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Effect of Different Rumen-degradable Carbohydrates on Rumen Fermentation, Nitrogen Metabolism and Lactation Performance of Holstein Dairy Cows

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ABSTRACT : Four multiparous lactating Holstein cows fitted with rumen cannulae were fed diets varying in the amount and source of rumen-degradable carbohydrates (starch vs. sucrose) to examine their effects on rumen fermentation, nitrogen metabolism and lactation performance. A 4×4 Latin square with four diets and four periods of 28 days each was employed. Corn starch and sucrose were added to diets and corn starch was replaced with sucrose at 0 (0 S), 2.5 (2.5 S), 5.0 (5.0 S) 7.5% (7.5 S) of diet dry matter in a total mixed ration (TMR) containing 60% concentrate and 40% forage (DM basis). Replacing corn starch with sucrose did not affect ($p>0.05$) ruminal pH which averaged 6.41, but the ruminal pH for 7.5 S decreased more rapidly at 2 h after morning feeding compared with other treatments. Sucrose reduced ($p\leq0.05$) ruminal NH_3-N concentration (13.90 vs. 17.09 mg/dl) but did not affect peptide-N concentration. There was no dietary effect on total volatile fatty acids (110.53 mmol/L) or the acetate to propionate ratio (2.72). No differences ($p>0.05$) in molar proportion of most of the individual VFA were found among diets, except for the molar proportion of butyrate that was increased ($p\leq0.05$) with the inclusion of sucrose. Total branched chain volatile fatty acids tended to increase ($p\geq0.051$) for the control treatment (0 S) compared with the 7.5 S treatment. Dry matter intake, body weight changes and digestibility of DM, OM, CP, NDF and ADF were not affected by treatments. Sucrose inclusion in the total mixed ration did not affect milk yield, but increased milk fat and total solid percentage ($p\leq0.05$). Sucrose tended ($p\geq0.063$) to increase milk protein percentage (3.28 vs. 3.05) and reduced ($p\leq0.05$) milk urea nitrogen concentration (12.75 vs. 15.48 mg/dl), suggesting a more efficient utilization of the rapidly available nitrogen components in the diet and hence improving nitrogen metabolism in the rumen. (**Key Words :** Sucrose, Rumen Degradable Carbohydrates, Rumen Fermentation, Nitrogen Metabolism, Lactation Performance)

INTRODUCTION

The efficiency of utilization of dietary N for milk protein synthesis in high- producing dairy cows is relatively low (19-21%) and loss of NH_3-N in the rumen is the main reason for this low efficiency (Tamminga, 1992). Rumen ammonia concentration is inversely related to the rate of energy fermentation and different studies (Hristov and Jouany, 2005) indicated that the efficiency of dietary N utilization will be improved when synchronization of carbohydrate and protein fermentation happened in the rumen Starch and sugars are the two dietary sources of energy for the high- producing dairy cows (Varga, 2003). Although these sources of carbohydrates besides other non-fiber carbohydrates are considered equal regarding fermentation characteristics, their fermentation produces different volatile fatty acid (VFA) profiles (Strobel and Russell, 1986; Ariza et al., 2001) and has varied effects on ruminal pH (Strobel and Russell, 1986; Khalili and Huhtanen, 1991), microbial product yield (Hall and Herejk, 2001; Sannes et al., 2002) and fiber digestion (Heldt et al., 1999; Miron et al., 2002). As documented in the Cornell Net Carbohydrate and Protein (CNCPS) model, sugars are considered to have a fast degradation rate, and starch an intermediate rate (Sniffen et al., 1992). Moreover, the CNCPS indicated that the organisms that ferment soluble sugars could contribute approximately 18% more microbial protein than the organisms that ferment starches in high moisture corn. This would imply that supplementation of dairy cows diets with sugars would result in more effective capture of rapidly available rumen degradable protein and improved supply of metabolizable protein to the dairy cow. Results of some studies showed that sucrose stimulates dry

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Table 1. Ingredients and chemical composition of diets fed to animals (% of DM)

Item	Treatments[1]			
	0 S	2.5 S	5.0 S	7.5 S
Ingredients				
Alfalfa hay	30.00	30.00	30.00	30.00
Corn silage	10.00	10.00	10.00	10.00
Barley grain	25.00	25.00	25.00	25.00
Wheat bran	6.50	6.50	6.50	6.50
Soybean meal	19.00	19.00	19.00	19.00
Sodium bicarbonate	0.62	0.62	0.62	0.62
Calcium carbonate	0.33	0.33	0.33	0.33
Vitamins and minerals	0.86	0.86	0.86	0.86
MagOx	0.19	0.19	0.19	0.19
Sucrose	0.00	2.50	5.00	7.50
Corn starch	7.50	5.00	2.50	0.00
Chemical composition				
DM	70.24	70.31	70.63	70.19
OM	92.13	92.75	92.88	92.47
CP	17.01	17.19	17.36	17.28
RDP (% of CP)[3]	68.12	68.12	68.12	68.12
RUP (% of CP)[3]	31.88	31.88	31.88	31.88
NDF	32.92	33.06	32.28	32.46
ADF	19.24	19.67	19.32	19.75
NFC[4]	40.05	40.32	41.23	40.56
NEL[3] (Mcal/kg)	1.67	1.67	1.67	1.67

[1] 0 S = 0% Sucrose, 2.5 S = 2.5% sucrose, 5.0 S = 5.0% sucrose, and 7.5 S = 7.5% sucrose of diet dry matter substituted for corn starch.

[2] Provided 65 mg of Zn, 51 mg of Mn, 22 mg of Fe, 15 mg of Cu, 0.9 mg of I, 0.5 mg of Co, 0.4 mg of Se, 6,640 IU of vitamin A, 2,500 IU of vitamin D, and 17 IU of vitamin E/kg of DM.

[3] Estimated using the NRC (2001) models.

[4] NFC = Non-fiber carbohydrate (organic mater-CP-ether extract-NDF).

matter intake (Broderick et al., 2000) and is effective in reducing ruminal ammonia concentration and increasing milk protein yield (Sannes et al., 2002). However, there is limited information about the effects of different sources of rumen degradable carbohydrates (starch vs. sucrose) on ruminal nitrogen metabolism, peptide nitrogen and animal performance The objective of this study was to determine the effects of two sources of carbohydrates with different rates of fermentation (starch vs. sucrose) on rumen nitrogen metabolism, peptide nitrogen, rumen fermentation and lactation performance of Holstein dairy cows, when corn starch was replaced by sucrose in the total mixed rations.

MATERIAL AND METHIODS

Cows, experimental design and diets

Four multiparous lactating Holstein cows (4 years of age), previously fitted with rumen cannulae (10 cm i.d.; Bar-Diamond Inc., Parma, ID), that averaged 665±45 kg in body weight (BW) and 170±22 days in milk (DIM) were used in this experiment. The surgery on animals was done according to procedures approved by the University of Tehran, Laboratory Animal Care Advisory Committee. Cows were housed in individual stanchions equipped with water bowls and bedded with rubber mats and straw. Cows had free access to salt stone. With the exception of the last day of each period when samples were being collected, cows were allowed to exercise in a dry lot from 1200 to 1300 h. Cows were fed a TMR at 0800 and 1900 h for *ad libitum* intake to allow 10% orts with half of the daily feed allotment offered at each feeding and were milked twice daily at the same time. The experimental design was a 4×4 Latin square with four periods of 28 days each. The first 21 d of each period were used to adapt the cows to treatments, and the remaining 7 d were used to collect data. Each cow was randomly assigned to one of 4 diets. Corn starch and sucrose were added to diets and corn starch were replaced with sucrose. The four experimental diets were: i) 7.5% corn starch+0.0% sucrose (0 S), ii) 5.0% corn starch+2.5% sucrose (2.5 S), iii) 2.5% corn starch+5.0% sucrose (5 S), and iv) 0.0% corn starch+7.5% sucrose (7.5 S) of diet dry matter in a total mixed ration (TMR) containing alfalfa hay, corn silage, barley, soybean meal and Min-Vitamin mixture. The ingredients and chemical composition of the diets are shown in Table 1.

Measurements and analytical methods

Body weight was measured at the beginning of period 1 (d 1) and at the end of each of the four periods (d 28) at the same time on each day. Dry matter intake and orts were measured and recorded daily. Samples of individual feed ingredients, TMR, and orts were collected for the last 5 d of each period. Samples of individual feedstuffs, TMR and orts (composited per cow and period) were dried at 55°C in an oven for 72 h, ground through a 1 mm screen in a Wiley Mill (Arthur Hill Thomas Co., Philadelphia, PA). Grab fecal samples (200 g per sampling) were collected from the rectum at 0800 and 1900 during the 5 days of each period. Samples were then composited per cow and period and oven-dried at 55°C for 72 h and then ground through a 1 mm sieve. Samples of individual feedstuffs, TMR and orts were analyzed for DM, OM, ether extract, Kjeldahl N (AOAC, 1999), NDF and ADF (Van Soest et al., 1991). Total-tract apparent digestibility of DM, OM, CP, NDF and ADF were determined using acid-insoluble ash (AIA; Van Keulen and Young, 1977).

Samples of ruminal fluid were collected from multiple sites in the rumen at 0, 1, 2, 4, 6, and 8 h post-a.m. feeding on the last two days of each experimental period. Samples of ruminal fluid were strained through two layers of cheesecloth and immediately the pH was measured using a portable pH meter with a combination electrode. Ruminal fluid (8 ml) from each collection at 0, 2, 4, 6 and 8 h was combined with 2 ml of 25% (wt/vol) metaphosphoric acid and frozen for VFA analysis and 20 ml was combined with 20 ml 0.2 N HCl (Robles and et al., 2007) and frozen for

Table 2. Least square means for ruminal fermentation parameters of lactating dairy cows fed diets with increasing levels of sucrose

Item	Treatments[1]				SE
	0 S	2.5 S	5.0 S	7.5 S	
pH	6.46	6.49	6.38	6.31	0.04
Ammonia N (mg/dl)	17.09 [a]	16.37 [a]	13.90 [b]	14.36 [b]	0.37
Peptide N (mg/L)	149.22	160.50	195.57	184.65	17.91
Total VFA (mmol/L)	105.38	112.35	113.24	111.17	3.89
VFA (mol/100 mol)					
Acetate (A)	61.01	61.15	62.11	61.28	1.41
Propionate (P)	23.38	23.22	22.44	21.86	0.44
Butyrate	11.76 [b]	11.94 [b]	12.35 [ab]	13.57 [a]	0.31
BCVFA [2]	3.85	3.69	3.10	3.29	0.17
A:P ratio	2.62	2.65	2.79	2.83	0.07

[1] 0 S = 0% sucrose, 2.5 S = 2.5% sucrose, 5.0 S = 5.0% sucrose, and 7.5 S = 7.5% sucrose of diet dry matter substituted for corn starch.
[2] Branched chain fatty acids. [a, b] Least squares means within the same row without a common superscript differ ($p<0.05$).

ammonia analysis. Thirty milliliters of ruminal fluid at 0, 2, 4, 6 and 8 h post-a.m. feeding, were collected for low molecular peptide-N concentration and prepared for analysis according to Chen et al. (1987). These samples were immediately centrifuged at 1,000×g for 10 min to remove protozoa and feed particles. The supernatant was then centrifuged at 30,000×g for 25 min to remove bacteria and then the supernatant was frozen for subsequent analysis. After thawing, ruminal fluid samples for VFA were centrifuged at 30,000×g for 20 min. Ruminal VFA concentration was measured in the supernatant by gas chromatography (model 5890, Hewlett-Packard, Avondale, PA) using a 1.8 m glass column packed with 10% SP 1,200/1% H_3PO_4 on 80/100 chromosorb WAW (Supelco, 1975). Nitrogen was the carrier gas and the temperature of the injector port and column was 175°C and 125°C, respectively. Ruminal NH_3-N was determined according to the procedures outlined by Crooke and Simpson (1971). Peptide-N concentration of rumen fluid samples (mg/L) was determined using the Kjeldahl method according to the procedures of Chen et al. (1987). Milk yields were calculated for the last week of each period. For compositional analyses, milk samples were collected from the a.m. and p.m. milking on two consecutive days (days 25 and 26), and analyzed for fat, protein, lactose, total solids (TS), solids not fat (SNF) and milk urea nitrogen (MUN) at the Central Milk testing Laboratory of Tehran.

Statistical analysis

Data were analyzed using the PROC MIXED procedure of SAS (version 8.1; SAS Institute Inc., Cary, NC). The following model was fitted to all variables that did not have repeated measurements over time:

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

Where Y_{jkl} is the dependent variable, μ is the overall mean, P_j is the effect of period j, C_k is the effect of cow k, T_l is the effect of treatment l, and ε_{jkl} is the residual error.

The following model was used for ruminal variables for which there were repeated measurements over time (pH, NH_3-N, VFA and Peptide-N):

$$Y_{jklm} = \mu+P_j+C_k+T_l+Z_m+ZT_{ml}+\varepsilon_{jklm}$$

where Y_{jklm} is the dependent variable, μ is the overall mean, P_j is the effect of period j, C_k is the effect of cow k, T_l is the effect of treatment l, Z_m is the effect of time m, ZT_{ml} is the interaction between time m and treatment l, and ε_{jklm} is the residual error. Various variance-covariance error structures were used, depending on which error structure produced the lowest Akaike's information criterion and Bayesian information criterion values for each variable. Considering this, the heterogeneous autoregressive structure ARH (1) was selected as the appropriate covariance structure. Differences between least squares means were considered significant at $p<0.05$, using PDIFF in the LSMEANS statement.

RESULTS AND DISCUSSION

Ruminal pH, nitrogen metabolism and volatile fatty acid concentration

In the present study, replacing corn starch with sucrose in TMR did not affect ($p>0.05$) mean ruminal pH and averaged 6.41 (Table 2), but the ruminal pH for 7.5 S diet decreased more rapidly at 2 h after morning feeding compared with other treatments (Figure 1). These results are consistent with some studies (Broderick et al., 2000), where ruminal pH of dairy cows was similar among treatments and averaged 6.19 and the results obtained by Sannes et al. (2002) in which ruminal pH was not affected by including 3.2% sucrose in the diet and averaged 6.02 .Our results were inconsistent with others (Khalili and Huhtanen, 1991; Lee et al., 2003) who reported a significant effect of sucrose inclusion in the diet on ruminal pH. Lee et

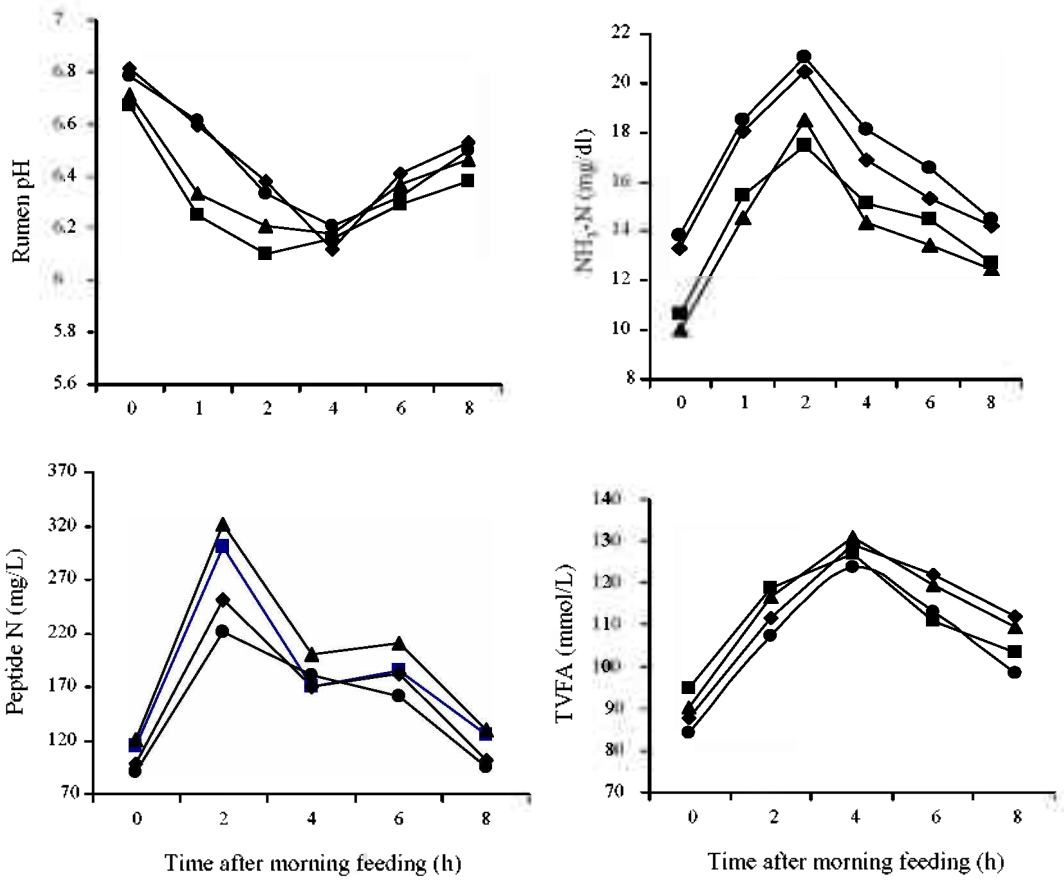

Figure 1. The effects of increasing level of sucrose in TMR on rumen pH, NH_3-N, peptide-N and total volatile fatty acids concentrations in lactating Holstein dairy cows. ■ 7.5 S; ▲ 5.0 S; ◆ 2.5 S; ● 0 S.

al. (2003) found a linear reduction in ruminal pH from 6.4 to 6.0 as sugar infusion levels increased. Differences between that study and our study could be attributed to the fact that in the study of Lee et al. (2003), sucrose infusion increased linearly the total content of NFC in the diet, whereas in our study, replacing sucrose for starch did not affect the NFC content in the diet (Table 1). Increasing levels of sucrose in diets compared with corn starch, reduced ($p \leq 0.05$) mean ruminal NH_3-N concentration (Table 2). Sannes et al. (2002) reported that ruminal ammonia concentration tended to be reduced from 4.92 to 3.89 mM with 3.2% sucrose inclusion in the diet of dairy cows. Other studies in which sucrose was included in the ration showed a reduction in ruminal ammonia N concentration (Broderick et al., 2000; McCormick et al., 2001; Lee et al., 2003). In another study (Vallimont et al., 2004), NH_3-N concentration was not affected by inclusion of sucrose in the diets and averaged 9.22 mg/dl. In the present study, the mean NH_3-N concentrations on all diets remained above the value of 5 mg/dl suggested (Satter and Slyter, 1974) as the minimum necessary for maintenance of ruminal bacterial growth. Fluctuations in NH_3-N concentration post a.m. feeding followed a similar pattern for all treatments, and treatment and hour were both highly significant ($p \leq 0.01$; Figure 1). NH_3-N concentrations increased during the 2 hours after the morning feeding, especially in the 0 S treatment (Figure 1). The reductions in ruminal NH_3-N for high-sucrose diets may suggest a more efficient utilization of the rapidly available nitrogen components in the diet and a concomitant increase in microbial growth and metabolism. Although no dietary effect on rumen peptide nitrogen ($p > 0.05$) was observed in this experiment, a none statistically significant accumulation of peptide-N for high-sucrose diets happened at 2 h post-feeding (Figure 1). Peptides which are intermediates in the conversion of ingested protein into ammonia in the rumen, are required for optimum microbial growth and their accumulation depends upon the nature of the diet (Mesgaran and Parker, 1995). Chen et al. (1987) found that peptides accumulated in the rumen when soybean meal was fed to dairy cows and suggested that microbial uptake of peptides, rather than the rate of cleavage of the polypeptide chain, is the rate-limiting step in protein degradation. Consequently, a transient accumulation of soluble N-fractions may indicate that parts of these fractions have an opportunity to escape the rumen.

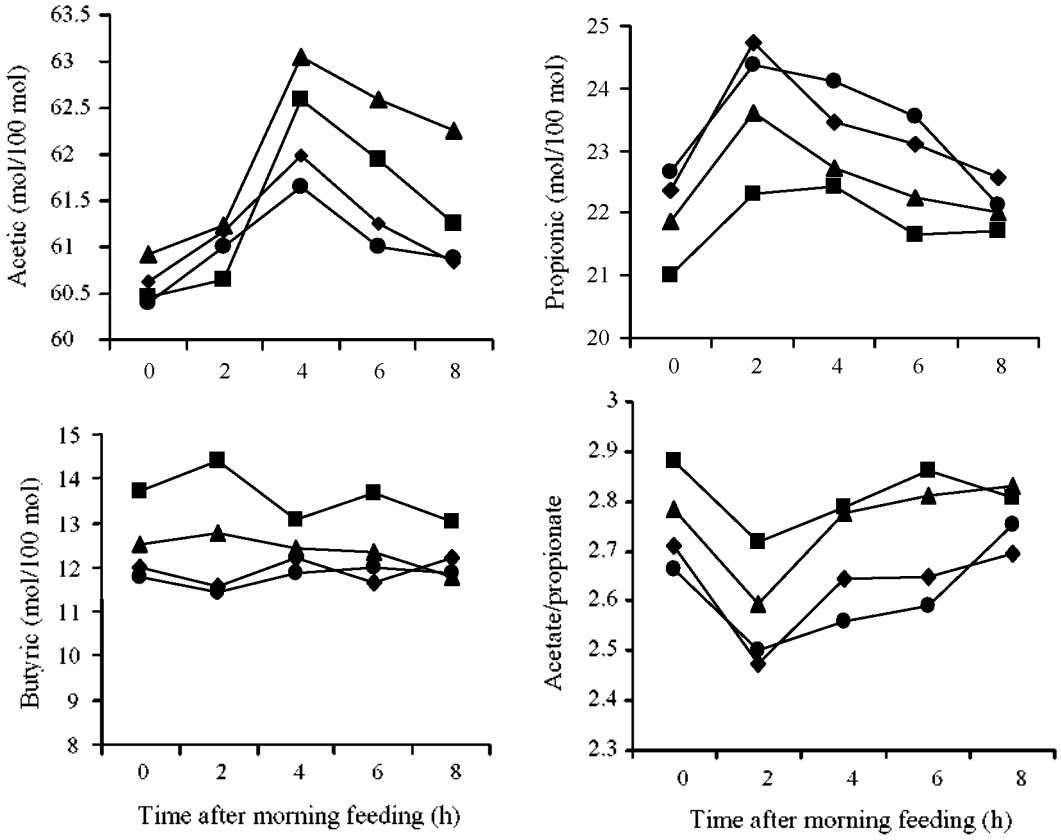

Figure 2. The effects of increasing level of sucrose in TMR on the molar proportions of individual fatty acids in lactating Holstein dairy cows. ■ 7.5 S; ▲ 5.0 S; ◆ 2.5 S; ● 0 S.

Wallace (1996) emphasized that if energy is insufficiently supplied or when the rate of peptide degradation exceeds the rate of AA used for microbial protein synthesis, peptide catabolism leads to excessive NH3 production. The concomitant decreases in ammonia concentration and increases in peptide nitrogen concentration in this study for high-sucrose diets showed that sucrose was more effective in controlling NH3 production and hence improving ruminal nitrogen metabolism than starch. Total VFA concentration was not affected ($p>0.05$) by replacing starch for sucrose and averaged 110.53 mmol/L (Table 2). Sannes et al. (2002) also reported no effect of including 3.2% sucrose in the diet on total VFA concentration (127.1 mmol/L), but Lee et al. (2003) reported a linear increase in total VFA concentration from 133.3 to 143.1 mmol/L as the amount of infusion of sucrose into the rumen increased linearly. Concentrations of VFA represent a balance between production and disappearance, and differences in production rate may not be apparent from VFA concentrations (Leng, 1970). In the present study no differences ($p>0.05$) in molar proportion of most of the individual VFA was found among diets (Figure 2), except for the molar proportion of butyrate that was increased ($p\leq0.05$) with the inclusion of sucrose in the diets (Table 2). Although not statistically significant ($p>0.05$), the acetate to propionate ratio was higher for 7.5 S diets compared with 0 S diets (2.83 vs. 2.62). This result confirmed the result obtained by Vallimont et al. (2004) who reported that sucrose supplementation increased molar proportions of acetate and butyrate, but not by Khalili and Huhtanen (1991) where molar proportions of acetate were decreased in response to sucrose supplement. Lee et al. (2003) reported significant decreases in quantities of propionate and butyrate, and increased acetate when fresh perennial ryegrass was fermented *in vitro* with increasing amounts of sucrose. In our study, sucrose tended to reduce ($p\geq0.051$) total branched chain VFA concentrations (Table 2). Sannes et al. (2002) also reported a decrease in total branched-chain VFA when a portion of the corn was replaced by sucrose in a TMR fed to lactating cows. The branched chain VFA are produced in the rumen from the deamination and decarboxylation of the branch-chained amino acids (Allison, 1970). Ruminal branched-chain amino acids may arise from feed protein or microbial protein, and differences in branched chain VFA concentrations probably reflect differences in one or both of these components. Broderick et al. (2000) observed that total ruminal AA were reduced with sucrose diets compared

Table 3. Least square means for apparent digestibility of nutrients through total tract of lactating dairy cows fed diets with increasing levels of sucrose

Item	Treatments[1]				SE
	0 S	2.5 S	5.0 S	7.5 S	
Apparent digestibility (% of DM)					
Dry matter	63.11	64.74	66.14	62.36	1.48
Organic matter	65.49	66.13	68.53	64.76	2.53
Crude protein	65.42	66.33	67.28	67.17	2.04
NDF	43.14	44.09	48.67	47.11	3.12
ADF	40.81	43.23	46.01	43.17	2.88

[1] 0 S = 0% sucrose, 2.5 S = 2.5% sucrose, 5.0 S = 5.0% sucrose, and 7.5 S = 7.5% sucrose of diet dry matter substituted for corn starch.

with starch diets; therefore, this may explain the reduced branched chain VFA with sucrose feeding. These differences in postfeeding VFA levels confirm that the ruminal fermentation was altered as a result of sucrose feeding.

Nutrient digestibility and lactation performance

Data of apparent digestibility of nutrients through the total tract are shown in Table 3. The digestibility of DM and OM were not affected ($p>0.05$) as sucrose replaced starch in the diet and averaged 64.08 and 66.22% respectively. Apparent digestibility of CP was not affected by the inclusion of sucrose in the diet and averaged 66.55%, but it was numerically higher for 5.0 S diets compared with 0 S diets (67.28 vs. 65.42%). In a review of molasses use in beef cattle nutrition, Pate (1983) discussed several studies that reported decreased DM and N digestibility when molasses was included in the ration depending on the level of molasses in the ration and concluded that the negative effects on nutrient digestibility were generally related to inadequate N to meet the needs of the rumen microbes or the animal, or both.

Inclusion of sucrose in the diet did not affect apparent digestibility of NDF and ADF ($p>0.05$) as sucrose increased in the diet, but was numerically higher for 5.0 S diet compared with 7.5 S and 2.5 S (Table 3). These results are consistent with the results obtained by Vallimont et al. (2004) who reported that sucrose supplementation increased apparent digestibility of NDF and ADF, but contrary to others (Huhtanen and Khalili, 1991; Khalili and Huhtanen, 1991; Heldt et al., 1999). The reduction in fiber digestibility in these latter studies may be due to the NFC- fermenting bacteria competing with the fiber-digesting bacteria for available N, and the inclusion of adequate quantities of RDP in the diet may prevent sucrose from decreasing fiber digestibility (Jones et al., 1998; Lee et al., 2003). However, Huhtanen and Khalili (1991) reported higher fiber digestibility with diets including 1 kg/d of sucrose fed twice daily. Based on the evaluation of experimental diets using the Cornell Net Carbohydrate Protein System (V4.026), the RDP in the diets fed in the current study was not limiting to NDF- or NFC-fermenting bacteria. Furthermore, decrease in fiber digestion can be attributed to a decrease in pH as a result of increased VFA production, or a "carbohydrate effect" (Mould and Ørskov, 1984). The carbohydrate effect refers to a preference by ruminal microorganisms for more readily available carbohydrates. In the current study, rumen pH (above 6.0) was not affected by dietary treatments which also explains the lack of rumen pH effect on fiber digestibility. The numerical increase in NDF and ADF digestibility for the 5.0% level of sucrose compared with the other levels of sucrose, especially the control diet, may reflect a shift in microbial populations or growth among the ruminal microbes present. It is not clear why increasing the level of sucrose from 5.0 to 7.5% of diet dry matter in this study, resulted in a slight decrease in the apparent digestibility of nutrients. It is possible that inclusion of high levels of sucrose in the diets stimulate sucrose utilizers to convert some portion of the sucrose to a storage polysaccharide. Although this storage polysaccharide is considered part of the microbial cell mass, it represents available substrate that has been stored but not yet metabolized by the cells. Therefore, when the sucrose concentration declined, they used their stores for maintenance of the microbial population (Hall and Herejk, 2001).

Intake, body weight change, milk yield and composition are shown in Table 4.

Although the inclusion of sucrose in the diets increased dry matter intake linearly, this increase was not statistically significant ($p>0.05$). Higher NDF fiber digestibility for high-sucrose diets partially accounts for the linear increase in DMI observed in this study (Table 4) and previous studies (Khalili and Huhtanen, 1991; Broderick et al., 2000). Nombekela and Murphy (1995) found that overall DMI was not enhanced by 1.5% sucrose supplementation compared with a control diet; however, sucrose transiently increased DMI during the first 2 wk postpartum. It is also possible that sucrose improved ration palatability or increased rate of passage from the rumen (Khalili and Huhtanen, 1991), enhancing the increment in DMI observed in our study (Table 4). There were no dietary effects ($p>0.05$) on BW change and milk yield. In this study, milk composition was affected ($p\leq0.05$) by inclusion of sucrose in the diets. Milk

Table 4. Least square means for intake, body weight (BW) change, milk yield and composition, and milk urea nitrogen (MUN) in lactating dairy cows fed diets with increasing levels of sucrose

Item	Treatments				SE
	0 S	2.5 S	5.0 S	7.5 S	
DMI (kg/d)	14.11	14.5	14.73	15.12	0.53
Milk (kg/d)	15.86	16.45	16.68	15.96	0.73
Fat (%)	3.47 [b]	3.51 [b]	3.75 [a]	3.88 [a]	0.06
Protein (%)	3.05	3.11	3.28	3.17	0.05
Lactose (%)	4.88	5.03	5.00	4.92	0.07
TS (%)	12.13 [b]	12.24 [b]	12.52 [ab]	12.67 [a]	0.12
SNF (%)	8.20	8.37	8.53	8.42	0.09
4% FCM (kg/d)	14.52	15.21	16.05	15.71	0.71
Yield (kg/d)					
Fat	0.55	0.57	0.64	0.62	0.03
Protein	0.47	0.50	0.55	0.51	0.02
Lactose	0.76	0.81	0.83	0.78	0.03
TS	1.90	2.03	2.08	2.01	0.08
SNF	1.29	1.38	1.41	1.34	0.05
MUN (mg/dl)	15.48 [a]	14.42 [ab]	12.75 [b]	13.31 [b]	0.60
BW change (kg/d)	0.57	0.47	0.44	0.50	0.06

[1] 0 S = 0% sucrose, 2.5 S = 2.5% sucrose, 5.0 S = 5.0% sucrose, and 7.5 S = 7.5% sucrose of diet dry matter substituted for corn starch.
[a, b] Least squares means within the same row without a common superscript differ ($p<0.05$).

fat (3.88 vs. 3.46%) and total solids percentage (12.67 vs. 12.13%) were increased by increasing level of sucrose (Table 4). Ordway et al. (2002) reported a numerical trend toward increased milk fat percentage (3.76 vs. 3.54%) when sucrose substituted for 2.7% ground corn in the prepartum diet. Broderick et al. (2000) reported an increase in milk fat percentage (4.16 vs. 3.81%) and yield (1.62 vs. 1.47 kg/d) in response to inclusion of 7.5% sucrose in diets. Butyrate is a substrate in *de novo* fatty acid synthesis (Van Soest, 1994), and the increased butyrate observed in the 7.5 S treatment (Table 2) might explain the increased milk fat production in cows supplemented with sucrose. Furthermore, the increase in the acetate to propionate ratio observed for high-sucrose diets post-feeding in the current study (Table 2) might help explain the increased milk fat and total solids. In our study, sucrose tended ($p\geq0.063$) to increase milk protein percentage (3.28 vs. 3.05%) and reduced ($p\leq0.05$) milk urea nitrogen concentration (12.75 vs. 15.48 mg/dl). These responses are consistent with the reduced ruminal NH_3-N concentration caused by sucrose (Table 2, Figure 1) and suggest a potential for improved nitrogen utilization efficiency (NUE).

CONCLUSION

Replacing corn starch with sucrose altered ruminal fermentation as evidenced by decreased proportions of branched chain fatty acids and increased butyrate at the level of 7.5% sucrose inclusion. Increasing levels of sucrose in the diet increased milk fat and total solids percentages and resulted in a numerical increase for NDF and ADF digestion, suggesting that rumen degradable protein was not limiting in these diets.

Given the increase in dry matter intake and the lack of significant reduction in ruminal pH or NDF digestibility observed in this study, sucrose supplementation in lactating cow diets might be beneficial. Adding sucrose to the control diet at 5.0% of diet dry matter decreased ruminal ammonia, milk urea nitrogen concentrations and tended to increase milk protein percentage compared with other treatments, all of which are indications of enhanced nitrogen utilization efficiency and indirectly show reduced nitrogen excretion to the environment which is critical for decreasing environmental pollution.

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