<0.05$) when waxy corn was substituted at 50% or 100% of the dent corn (Table 5). The nature of the starch in waxy corn suggests that perhaps it was fermented faster in the rumen, decreasing microbial proteolytic activity and contributing to lower serum urea nitrogen. This would be expected with a higher proportion of the more digestible starch (amylopectin) inherent to waxy corn in these isonitrogenous diets. These data confirm the importance of considering starch sources and their degradability when preparing diets for high producing dairy cows.

3.5. Economics of waxy corn

Milk yield and compositional differences were not of a magnitude to suggest an advantage to waxy corn over dent corn as a livestock feed. Although we found no added economic advantages to feeding waxy corn to lactating dairy cows under the conditions of this experiment, there were no distinguishing disadvantages as well. When used in rations for lactating dairy cattle, herd managers can expect production performance from diets with waxy corn to be very similar to dent corn. Conditions and limitations of the use of waxy corn have yet to be adequately documented.

3.6. Considerations when processing waxy corn

Method of processing was not integrated into this research. In retrospect, it is noteworthy however, that since the diet was pelleted, this process may have diminished possible treatment differences. Methods used to process waxy corn may be an important factor to consider when substituting waxy hybrids for dent corn in the diet (Theurer, 1986). Studies by Kotarski et al. (1992) and Wester et al. (1992) show that starches from waxy cereal grains are among the most digestible of all starches, and their protein-starch structure is more easily altered when exposed to various processing techniques.

Subtle differences in starch granule structure affect both digestibility and the processing properties (Nocek, 1987; Rooney and Pflugfelder, 1986). According to Kimura and Robyt (1995), dent corn starch, is difficult to gelatinize (gelatinization temperature of 70°C), however, waxy corn starch, which has a gelatinization temperature of 65°C, is rather susceptible to heat processing. Therefore, the heat and pressure of pelleting used for this experiment may have unintentionally affected treatment responses.

4. Summary

Complete replacement of dent corn with waxy hybrids resulted in similar milk yield, milk composition, ruminal fermentation characteristics and modest differences in DMI. A 50:50 blend of dent and waxy corn tended to reduce concentrations of milk fat and ruminal acetate, yet there appeared to be a symbiotic interaction between amylose and amylopectin utilization. While acetate and, to a lesser extent, butyrate are important blood precursors for the synthesis of milk fat, the decrease in concentrates of acetate and the iso-forms of butyrate and valerate in the rumen had no effect on milk composition, apart from fat content which was inconsistent with level of waxy corn in the diet. Diets containing waxy corn were lower in serum urea nitrogen and tended to have lower ruminal VFA concentrations.

Rate and extent of starch digestion in the rumen are determined by intricate interrelations among several factors including source of dietary starch, diet composition, amount of feed consumed per unit time, mechanical alterations (grain processing, chewing), chemical alterations (degree of hydration, gelatinization), and degree of adaption of ruminal microbiota to the diet. Additionally, not all cows respond similarly to identical environmental and feeding conditions.

Waxy corn is an excellent feed for dairy cattle. Type and method of processing, energy level and protein content of the diet, and stage of milk production must be taken into account to make the best use of this feed. Under the conditions of our research, to pay a premium for waxy corn as a replacement for dent corn was not founded. This does

not preclude its importance as a feedstuff, but rather suggests that there is much more to understand about the differences in starch composition before precise recommendations can be made to maximize its use.

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