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Effects of NutriDense and Waxy Corn Hybrids on the Rumen Fermentation, Digestibility and Lactational Performance of Dairy Cows[1]

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ABSTRACT

The objectives of this study were to determine the effects of NutriDense and waxy corn hybrids as silage and grain sources on milk yield, milk composition, digestibility of dietary components, and rumen characteristics. Six multiparous (intact) and six primiparous (ruminally cannulated) Holstein cows were assigned at 72 to 90 d of lactation to a 3 × 6 Latin rectangle design experiment to treatment of: 1) control diet, 2) NutriDense corn diet, and 3) waxy corn diet. Diets consisted of 10.9% alfalfa silage, 32.8% corn silage, 27.9% cracked corn grain, and 28.4% other ingredients (DM basis). Milk, FCM, and milk fat and protein yields were higher for cows fed the waxy diet than those fed the control diet. Milk protein percentage tended to be higher for cows fed the control and waxy diets than those fed the NutriDense diet. Dry matter intake tended to be higher for cows fed the waxy diet than the NutriDense diet. Apparent DM, OM, CP, ADF, NDF, and gross energy digestibilities were similar among dietary treatments, while apparent starch digestibility was higher for the waxy corn than for the NutriDense corn. Rumen NH_3-N concentration was higher for cows fed the NutriDense diet than for those fed the control and waxy diets. The proportion of ruminal propionate was higher for the waxy diet than the control diet. NutriDense and waxy corn hybrids can be effective substitutes for conventional yellow dent corn hybrids in lactating dairy cow rations.
(**Key Words:** NutriDense corn, waxy corn, digestibility, dairy cows)

Abbreviation key: EE = ether extract, **NUTR** = NutriDense corn (diet).

INTRODUCTION

Corn harvested for silage or grain is a major component of dairy rations, often accounting for 40 to 60% of dietary DM. Many new corn hybrids, including high oil and waxy corn hybrids, have recently become the subject of renewed interest due to improvements in agronomic performance and our understanding of digestion and nutrient requirements (Dado, 1999). High oil corn hybrids have been evaluated for their nutritional value for dairy cattle (Atwell et al., 1988; LaCount et al., 1995; Weiss and Wyatt, 2000) due to the elevated level of oil content in the seed. High oil corn has a larger germ in the kernel than conventional yellow dent corn, and the protein content of the germ is normally higher than the rest of the kernel (Parsons et al., 1998). Therefore, high oil corn has a higher level of CP content than conventional yellow dent corn. A new corn hybrid, "NutriDense," has a minimum 1% unit higher oil and 1 to 2% units higher protein content compared with conventional yellow dent corn and contains greater amounts of essential amino acids, including lysine, sulfur amino acids, threonine, and tryptophan. High yielding dairy cows may benefit from the dietary inclusion of NutriDense corn because of its higher energy concentration compared with conventional yellow dent corn. Also, the composition of protein in NutriDense corn is derived from the amino acid contributions of the germ and is highly degradable in the rumen (Jerry Weigel, 1998, personal communication). Ruminal microbes could use ruminally available protein and starch from NutriDense corn to synthesize the microbial proteins. Waxy corn hybrids may also be especially beneficial to dairy cows due to composition of the starch. A branched polysaccharide known as amylopectin makes up nearly 100% of the starch in waxy corn, unlike conventional yellow dent corn, which is made up of only 75% amylopectin and 25% amylose. Because of the high digestibility of amylopectin in the rumen (Mohd and Wootton, 1984), it is believed that waxy corn may be more beneficial than conventional yellow dent corn for ruminants. Diets

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with increased ruminally available starch increase microbial protein synthesis (Sniffen and Robinson, 1987) and thereby increase amino acid flow to the duodenum of dairy cows (Poore et al., 1993a) if rumen pH is maintained. This results in higher milk yield and protein percentage (Poore et al., 1993b). Feeding waxy corn silage (Moreira et al., 2000) or waxy corn grain (Schroeder et al., 1996) to lactating dairy cows increased yields of milk and FCM yield compared with the conventional yellow dent corn silage or grain. The objectives of this study were to determine the effects of NutriDense and waxy corn hybrids used as silage and grain sources in the diets of lactating dairy cows on DMI, milk production and composition, total tract dietary component digestion, and rumen characteristics.

MATERIALS AND METHODS

Corn Silage and Grains

Corn hybrids, Exsegen 617 (conventional yellow dent corn), Exsegen 404ND (NutriDense corn), and Exsegen ESX4WX (waxy corn) from ExSeed Genetics, L.C.C. (Decatur, IL), were planted on the same day in adjacent 2.02-ha plots at the University of Kentucky Coldstream Research Farm during late April 1998. Fields had similar soils, and the same agronomic practices were used for all three corn hybrids. Approximately 0.81 ha from each of the 2.02-ha plots were harvested with a silage chopper on two consecutive days (NutriDense corn hybrid on the first day, and conventional and waxy corn hybrids the following day) for silage, at 67% whole plant moisture, and stored individually in 30.50-m long silage bags. Silage was stored for approximately 120 d before the start of the experiment. Each of the remaining 1.21 ha was harvested for grain when corn hybrids were field dried (88% DM), and the grain was stored in steel grain bins. During grain harvesting, three field replicates of each corn hybrid were taken in three different locations of the field for chemical analysis. Approximately 44 d after silage was packed, three replicates of each corn hybrid were taken in different locations from the silage bag by using a sampling probe connected to an electrical drill. Samples of grains and silage were dried in a forced-air oven at 55°C for 48 h (model 625, Precision Scientific Co., Chicago, IL) and then ground in a Wiley mill (Arthur H. Thomas, Philadelphia, PA) fitted with a 1-mm screen. Silage samples were analyzed for DM (lyophilized), CP (Leco FP-2000, Leco Corporation, St. Joseph, MI), ADF (Robertson and Van Soest, 1981), NDF (Van Soest et al., 1991), ash (500°C for 5 h), acid-detergent lignin (Robertson and Van Soest, 1981), and starch (Dado and Beek, 1998). Grain samples were analyzed for DM (105°C for 8 h), CP, starch, ash and ether extract (**EE**) (Soxtec System HT6, part no. 1000-1590, 9004, Tecator AB, Höganäs, Sweden).

Experimental Design and Diets

Six primiparous (79 ± 4 DIM) Holstein cows (square 1) were used in an experiment with a 3 × 6 Latin rectangle (Lentner and Bishop, 1993) design (two cows per treatment per period) to determine the effects of three corn hybrids fed as both grain and silage on milk production, milk composition, DMI, BW change, dietary component digestibility, and ruminal characteristics. Simultaneously, six multiparous (81 ± 9 DIM) Holstein cows (square 2) were used in an experiment with a 3 × 6 Latin rectangle design (two cows per treatment per period) to determine the effect of three corn hybrids fed as both grain and silage on milk production, milk composition, DMI, and BW change. Treatments were 1) conventional yellow dent corn (control) diet, 2) NutriDense corn (**NUTR**) diet, and 3) waxy corn (waxy) diet (Table 1). Primiparous cows were surgically fitted with soft plastic ruminal cannulas (10.2 cm i.d.; Bar Diamond, Parma, ID) at 25 to 35 d prepartum to assure complete healing before the start of the experiment. Experimental periods continued for 28 d. The first 14 d served as an adjustment period, and the last 14 d was the sample collection period. Cows were housed in individual tie stalls, had 24-h access to fresh water, and were allowed to exercise daily from 1300 to 1530 h. Diets were fed as TMR and consisted of 32.8% corn silage (control, NUTR, or waxy corn), 27.9% corresponding corn grains, 10.9% alfalfa silage, 9.77% soybean meal, 11.8% whole cottonseed, 3.36% corn distillers dried grains, 0.06% urea, and 3.43% mineral and vitamin supplements (DM basis) (Table 2). Forage to concentrate ratio was 1.2 to 1. Cows were fed the TMR twice daily at 0415 and 1600 h in amounts to ensure 5 to 10% feed refusal. Feed intake and orts were measured and recorded daily to determine DMI. Feed samples and orts from individual cows were collected for the last 7 d of each period and stored at −20°C until the end of each period. At the end of each period, samples of feed and orts were pooled, dried at 55°C for 48 h, ground through a 1-mm screen in a Wiley mill (Arthur H. Thomas, Philadelphia, PA), and analyzed for contents of DM, OM, CP, ADF, NDF, starch, and EE according to procedures described earlier, and energy (1261 Isoperibol calorimeter; Parr Instrument Co., Moline, IL). Cows were weighed on two consecutive days at the beginning and at the end of each period to determine BW change.

Milk Production and Composition

Cows were milked twice daily at 0400 and 1530 h, and milk weights were recorded at each milking. On d 23 and 28, a.m. and p.m. milk samples were collected to determine milk composition. Samples of milk were preserved with 2-bromo-2-nitropropane-1,3-diol and shipped by overnight delivery to the Mid-South DHIA Laboratory (Springfield, MO) for analysis. Samples of milk were analyzed for contents of CP, fat, and SCC by mid-infrared spectrophotometric analysis.

Apparent Digestibility of Dietary Components

Cows were dosed with 10 g of Cr_2O_3 via the ruminal cannula twice daily at 1200 and 2400 h on d 18 to 28 of each period to allow for determination of apparent digestibility of dietary components in the total tract. On d 23 to 28 of each period, fecal grab samples (approximately 150 g) were collected at 12-h intervals starting at 6 a.m.; collection times were postponed 2 h daily so that by the end of d 6, 12 samples had been collected, one for each even hour of the 24-h day. Fecal samples were frozen (–20°C) until the end of each period. Fecal samples were then thawed at room temperature, mixed well, pooled on equal wet-weight basis for each cow, dried at 55°C for 72 h, and ground through a 1-mm screen in a Wiley mill (Arthur H. Thomas, Philadelphia, PA). Samples were analyzed for DM (105°C for 8 h), OM, CP, ADF, NDF, starch, and energy according to procedures described earlier. Chromium contents of fecal samples were determined with a spectrophotometer as described by Fenton and Fenton (1979).

Table 1. Ingredient and chemical composition of TMR for cows fed conventional (control), NutriDense (NUTR), and waxy (waxy) corn as silage and grain.

Composition	Treatments		
	Control	NUTR	Waxy
	% of DM		
Ingredients			
Alfalfa silage	10.93	10.93	10.93
Normal corn silage	32.76	…	…
NutriDense corn silage	…	32.77	…
Waxy corn silage	…	…	32.80
Normal corn grain, cracked	27.93	…	…
NutriDense corn grain, cracked	…	27.92	…
Waxy corn grain, cracked	…	…	27.89
Whole cottonseed	11.76	11.76	11.76
Soybean meal, 48% CP	9.77	9.77	9.76
Corn distillers dried grains	3.36	3.36	3.37
Urea	0.06	0.06	0.06
Dicalcium phosphate	0.25	0.25	0.25
Calcitic limestone	1.71	1.71	1.71
White salt	0.32	0.32	0.32
Dynamate[1]	0.06	0.06	0.06
Magnesium oxide	0.21	0.21	0.21
Sodium bicarbonate	0.53	0.53	0.53
Trace mineral premix[2]	0.03	0.03	0.03
Selenium 90[3]	0.15	0.15	0.15
Vitamin ADE[4]	0.12	0.12	0.12
Vitamin E20[5]	0.05	0.05	0.05
Chemical composition			
DM, %	49.9	51.2	50.7
OM, % of DM	91.7	91.9	92.4
CP, % of DM	17.6	18.0	17.4
ADF, % of DM	20.0	19.6	19.2
NDF, % of DM	30.4	30.7	30.2
Starch, % of DM	22.2	21.9	23.5
Ether extract, % of DM	5.10	5.67	5.13
Gross energy, Mcal/kg of DM	4.53	4.54	4.54

[1]Contained 22.23% S, 18% K, and 11.67% Mg (IMC-Agrico Feed Ingredients, Bannockburn, IL 60015).

[2]Contained 16.01% S, 8.00% Mn, 8.00% Fe, 8.00% Zn, 4.00% Cu, 0.20% Co, 0.20% I, 0.02% K, 0.02% Mg, 0.0032% Cl, 0.004% Na, and 0.004% P.

[3]Contained 198 mg Se/kg.

[4]Contained 8,800,000 IU of vitamin A/kg, 1,760,000 IU of vitamin D/kg, and 1,100 IU of vitamin E/kg.

[5]Contained 44,000 IU of vitamin E/kg.

Table 2. Chemical composition of conventional, NutriDense, and waxy corn silage and grains.[1]

Item	Corn Hybrids			
	Conventional	NutriDense	Waxy	SEM
Corn Silage				
DM[2], %	35.1[b]	37.1[a]	36.9[a]	0.3
	% DM			
CP	9.08[b]	9.00[b]	9.53[a]	0.05
NDF	40.2[a]	39.6[a]	37.6[b]	0.5
ADF	22.9[a]	22.3[a]	20.9[b]	0.2
ADL[3]	2.19	2.42	2.16	0.09
Starch	29.8[b]	31.7[a]	31.1[ab]	0.5
Ash	4.90[a]	4.23[c]	4.38[a]	0.02
Corn grains				
	% DM			
CP	10.9[b]	11.6[a]	10.9[b]	0.1
Starch	62.9[b]	60.9[b]	68.5[a]	0.6
Ether extract	4.29[c]	6.26[a]	4.44[b]	0.03
Ash	2.20[b]	2.73[a]	2.12[b]	0.04

[a,b,c]Means within the same row without common superscripts differ ($P < 0.05$).

[1]Mean of three replicates.

[2]Freeze dried.

[3]Acid-detergent lignin.

Ruminal Fermentation

Ruminal fluid (75 ml) was collected from multiple sites in the rumen via ruminal cannula every 6 h during the last 6 d of each period. The sampling time was adjusted ahead 1 h daily so that, by the end of d 6, 24 samples had been collected, one for each hour of the day. Ruminal fluid was strained through two layers of cheesecloth and the pH (Corning M120, Corning Medical and Scientific Instruments, Halstead Essex, England) was immediately measured. Ten milliliters of rumen fluid was acidified with 2 ml of 25% (wt/vol) meta-phosphoric acid and stored at -20°C for later analysis of VFA by gas chromatography (Erwin et al., 1961), and NH_3-N (Weatherburn, 1967).

Statistical Analysis

Data on the composition of corn silage and grains were analyzed by ANOVA using the GLM procedure of SAS (1996). The model included the main effect of corn hybrid. Least significant differences were used to examine differences between means of corn hybrids. Differences were considered significant at $P < 0.05$.

Feed intake, milk composition, and production of milk, fat, and protein were analyzed by ANOVA using the GLM procedure of SAS (1996). Means were separated by PDIFF test. Differences were considered significant at $P < 0.05$, and trends were noted at $P < 0.10$. Except for BW change, the square × treatment interaction term in the model was not significant at $P < 0.20$; therefore, data were analyzed without interaction term in the model. The statistical model used was:

$$Y_{ijkl} = \mu + S_i + P_j + C_k(S_i) + T_l + (S_i \times P_j) + (S_i \times T_l) + e_{ijkl},$$

where

Y_{ijkl} = observation,
μ = overall mean,
S_i = mean effect of square i,
P_j = mean effect of period j,
C_k = mean effect of cow k,
$C_k(S_i)$ = mean effect of cow k within square i,
T_l = mean effect of treatment l,
$S_i \times P_j$ = interaction of square i and period j,
$S_i \times T_1$ = interaction of square i and treatment l, and
e_{ijkl} = residual error.

Apparent digestibility of dietary components was analyzed by ANOVA using the GLM procedure of SAS (1996). Means were separated by PDIFF test. Differences were considered significant at $P < 0.05$. The statistical model used was:

$$Y_{jkl} = \mu + P_j + C_k + T_l + e_{jkl},$$

where

Y_{jkl} = observation,
μ = overall mean,
P_j = mean effect of period j,
C_k = mean effect of cow k,
T_l = mean effect of treatment l, and
e_{jkl} = residual error.

Ruminal VFA, pH, and NH_3-N data were analyzed as repeated measures by MIXED procedure of SAS (1989). Means were separated by PDIFF test. Differences were considered significant at $P < 0.05$. The statistical model used was:

$$Y_{jklm} = \mu + P_j + C_k + T_l + e_{jkl} + M_m + (T_l \times M_m) + e_{jklm},$$

where

Y_{jklm} = observation,
μ = overall mean,
P_j = mean effect of period j,
C_k = mean effect of cow k,
T_l = mean effect of treatment l,
e_{jkl} = whole plot error,
M_m = mean effect of time m,
$T_l \times M_m$ = interaction of treatment l and time m, and
e_{jklm} = repeated subplot error.

One primiparous cow receiving conventional corn diet developed severe diarrhea and was removed from the experiment during period 3, and her data were not included in the statistical analyses.

RESULTS AND DISCUSSION

Nutrient Composition of Corn Hybrids and Diets

Chemical composition of conventional, NUTR, and waxy corn silages and grains are shown in Table 2. Waxy corn silage had lower NDF and ADF contents than conventional and NUTR corn silage, and starch content of NUTR corn silage was higher than for conventional corn silage. Crude protein content of waxy corn silage was higher than conventional and NUTR corn silages. Waxy corn grain had higher starch content than conventional and NUTR corn grains. The NUTR corn grain had higher concentration of CP, EE, and ash than conventional and waxy corn grains. Higher concentrations of CP and EE were also reported for high oil corn grain than conventional corn grain by Atwell et al. (1988).

Ingredients and chemical composition of experimental diets are shown in Table 1. Dietary treatments were isonitrogenous and isocaloric, and protein and energy met nutritional requirements (NRC, 1989). Dry matter, OM, CP, ADF, and NDF contents of TMR were similar among diets. Starch content of the waxy diet was numerically higher than the control and NUTR diets. The NUTR diet had numerically higher EE content than the control and waxy diets.

Table 3. Least square means for DMI, BW change, production efficiency, and yield of milk and milk components in cows fed conventional (control), NutriDense (NUTR), and waxy (waxy) corn as silage and grain.

	Treatments				
Item	Control	NUTR	Waxy	SEM[1]	$P<$[2]
DMI, kg/d	23.9[cd]	23.8[d]	24.4[c]	0.2	0.14
BW change, kg/28 d	4.69	–0.04	3.94	3.75	0.72
Milk yield, kg/d	33.0[b]	34.2[ab]	34.9[a]	0.5	0.06
3.5% FCM,[3] kg/d	34.2[b]	35.5[ab]	36.4[a]	0.5	0.03
Milk yield/DMI	1.38[b]	1.43[a]	1.43[a]	0.02	0.08
3.5% FCM/DMI	1.43[b]	1.49[a]	1.49[a]	0.02	0.05
Composition, %					
Fat	3.76	3.76	3.78	0.04	0.88
Protein	3.21[c]	3.15[d]	3.22[c]	0.02	0.09
Yield, kg/d					
Fat	1.23[b]	1.28[ab]	1.31[a]	0.02	0.04
Protein	1.06[b]	1.08[ab]	1.12[a]	0.02	0.08
SCC, (cells/ml)/1000	364.4	109.1	279.8	120.4	0.31
Log SCC	1.84[c]	1.67[d]	1.76[cd]	0.06	0.14

[a,b]Means in rows with no common superscripts differ ($P < 0.05$).

[c,d]Means in rows with no common superscripts differ ($P < 0.10$).

[1]Calculated as n = 12; n was 11, 12 and 12 for control, NUTR and waxy treatments, respectively.

[2]Main effect of treatment.

[3]3.5% FCM = 0.4324 (kilograms of milk) + 16.216 (kilograms of milk fat).

Feed Intake, Milk Yield, and Composition

Dry matter intake, milk yield, and milk composition are shown in Table 3. Dry matter intake tended to be higher for cows fed the waxy diet than for those fed NUTR diet. Milk yield, FCM yield, efficiency of milk and FCM, and fat and protein yields were higher for cows fed the waxy diet than cows fed the control diet. Efficiency of milk and FCM was higher for cows fed the NUTR diet than cows fed the control diet. Milk protein content tended to be lower for cows fed NUTR diet than for cows fed the control and waxy diets. Milk fat content was similar among dietary treatments. Feeding waxy corn silage (Moreira et al., 2000) or waxy corn grain (Schroeder et al., 1996) to lactating dairy cows increased yields of milk and FCM compared with the conventional corn silage or grain. Starch in waxy corn may be more digestible than that of conventional corn, and may therefore result in higher microbial protein synthesis and higher milk yield. Diets with increased amount of ruminally available starch increased microbial protein synthesis (Sniffen and Robinson, 1987) and thereby increase amino acid flow to the duodenum of dairy cows (Poore et al., 1993a) if rumen pH is maintained. This resulted in higher milk yield and protein percentage (Poore et al., 1993b). Increasing ruminally available starch in the diet of lactating dairy cows by steam flaking of corn or sorghum increased milk yield, FCM yield, protein percentage, and yields of protein and fat (Chen et al., 1994). Higher ruminal fiber digestibility and rate of fiber digestibility may have allowed the cows fed waxy corn to eat slightly more DM than their NUTR-fed counterparts. An in vitro study conducted in this laboratory (Akay et al., 1999) indicated that the fiber fractions of waxy corn silage had higher digestion values and rates than conventional and NutriDense corn silages. Highly digestible fiber will digest and pass through the rumen more quickly and will therefore occupy less space in the rumen over time (Allen et al., 1997).

Cows fed the NUTR had similar milk yield, FCM yield, and fat and protein yields compared with the those fed control diet; however, milk protein content tended to be lower for cows fed NUTR diet than those fed the control diet. These results were in agreement with an earlier study by Atwell et al. (1988), who reported that yield and composition of milk were similar among diets when lactating dairy cows were fed high oil corn grain and corn silage as opposed to conventional corn grain and corn silage. Feeding lactating dairy cows high oil corn silage had no effect on DMI, yields of milk, fat, and protein, and milk fat percentage; however, FCM yield was increased and milk protein percentage was decreased with high oil corn silage compared with conventional corn silage (Weiss and Wyatt, 2000). Dietary inclusion of high oil corn silage decreased the percentage of protein in milk only during the early lactation period when compared with the dietary inclusion of conventional corn silage (LaCount et al., 1995).

Somatic cell count was numerically higher for cows fed control diet than those fed NUTR or waxy diets. However, no differences were observed for SCC among treatments because of the high variability among cows. Log transformation of SCC indicated that cows fed the NUTR diet tended to have lower scores than those fed the control diet. High SCC would be expected to decrease milk yield. There was a statistically significant interaction between treatment and parity ($P = 0.14$) for BW change. Multiparous cows fed NUTR diet lost BW, while those cows fed the control diet gained BW. Because cows were weighed at the beginning and at the end of each period, it is not clear whether this difference in BW change among diets was due to treatment effects or gut filling effects of diets. Primiparous cows fed the NUTR or waxy diets had numerically higher BW gain than cows of similar parity that were fed the control diet. High yielding cows in early lactation need more nutrients to support their milk production than low yielding cows. If enough nutrients are not supplied to the high producing cows to support their milk yield, body reserves will be mobilized to support milk yield. Keery and Amos (1993) fed

Table 4. Least square means for apparent digestibility of dietary components in the total digestive tract for cows fed conventional (control), NutriDense (NUTR), and waxy (waxy) corn as silage and grain.

	Treatments				
Item	Control	NUTR	Waxy	SEM[1]	$P<$[2]
	%				
DM	56.0	55.1	57.5	1.1	0.33
OM	57.8	57.2	59.5	1.1	0.37
CP	58.5	59.8	58.2	0.6	0.17
ADF	37.5	35.8	35.0	1.2	0.42
NDF	35.7	35.9	34.3	1.6	0.76
Starch	83.4[ab]	82.0[b]	88.6[a]	1.6	0.05
Gross energy	55.6	54.6	57.3	1.7	0.32

[a,b]Means in rows with no common superscripts differ ($P < 0.05$).

[1]Calculated as n = 6; n was 5, 6 and 6 for control, NUTR and waxy treatments, respectively.

[2]Main effect of treatment.

primiparous and multiparous cows the same diet and reported that primiparous cows gained 8.7 kg of BW, while multiparous cows lost 1.5 kg of BW during wk 4 to 8. In the present study, however, cows were 11 to 12 wk in lactation.

Apparent Digestibilities

Apparent digestibilities of dietary components in the total tract are presented in Table 4. Apparent digestibility coefficients for DM, OM, and gross energy were numerically higher, and ADF and NDF were numerically lower for cows fed waxy diet compared with those fed control diet ($P > 0.05$). Starch digestibility was 8% higher for cows fed the waxy diet compared with those fed the NUTR diet. Poore et al. (1993a) found that total tract digestibility of OM and starch were higher for diets with higher ruminally available starch. Feeding dairy cows increasing dietary contents of ruminally available starch negatively impacts NDF and ADF digestibilities (McCarthy et al., 1989). El-Shazly et al. (1961) reported that microorganisms preferentially digest starch before digesting fiber. Starch digestion of the waxy diet in the rumen may be more rapid and extensive than for the control diet and, therefore, decrease ruminal pH (Table 5). Atwell et al. (1988) reported that apparent digestibility of DM was decreased with high oil corn grain but not with high oil corn silage compared with the conventional corn grain or silage, respectively. Also, Weiss and Wyatt (2000) reported that apparent digestibilities of OM, NDF, and starch were similar between a high oil corn silage diet and a conventional corn silage diet; however, apparent digestibility of CP tended to be higher for high oil corn silage than the conventional corn silage diet.

Ruminal Fermentation

Ruminal pH and concentrations of NH_3-N and VFA are shown in Table 5. There was no statistically significant treatment × time interaction for any parameters analyzed. The ruminal pH was lower for cows fed the waxy diet than those fed the control diet. Diurnal fluctuations of ruminal pH are shown in Figure 1. Ruminal pH gradually decreased after meals. Greater availability of ruminally digestible starch in the waxy diet decreased ruminal pH more than for the control diet. Ruminal NH_3-N concentration was higher for cows fed the NUTR diet than those fed the control or waxy diets at all time periods (Figure 1). This indicates that protein in the NUTR diet was highly degradable in the rumen, or that NH_3-N usage by ruminal microorganisms was slower than the breakdown of protein. NutriDense corn grain has less starch and more oil and protein in the grain than waxy corn grain (Table 2). Because starch is fermentable in the rumen and oil is not, a lesser quantity of starch in NutriDense corn may result in less microbial growth and microbial protein synthesis. Aldrich et al. (1993) reported that ruminal pH and NH_3-N concentration were higher when cows were fed ruminally available protein diets. The lower pH and acetate-to-propionate ratio for cows fed waxy corn diet compared with the control diet may reflect faster and more extensive starch degradation in the rumen. Feeding dairy cows ruminally available starch from barley compared with milo lowered ruminal pH and acetate-to-propionate ratio (Herrera-Saldana et al., 1990). Lykos et al. (1997) fed dairy cows varying levels of ruminally available total NSC and reported that ruminal pH and NH_3-N concentration were linearly decreased as ruminally available NSC increased in the diet. Ruminal NH_3-N concentrations were significantly lower in dairy cows fed ground high moisture corn (more digestible) versus those fed whole high moisture corn (less digestible) (Ekinci and Broderick, 1997). However, Herrera-Saldana and Huber (1989) did not observe reduced ruminal NH_3-N concentrations when rapidly degradable carbohydrates from barley compared to milo were fed. Mean NH_3-N concentrations for all diets at all times were higher (Figure 1) than the 5 mg/dl suggested to be optimal for synthesis of microbial protein (Satter and Slyter, 1974).

Ruminal total VFA concentrations were similar among diets (Table 5). Diurnal fluctuations of total VFA concentration are shown in Figure 2. Molar proportion of acetate decreased and propionate increased when cows were fed the waxy diet compared with those fed the control diet. Except for a few data points, the molar proportion of acetate was lower and propionate

Table 5. Least square means for rumen characteristics for cows fed conventional (control), NutriDense (NUTR), and waxy (waxy) corn as silage and grain.

Item	Treatments				
	Control	NUTR	Waxy	SEM[1]	$P<$[2]
pH	5.90[a]	5.83[b]	5.84[b]	0.05	0.04
NH_3-N, mg/dl	9.62[b]	11.1[a]	8.87[b]	1.1	<0.01
Total VFA, m*M*	150.8	156.1	155.9	21.8	0.17
Acetate (A), mol/100 mol	59.3[a]	58.2[b]	57.2[c]	1.9	<0.01
Propionate (P), mol/100 mol	21.1[b]	22.2[ab]	23.3[a]	1.7	0.03
Isobutyrate, mol/100 mol	2.89[b]	2.97[a]	2.81[b]	0.26	<0.01
Butyrate, mol/100 mol	12.6	12.4	12.8	0.5	0.73
Isovalerate, mol/100 mol	2.32[a]	2.34[a]	2.15[b]	0.11	0.02
Valerate, mol/100 mol	1.93	1.91	1.98	0.11	0.22
A:P	2.87[a]	2.72[ab]	2.51[b]	0.27	0.02

[a,b,c]Means in rows with no common superscripts differ ($P < 0.05$).

[1]Calculated as n = 6; n was 5, 6 and 6 for control, NUTR and waxy treatments, respectively.

[2]Main effect of treatment.

higher for cows fed the waxy diet than for those fed the control diet during a 24-h period (Figure 2). The ratio of acetate to propionate was lowest for cows fed waxy diet, and highest for cows fed control diet. Sharp et al. (1982) observed that a higher percentage of corn carbon was converted into propionate in steers fed ground (more digestible) versus whole corn (less digestible). Poore et al. (1993b) reported lower molar

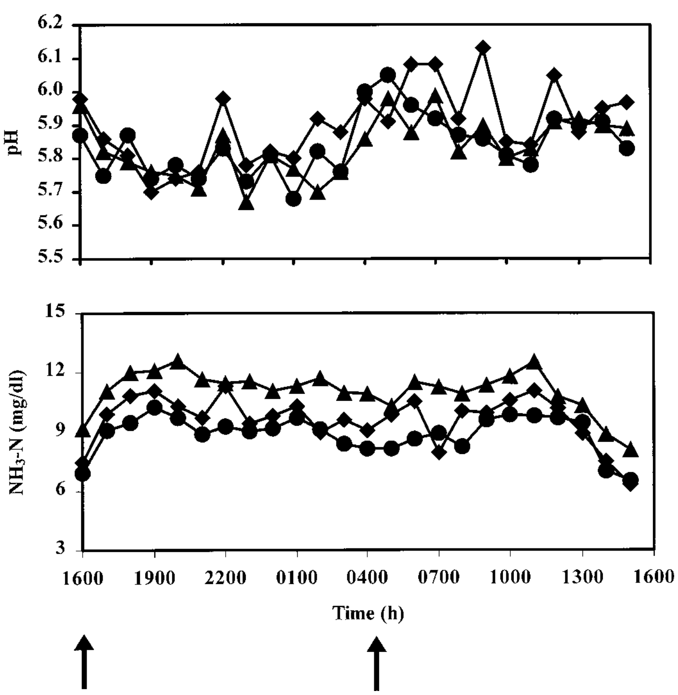

Figure 1. Means for ruminal pH and NH_3-N by hourly. Each point represents the mean of six observations of cows fed each diet, except the control diet (n = 5). Arrows indicate feeding times. Legend: control diet (♦), NUTR diet (▲), and waxy diet (●). Pooled standard errors for pH = 0.05 and for NH_3-N = 1.1.

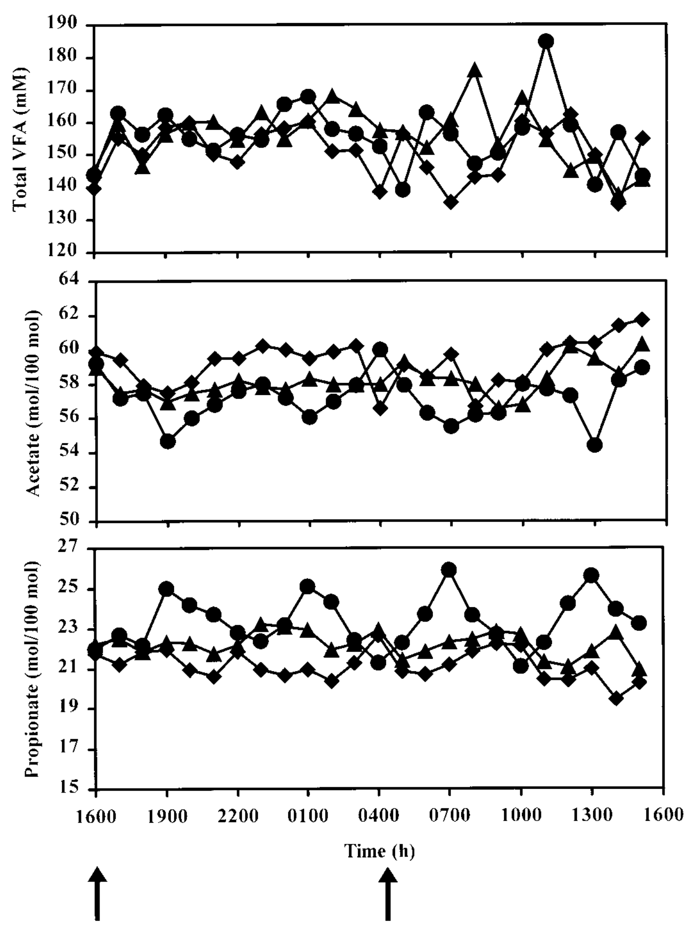

Figure 2. Means for concentrations of ruminal total VFA and proportions of acetate and propionate by hourly. Each point represents the mean of six observations of cows fed each diet, except the control diet (n = 5). Arrows indicate feeding times. Legend: control diet (♦), NUTR diet (▲), and waxy diet (●). Pooled standard errors for total VFA = 21.8, for acetate = 1.9 and for propionate = 1.7.

acetate percentage and acetate-to-propionate ratio, and higher molar propionate percentage when cows were fed steam-flaked sorghum grain diet compared with those fed dry-rolled sorghum grain diet. However, Lykos et al. (1997) reported an increased concentration of propionate and a decreased acetate-to-propionate ratio when cows were fed higher concentrations of ruminally available nonstructural carbohydrates. Molar proportion of acetate, and acetate-to-propionate ratio also were found to be higher for a high oil grain diet compared with a conventional corn grain diet (Atwell et al., 1988).

CONCLUSIONS

Data from this study indicate that cows fed the waxy corn diet produced more milk, FCM and fat than those fed the control diet. Milk protein percentage tended to be higher for cows fed the control and waxy diets than for cows fed the NUTR diet. Dry matter intake tended to be higher for cows fed the waxy diet than for cows fed the control diet. Efficiency of milk and FCM yields were higher for cows fed the NUTR and waxy diets than for cows fed the control diet. Apparent DM, OM, CP, ADF, NDF, and gross energy digestibilities were similar among diets; however, apparent starch digestibility was higher for the waxy diet than the NUTR diet. Cows fed the NUTR diet had higher ruminal NH_3-N concentration than those cows fed the control or waxy diets. Ruminal propionate percentage was higher for cows fed the waxy diet than those fed the control diet. NutriDense and waxy corn hybrids can be effectively included as silage and grain sources in substitution for conventional corn hybrids in lactating dairy cow rations.

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