Effects of Corn Silage Processing and Amino Acid Supplementation on the Performance of Lactating Dairy Cows¹

D. R. Ouellet, H. Lapierre, and J. Chiquette

Dairy and Swine Research and Development Centre,
Agriculture and Agri-Food Canada, Lennoxville, Canada

ABSTRACT

This experiment was conducted to determine the effect of crop processing and amino acid supplementation on dairy cow performance. Corn silage processed (PCS) or unprocessed (UCS) was used as the main forage (45% of dry matter, DM) in a total mixed ration (TMR). Each TMR was either supplemented (AA) or not (AAO) with ruminally protected amino acids (lysine, 3 g/d and methionine, 14 g/d). Thirty-two (551 kg) Holstein cows were randomly assigned to four treatments: PCS-AA, PCS-AA0, UCS-AA, and UCS-AA0 in a 2 × 2 factorial structure. Between wk 7 and 17 of lactation, cows were fed ad libitum TMR comprising 45% of corn silage plus 1 kg of grass hay once a day. The UCS presented better fermentation characteristics than PCS. Dry matter intake (DMI) of the TMR was not affected by treatment and averaged 22.7 kg/d. Energy-corrected milk (ECM) production was 9% higher with UCS than with PCS (33.1 vs. 30.1 kg/d). Milk efficiency was therefore 6% higher with UCS than with PCS (1.43 vs. 1.35 kg ECM/kg of DMI). The concentration of major milk constituents (fat, protein, lactose, urea) was not affected by treatments. Apparent digestibility of DM, organic matter, N, starch, acid detergent fiber, and neutral detergent fiber were similar among treatments. The effective ruminal degradability of DM, starch, and protein, however, was greater with PCS than with UCS. Amino acid supplementation had no effect on milk production nor on milk constituents, whether it was used with processed corn silage or with unprocessed corn silage. These data indicate that feeding UCS resulted in a greater milk production compared with PCS. The numerically higher DMI, a potentially greater intestinal digestion of starch or the better conservation of UCS could have contributed to the greater milk production. (**Key words:** corn silage, kernel processor, amino acids)

Abbreviation key: AAO = no amino acid supplement, PCS = processed corn silage TMR, RPAA = ruminally protected amino acids, UCS = unprocessed corn silage TMR.

INTRODUCTION

Processing has been proposed to improve the feed value of corn silage (Harrison et al., 1996; Johnson et al., 1999). Mechanical processing can alleviate grain hardening and reduced digestibility associated with maturity. Likewise, processing can break coarse cobs and stalks, which are also subject to a decrease in quality with increased maturity (Johnson et al., 1999). Processing can also keep cows from sorting out cobs, which contain a high proportion of NDF. Processing, however, may result in a negative or negligible effect, especially in early maturity corn when the grain is milky and highly digestible (Demarquilly, 1994; Johnson et al., 1996). A review of European research by Demarquilly (1994) indicated that corn silage processing had little effect on ruminant performance, although less whole grain contents were found in the feces.

Whereas corn silage is a good source of energy in ruminant diets, its amino acid profile shows a relatively low content in lysine and methionine (NRC, 1989). The relative concentration of lysine and methionine in corn silage is only 45 and 85%, respectively, of the concentration of these amino acids in alfalfa silage at 10% bloom (NRC, 1989). Improvements of dairy cow performance have been reported when these two amino acids were included in corn-based diets in the form of an additive with a protective coating against ruminal breakdown (Schwab et al., 1976; Rogers et al., 1989; Chapoutot et al., 1992). However, increased starch degradation in the rumen through processing could result in improved microbial growth and therefore in increased supply of metabolizable protein, which could diminish the response to ruminally protected amino acids. A review of amino acid supplementation in dairy cows (Rulquin et al., 1995) indicated that the response was related to the relation between requirements and supply, determined by ingredients used to formulate the diet as well

Received June 10, 2002.

Accepted May 7, 2003.

Corresponding author: D. R. Ouellet; e-mail: ouelletd@agr.gc.ca.

¹Contribution Number 803 from the Dairy and Swine Research and Development Centre, Agriculture and Agri-Food Canada, P. O. Box 90, Lennoxville, QC, Canada J1M 1Z3.

as the physical form of these ingredients (see also Thomson, 1972).

The objective of this study was to determine the effect of corn silage processing in combination with amino acid supplementation on the performance of early lactating cows. Kinetics of ruminal degradation for DM, protein, NDF, and starch were also measured. This study evaluated whether there was any interaction between corn silage processing and ruminally protected lysine and methionine supplementation.

MATERIALS AND METHODS

Cows

Thirty-two Holstein cows ($551 \text{ kg} \pm 22 \text{ kg}$; primiparous, $n = 12$; multiparous, $n = 20$) were assigned to eight equal blocks. Cows were blocked within parity for similar calving dates. Each cow within a block was assigned randomly to one of four diets. The experiment was carried out from wk 7 to 17 of lactation. Cows were housed in tie stalls, fed individually, and milked twice daily at 0600 and 1800 h. Milk production was recorded at each milking. Milk samples were collected weekly from each cow for two consecutive milkings and were analyzed separately to determine milk composition. Live BW and BCS (five-point scale, 1 = very thin to 5 = extremely fat, measured in 0.5 increments) were recorded by the same barn staff member on three consecutive days at wk 7 and 17 of lactation. One cow suffered from severe mastitis during the project, and data collected from this cow were not included in the statistical analysis.

Diets

Four treatments were tested according to a 2×2 factorial design: processed (**PCS**) or unprocessed (**UCS**) corn silage TMR, supplemented or not with ruminally protected lysine and methionine. Two fields were planted with corn of 2250 and 2500 heat units, and 78 and 81 d to maturity. Before mechanical harvest, 33 strips consisting in 1 row $\times$ 7.32 m length were hand-harvested and indicated on average 80,735 plants/ha and 9667 kg of DM/ha. Whole-plant DM was 36.2% with 44.5% of DM composed of grains. Silage was harvested on 2 d, with the two types of processing equally distributed between the two fields. For crop processing, a prototype pull-type forage harvester (model 1218, Dion Machineries, Quebec) was modified to include two corrugated rolls as described by Roberge et al. (1998). The UCS was harvested with a conventional forage harvester (New Holland model 900, New Holland, PA). The forage harvester with processing rolls (4 mm between rolls) was set at a theoretical chop length of 12.7 mm while the forage harvester without processing rolls was

set at a theoretical chop length of 9.5 mm. Both harvesters were operated simultaneously.

High-dump trucks were used to transport corn to the silos. Samples of corn were taken at the blower at each odd trip number. Twenty-three samples for PCS and 19 for UCS were collected. From these samples, 750 g per sample was used to determine DM, and 10 kg per sample was used to evaluate mean particle length, using standard method S424.1 (ASAE, 1999). One kilogram of each sample collected at harvest was used to assess processing effect on grains. Proportion of visible grains (percentage of DM) was estimated and was also evaluated as intact (whole) grains, cracked (whole) grains, and broken grain particles usually greater than 2.5 mm and were separated manually from the non-grain mass (leaf, cob, and stalk particles). The proportion of cob slices (number/kg of DM) was also evaluated; this fraction included cob with grain, cob without grain, and stalk tip. Corn silage was harvested at two-thirds milkline. About 180 tonne of wet unprocessed corn was ensiled in a $5.5 \times 18.3\text{-m}$ ($18' \times 60'$) tower silo, whereas about 170 tonne of wet processed corn was ensiled in a $6.1 \times 24.4\text{-m}$ ($20' \times 80'$) tower silo. Silage height after consolidation was estimated from Table 1 of the engineering data D252.1 (ASAE, 1999). From the appropriate silo diameter, interpolation of silage height was estimated for 70 and 63 tonne of DM for UCS and PCS, respectively. Volume of the silo was estimated as $\pi \times r^2 \times \text{silage height}$.

Processed and unprocessed corn silage represented 44.6% of DM in PCS and UCS TMR. The TMR included also 18.8% cracked corn, 11.6% barley, 22.3% of a protein supplement (71% soybean meal, 22% soybean hulls, 6% blood meal, and 1% urea), and 2.7% of a mineral-vitamin mix to meet the energy and metabolizable protein requirements of dairy cows (NRC, 1989). Nutrient composition of the TMR is presented in Table 1. The TMR made from each type of corn silage was either supplemented (AA) or not (AAO) with ruminally protected amino acids (lysine, 3 g/d and methionine, 14.2 g/d; 6 g/d of Smartamine ML plus 19 g/d of Smartamine M, Rhône Poulenc Animal Nutrition). Using Rhône Poulenc Animal Nutrition database and software, basal diets were estimated to provide 174 g/d of lysine and 48 g/d of methionine, representing 6.81 and 1.75% of digestible protein, respectively. The amino acid supplements were estimated to bring the supply of lysine to 177 g/d and the supply of methionine to 62 g/d, increasing the ratio to 6.85 and 2.19% of digestible protein, respectively. The amino acid supplements were mixed with 100 g of cracked corn as a carrier and served as top dress once per day. Cows on AAO treatment received 100 g of cracked corn as a topdress placebo. The amount of TMR offered was planned to result in 5%

Table 1. Nutrient composition of the TMR.¹

	Unprocessed corn silage TMR ²	Processed corn silage TMR	SEM	P ³
DM, %	60.9	59.4	0.6	0.10
N, % of DM	2.62	2.58	0.02	0.20
NDF, % of DM	28.7	27.9	0.6	0.35
ADF, % of DM	16.2	16.4	0.4	0.81
Starch, % of DM	24.49	24.08	0.61	0.62
Ash, % of DM	6.6	6.5	0.1	0.20

¹Least square means with standard errors (SEM; number of samples = 4 and 5 for processed and unprocessed corn silage TMR, respectively).

²Each TMR was composed, on a DM basis, of 44.6% corn silage, 18.8% cracked corn, 11.3% barley, 22.7% protein supplement (composed of 71% soybean meal, 22% soybean hulls, 6% blood meal and 1% urea) and 2.7% mineral and vitamin mix.

³P = probability of a processing effect.

orts. The TMR was fed once a day between 1000 and 1100 h; orts were removed and weighed daily between 0800 and 1000 h.

All cows were treated and fed similarly before calving. After parturition and before the start of the experiment, all cows received hay ad libitum and a TMR based on PCS. Cows assigned to the UCS TMR treatment were introduced gradually to their experimental diets over a 7-d period starting on wk 5 postpartum. At the same time, daily hay consumption was reduced and then maintained at 1 kg/cow, throughout the experimental period.

Blood Sampling

A polyvinyl catheter was inserted into a jugular vein of each cow on the day before the end of the experiment. Seven hourly blood samples were collected into heparinized evacuated tubes from 0800 to 1400 h during the last day of the experiment, starting after the morning milking. Samples were placed on ice and analyzed the same day (Autoanalyzer II, Technicon Instruments Corporation, Tarrytown, NY) for urea nitrogen and alpha-amino nitrogen (Huntington, 1984).

Digestibility, Nitrogen Balance, and Ruminal Degradability

During wk 16 of lactation, total feces, urine, and milk were collected from each cow during 6 d as described by Petit et al. (1997). Daily composite samples representing 2% of feces, 2% of urine and 0.05% of milk were prepared for analysis. At each collection period, feeds were sampled daily and kept frozen, thawed to make a composite sample, and frozen until analysis. Feed and feces were analyzed for DM, OM, N, starch, ADF, and NDF. Urine and milk were analyzed for N content. These data were used to estimate the apparent total tract nutrient digestibility and the N balance.

Four ruminally cannulated nonlactating Holstein cows were fed the control diet, UCS-AA0, ad libitum. Forages incubated in the rumen were UCS, with mean particle length of samples used between 10 to 15 mm, and PCS with additional chopping, i.e., double chopping, to further reduce the length of cut between 10 to 15 mm, similar to that of UCS. This chopping was obtained using a food cutter for approximately 45 s. (Hobart Food Group Equipment, model 84145, Ontario, Canada). Fifteen grams (fresh weight) of each silage were placed in duplicate polyester bags (7.5 × 16 cm, 48-μm pore size) and incubated in the rumen of each of the four cows for: 0, 8, 24, 48, 72, 96, and 120 h. These incubations were repeated over six experimental periods.

Upon removal from the rumen, bags were treated as described by Chiquette et al. (1994). The forage remaining in the bags was analyzed for DM, N, NDF, and starch to allow for ruminal nutrient digestibility estimation. The average percentage of DM, N, NDF, and starch disappearances from the two bags withdrawn after each incubation time was used for statistical analysis. Data were fitted to the exponential equation of Ørskov and McDonald (1979):

$$P = a + b(1 - e^{-kt}),$$

where P is the proportion of forage constituent that has disappeared at time t, a is an intercept representing the portion of the constituent that is rapidly solubilized, b is the fraction potentially degradable, k is the rate constant of disappearance of fraction b, and t is the incubation time (h). Nonlinear parameters a, b, and k were estimated using NLIN, an iterative least-square procedure (SAS, 1996). The effective degradability was estimated according to the following equation of Ørskov and McDonald (1979):

$$ED = a + (b \times k) / (k + r),$$

where r is the estimated rate of outflow from the rumen and a , b , and k are parameters described earlier. A ruminal outflow rate of 0.04/h was assumed to estimate the effective degradability of the corn silage fractions.

Chemical Analyses

Dry matter and pH of corn silages were determined according to the methods of Dewar and McDonald (1961) and Playne and McDonald (1966), respectively. Dry matter of other feed ingredients was obtained by drying at 100°C for 48 h. Concentrations of D- and L-lactate in silages were determined according to the methods of Gawehn and Bermeyer (1974) and Gutmann and Wahlefeld (1974), respectively, with modifications described by Petit et al. (1997). Silage VFA were determined using gas chromatography (Petit et al. 1997). Protein N of silages was analyzed using an acidified extract (20 g of fresh sample in 200 ml of 0.01 N HCl agitated at 21°C for 22 h) and deproteinized with TCA (Siddons et al. 1979). Determinations of N and ammonia ($\text{NH}_3\text{-N}$) were done by the Kjeldahl method. The nonsequential procedures of Van Soest et al. (1991) were used to determine NDF and ADF concentrations in ingredients, TMR, Orts, and feces. Starch and ash content of ingredients, TMR, and feces were analyzed by a colorimetric method (kit 207 748; Boehringer Mannheim, Xygen Diagnostics, Burgersville, Canada) and by burning in an electric muffle furnace at 550°C for 24 h, respectively.

One portion of each milk sample was immediately frozen at -20°C, while a second portion was kept at 4°C using bronopol as a preservative and shipped weekly for determination of fat, protein, and lactose using near-infrared (B-2000; Bentley Instrument, Inc. Chaska, MN) according to AOAC (1990) procedures at the DHI laboratory (PATLQ, Ste-Anne-de-Bellevue, QC). Milk urea N was analyzed on frozen samples according to the methods of Broderick (1985). Purine derivatives in urine were analyzed by HPLC (Balcells et al., 1992). Blood urea N and alpha-amino N were analyzed as described by Huntington (1984).

Statistical Analysis

Data measured daily were averaged by week and subjected to analysis of variance according to a randomized complete block design with the treatments structured in a 2 × 2 factorial fashion. The data were analyzed using the repeated statement in the GLM procedure of SAS (1996). The model included the effects of corn silage processing, amino acid supplementation, in-

teraction of corn silage processing, and amino acid supplementation, week, and all interactions with the week effect. Average milk production and composition for wk 5 and 6 of lactation were used as covariate. Blood parameters measured over the 7 h were analyzed with the same model using the repeated statement with the profile option to test the slope between subsequent hours of sampling. Ruminal degradability was analyzed according to a randomized complete block design with animals as blocks and processing or not of the corn silage as treatments.

RESULTS AND DISCUSSION

Processing had a significant effect in reducing the number of coarse particles in the corn silage (Table 2). There were less visible cob slices, less visible grains, less intact grains and more broken grain particles after processing. The mean particle length, however, was not shorter with PCS compared to UCS (11.1 vs. 10.4 mm) because the harvester for UCS had been set at a shorter theoretical chop length. Dry matter content of UCS was higher than DM of PCS (38.9 vs. 37.1%). The two silages were stored in vertical silos of different sizes for reasons of availability. When silage height and density were calculated from Engineering Tables of Silo Capacities (ASAE, 1999), the UCS was calculated to be denser than the PCS (231 vs. 211 kg DM/m³). It is recommended to achieve a minimum of 225 kg of DM/m³ of density for corn silage (Muck and Holmes, 1999); this value was not obtained for the PCS. Using 20-L mini-silos, Johnson et al. (2002a) in two of three experiments observed a greater wet pack density for processed corn silage compared with unprocessed corn silage. A greater density normally results in better conservation because of less initial air present and less subsequent air infiltration thereby reducing oxidation and loss of nutrients (Muck and Holmes, 1999).

Visual examination of the corn silage treatments showed a lesser proportion of grain in PCS than in UCS. When the processor was activated, 16% of corn grains were pulverized compared with 5% when the processor was not activated (data not shown). The significantly higher level of ammonia ($\text{NH}_3\text{-N}$) in PCS indicated that more extensive degradation of protein occurred in PCS (Table 3).

Other fermentation characteristics were not significantly different between PCS and UCS. The UCS, however, tended to be better conserved: higher DM, lower pH, more lactic acid, and less acetic acid than in the PCS (Table 3). The compounding effect of several small differences may result in a significant effect in the overall feed value of UCS over PCS. Referring to studies published previously, Johnson et al. (2003) reported

Table 2. Physical characteristics of whole plant corn at harvest and estimated silage density¹

	Unprocessed corn	Processed corn	SEM	P ²
Harvester and theoretical chop length ³				
DM, %	38.9	37.1	0.39	0.02
Geometric MPL ⁴ (mm)	10.4	11.1	0.09	<0.001
Cob slices ⁵ (number/kg DM)	52.8	3.1	1.5	<0.001
Visible grains ⁶ (% of DM)	39.0	28.2	1.0	<0.001
Intact grains (% of VG)	48.3	12.9	1.1	<0.001
Cracked grains (% of VG)	10.7	12.4	0.9	0.35
Broken grains (% of VG)	41.0	74.7	1.3	<0.001
Silos used for storage: diameter × height ⁷				
Total harvested wet mass (t)	180	170	...	...
Estimated silage height ⁸ (m)	12.8	10.2	...	...
Average density (kg DM/m ³)	231	211	...	...

¹Least square means with standard errors (SEM; number of samples = 19 for unprocessed corn, and = 23 for processed corn).

²P = probability of a processing effect.

³Unprocessed corn : NH 900 set at 9.5 mm. Processed corn : Dion prototype set at 12.7 mm.

⁴MPL = mean particle length estimated by standard method S424.1 (ASAE, 1999).

⁵Cob slices are composed of cob with grain, cob without grain and stalk tips.

⁶Visible grains (VG) are composed of intact (whole) grains, cracked (whole) grains and broken grain particles usually greater than 2.5 mm that were separated manually from the non-grain mass (leaf, cob and stalk particles).

⁷Unprocessed corn : 5.5 × 18.3 m (18' × 60"). Processed corn : 6.1 × 24.4 m (20' × 80').

⁸Silage height after consolidation was estimated from engineering data D252.1 (ASAE, 1999).

that mechanical processing had minimal and inconsistent effects on silage fermentation characteristics.

Daily DMI was not statistically different (Table 4; $P > 0.05$) between treatments and averaged 22.7 kg/d. Average milk production (Figure 1) and energy-corrected milk were higher (Table 5; $P < 0.02$) for cows fed UCS TMR than for those fed PCS TMR. This resulted in an improvement of 6.2% in milk efficiency (Table 5; $P < 0.05$) when cows received UCS diet. This suggests that the nutritive value of PCS was lower than that of UCS. The decline in milk production observed in the

present study for cows fed PCS is larger than what was observed by others (Satter et al., 1999), and reasons for this are not totally clear from the parameters studied. Although not statistically significant, DMI was numerically lower in cows consuming PCS. The efficiency factor measured in this study (1.45 kg of milk/kg of DMI) would explain a decrease of 1.3 kg in milk production. In their review, Johnson et al. (1999) reported that milk production increased in several experiments when processed corn silage was compared with unprocessed corn silage. These increases in milk production, how-

Table 3. Chemical composition and fermentation characteristics of corn silages.¹

	Unprocessed corn silage	Processed corn silage	SEM	P ²
DM, %	43.1	42.0	0.7	0.26
pH	4.2	4.4	0.1	0.35
N, % of DM	1.13	1.15	0.04	0.85
Ammonia-N, % of total N	4.9	6.7	0.4	0.02
D-L-lactic acid, % of DM	2.2	1.8	0.3	0.29
Acetic acid, % of DM	3.2	4.2	1.4	0.60
Propionic acid, % of DM	ND ³	ND	...	...
Butyric acid, % of DM	ND	ND	...	...
Starch, % of DM	26.55	25.41	0.14	0.34
NDF, % of DM	41.8	39.4	1.3	0.23
ADF, % of DM	24.3	24.3	0.9	0.98
Ash, % of DM	3.7	3.6	0.1	0.81

¹Least square means with standard errors (SEM; number of samples = 4 and 5 for processed and unprocessed corn silage).

²P = probability of a processing effect.

³ND = not detectable.

Table 4. Dry matter intake, BW change, and BCS of Holstein cows fed a TMR based on processed or unprocessed corn silage supplemented or not with ruminally protected amino acids, between wk 7 and 17 of lactation.¹

Item	Unprocessed corn silage TMR ²		Processed corn silage TMR		SEM	Contrasts		
	AA	AAO	AA	AAO		Corn silage type	AA	Corn silage × AA
<i>P</i>								
DMI, kg of DM/d	23.2	23.0	22.4	22.1	0.5	0.14	0.65	0.92
DMI, % of BW	3.92	3.96	3.83	3.78	0.08	0.13	0.94	0.62
BW, kg								
wk 7	557	544	553	551	22	0.95	0.72	0.79
wk 17	622	617	630	611	25	0.98	0.63	0.77
BW change, kg/d	0.93	1.05	1.10	0.86	0.12	0.93	0.57	0.12
Body condition score								
wk 7	3.5	3.2	3.4	3.1	0.2	0.68	0.09	0.98
wk 17	3.0	3.2	3.3	3.3	0.1	0.05	0.55	0.16
BCS change	−0.5	0	−0.1	0.1	0.2	0.11	0.03	0.39

¹Least square means with pooled standard errors (SEM).

²AA = TMR supplemented with ruminally protected amino acids; AAO = no addition of ruminally protected amino acids.

ever, were accompanied by a proportional increase in DMI. Bal et al. (2000) reported an increase in milk production of 1.5 kg/d (4% FCM) with cows fed processed corn silage compared to those fed unprocessed corn silage. In their study, daily DMI expressed as % BW was similar between processed corn silage and unprocessed corn silage. However, Weiss and Wyatt (2000) and Schwab et al. (2002) reported no significant effect of corn silage processing on milk production. Dhiman et al. (2000) also reported no improvement in milk production for three different trials. Satter et al. (1999) summarized 11 experiments in which milk production was improved, equaled, or decreased when processed

corn silage was compared to unprocessed corn silage. The average response in milk production reported was 0.45 kg/d. Corn silage maturity, hybrid, and fiber length can affect the response to processing.

Cows fed PCS had a higher BCS at wk 17 than those fed UCS (Table 4; $P < 0.05$), most likely as a result of the lower milk production measured for the former group of cows. The RPAA supplement resulted in a slightly negative BCS change (Table 4; $P < 0.05$) when compared to cows receiving no supplement. There is no evidence why amino acids would increase fat mobilization and values of -0.3 units may not be metabolically significant.

Although milk component production increased in animals fed UCS (Table 5; $P < 0.07$), no effect on the concentration of major milk constituents was observed. Double-chopped corn silage has been reported to reduce milk fat concentration (Miller et al., 1969) in lactating cows. This observation was associated with the intake of finely ground material affecting effective fiber level into the rumen. A significant decrease in fat percent has been reported by Johnson et al. (1996) when cows were fed processed corn silage as compared with a control diet. When processed corn silage was compared to unprocessed corn silage, the number of particle sizes greater than 19 mm was lower, whereas the number of particles shorter than 8 mm was higher (Johnson, 1996), supporting the hypothesis of effective fiber on milk fat content (Woodford et al., 1986). In the present experiment, the mean particle lengths were significantly different, but the difference was of a relatively small magnitude (10.4 vs. 11.1 mm for UCS and PCS, respectively), thereby explaining the lack of any effect on milk fat content.

Figure 1. Milk production during early lactation of cows fed processed (PCS) or unprocessed corn silage (UCS) in a total mixed ration (averaged over amino acid supplementation which was not significant).

Table 5. Milk production and composition of Holstein cows fed a TMR based on processed or unprocessed corn silage supplemented or not with ruminally protected amino acids, between wk 7 and 17 of lactation.¹

Item	Unprocessed corn silage TMR ²		Processed corn silage TMR		SEM	Contrasts		
	AA	AAO	AA	AAO		Corn silage type	AA	Corn silage × AA
<i>P</i>								
Milk Production, kg/d	36.9	37.4	34.2	33.7	1.2	0.02	0.99	0.68
ECM ³ , kg/d	32.9	33.3	29.6	30.6	1.1	0.02	0.52	0.78
Milk composition, %								
Fat	3.38	3.26	3.13	3.47	0.16	0.89	0.48	0.17
Protein	3.26	3.10	3.13	3.13	0.06	0.40	0.23	0.15
Lactose	4.64	4.68	4.64	4.66	0.03	0.56	0.35	0.77
Milk urea N, (mg of N/dL)	11.9	12.4	11.7	11.9	0.3	0.23	0.44	0.90
Milk component production, kg/d								
Fat	1.21	1.19	1.03	1.15	0.06	0.07	0.39	0.27
Protein	1.16	1.14	1.05	1.03	0.05	0.02	0.62	0.91
Lactose	1.70	1.75	1.55	1.55	0.07	0.02	0.66	0.75
Milk efficiency (kg of ECM/kg of DMI)	1.44	1.46	1.32	1.41	0.04	0.05	0.18	0.45
Purine derivatives (mmol/d)	420	396	439	344	34.4	0.62	0.09	0.30

¹Least square means with pooled standard errors (SEM).²AA = TMR supplemented with ruminally protected amino acids; AAO = no addition of ruminally protected amino acids.³ECM = energy-corrected milk.

Kinetics of ruminal degradability are shown on Table 6. Processing resulted in a greater ($P < 0.01$) disappearance of the rapidly degradable fractions of DM, protein, and starch. Plant tissues were effectively more damaged after processing that increased the loss of soluble nutrients (Hintz et al., 1999). The slowly or potentially

degradable fraction of DM and protein decreased ($P < 0.01$) as a result of processing. Similar results were obtained by Savoie et al. (1999). The lower potentially degradable fraction of DM and protein observed for PCS is a consequence of the reverse relationship between soluble fraction and the former fraction. Processing in-

Table 6. Effect of processing corn silage on kinetics of ruminal degradability in non-lactating fistulated Holstein cows.¹

Items	Kinetic parameters			
	Rapidly degradable fraction, a (%)	Potentially degradable fraction, b (%)	Disappearance rate of b fraction (% h ⁻¹)	Effective degradability (%)
Dry matter				
UCS ²	32.6	50.6	2.5	52.1
PCS ³	36.6	44.9	2.4	53.1
SEM	0.2	0.7	0.1	0.5
P	<0.01	<0.01	NS	<0.05
Protein				
UCS	46.3	35.1	3.6	62.6
PCS	55.6	24.5	5.6	68.5
SEM	0.2	0.3	0.4	0.5
P	<0.01	<0.01	<0.03	<0.01
Starch				
UCS	67.0	31.8	7.2	84.5
PCS	69.1	32.4	7.7	87.9
SEM	0.2	1.6	1.2	0.6
P	<0.01	NS	NS	<0.03
NDF				
UCS	3.9	76.3	1.7	25.5
PCS	5.1	72.5	1.5	24.1
SEM	1.6	5.3	0.2	1.8
P	NS	NS	NS	NS

¹Least square means with pooled standard errors (SEM).²Unprocessed corn silage.³Processed corn silage.

Table 7. Apparent total tract nutrient digestibility and N balance for lactating Holstein cows fed a TMR based on processed or unprocessed corn silage supplemented or not with ruminally protected amino acids.¹

Nutrient	Unprocessed corn silage TMR ²		Processed corn silage TMR		SEM	Contrasts		
	AA	AAO	AA	AAO		Corn silage type	AA	Corn silage × AA
— Apparent digestibility of nutrient (%) —						<i>P</i>		
DM	71.0	71.0	70.3	71.0	0.8	0.69	0.67	0.67
Organic matter	72.5	72.5	71.8	72.7	0.8	0.77	0.59	0.60
N	70.9	70.6	70.3	70.7	1.1	0.84	0.97	0.74
Starch	92.7	94.5	93.8	94.0	0.7	0.64	0.17	0.24
ADF	57.1	56.9	56.1	57.3	1.4	0.85	0.73	0.62
NDF	61.8	60.5	59.6	62.3	1.3	0.84	0.56	0.12
— N balance (g/d) —								
N intake	602	576	640	601	32	0.32	0.29	0.85
Feces	174	169	190	178	12	0.30	0.46	0.75
Urine	220	230	225	209	11	0.46	0.79	0.25
Milk	175	168	172	162	11	0.69	0.44	0.90
N retained	33	9	53	52	14	0.03	0.34	0.38

¹Least square means with pooled standard errors (SEM); measured on week 16 of lactation.

²AA = TMR supplemented with ruminally protected amino acids; AAO = no addition of ruminally protected amino acids.

creased ($P = 0.03$) disappearance rate of the protein only. When taking into account the ruminal outflow rate in the calculation of degradability, the effective degradability of plant DM, protein, and starch increased ($P < 0.05$) with processing. The increase in effective degradability of corn silage DM, protein, and starch following processing was due to the greater solubility of these constituents associated with the mechanical treatment used. Increase in ruminal starch digestibility of processed corn silage has been reported in several studies (Bal et al., 2000; Johnson et al., 2002b). Effective degradability of corn silage NDF was not affected by processing. Savoie et al. (1999) also observed an increased ruminal effective degradability for DM and protein when corn was processed similarly, and no effect of corn fiber.

Differences in ruminal degradabilities after processing were not large enough to impact on total tract digestibility (Table 7). Bal et al. (2000) reported increases of 4.2 percentage units in total starch digestibility when ruminal degradability of starch was increased by 19.5 units. Incorporation of silages in the TMR most likely contributed to further mask the small effect of processing.

Another contributing factor to decreasing milk production could be the apparent shift in the site of starch digestion (Nocek and Tamminga, 1991). Although digestibility of PCS was greater than that of UCS at the rumen level (Table 6), total digestibility was the same between the two TMR (Table 7). This implies that UCS was more digested postruminally than PCS. Studies suggest that starch digested postruminally is used more

efficiently for milk synthesis than that digested in the rumen (Nocek and Tamminga, 1991). Indeed, the decrease in duodenal starch supply could also explain part of the decrease in milk production in cows fed PCS. Using ruminal data from the present study, with a rate of passage of 4%, effective ruminal degradability of starch was estimated to be 84.5 vs. 87.9% for UCS and PCS, respectively (Table 6). As a result, there would be a 101 g/d decrease in duodenal supply of starch from corn silage contained in PCS, equivalent to 1.6 kg of milk (assuming a factor of 1.1 to convert starch to glucose, an intestinal starch digestibility of 90%, and a ratio of 0.74 for milk lactose output/mammary gland glucose uptake; Danfr, 1994).

In the present experiment, dairy cows had a lower nitrogen retention when fed UCS compared with PCS (21 vs. 53 g/d, respectively; Table 7; $P < 0.03$). This could partly be explained by the cumulative effect of nonsignificant trends such as a lower N intake and a higher N output in milk and in urine for cows fed the UCS TMR (Table 7).

Blood urea nitrogen concentration was not affected by treatments and varied with time ($P < 0.001$; Figure 2). Concentrations increased 3 h after cows were back from milking parlor, having free access to their non-eaten portion of their previous meal. Treatments did not have any effect on blood alpha-amino nitrogen concentration, which decreased ($P < 0.001$; Figure 3) over the sampling period. Although cows were eating during this period, this decrease might be related to stimulated insulin secretion observed after meal (Bassett, 1975),

Figure 2. Blood urea nitrogen concentration after morning milking in cows fed processed (PCS) or unprocessed corn silage (UCS) supplemented (AA) or not (AA0) with ruminally protected amino acids, after 10 wk of treatment.

which can induce amino acid uptake by tissues (Huntington and Prior, 1985).

The addition of ruminally protected methionine and lysine affected urinary purine derivatives excretion (Table 5). Purine derivatives indicated a trend ($P < 0.09$) for ruminally protected methionine and lysine to increase, microbial mass production by 16%. This could be related to the beneficial effect of lysine and methionine release in the rumen. Previous experiments reported some release of the pH-sensitive product in the rumen (Robert and Williams, 1997). Arambel et al. (1987) reported a 35% increment of the total N reaching the duodenum of cattle fed a ruminally protected methionine supplement releasing 28% of its content into the

rumen. The RPAA supplement, however, had no effect on milk or protein production. The basal diets not supplemented with RPAA, provided only 79% of methionine and 98% of lysine requirements (NRC, 2001). Although such diets would suggest a limitation in methionine, supplementation with RPAA did not increase milk protein secretion, suggesting no beneficial effect of additional methionine. When expressed, however, in absolute amounts instead of proportion (CPM-Dairy, 1997), methionine supply from the basal diets met the requirement. These results suggest that estimation of methionine and lysine availability based only on proportion should be combined to total supply to assess whether there is a limitation.

CONCLUSIONS

Cows fed corn silage representing 45% of a TMR produced more milk from UCS than from PCS. Dry matter, protein, and starch ruminal degradability of PCS were greater than those of UCS, but these differences were not reflected on total tract digestibility. Ruminally protected lysine and methionine tended to increase the concentrations of purine derivatives in urine. There was, however, no interaction between amino acid supplementation and corn silage processing on production parameters. Results showed that expected beneficial results from corn silage processing could be negated by conservation, intake, and digestion, so caution is required when using novel technology on a whole farm context.

ACKNOWLEDGMENT

The authors thank M. Pelletier, M. Léonard, F. Markwell, I. Lauzon, I. Therrien, L. Veilleux, F. Clavet, and D. Tremblay for technical assistance and M. Perreault and his staff for taking care of the cows. The authors acknowledge the financial support from the Conseil de recherches en pêcheries et agro-alimentaire du Québec (CORPAQ), Agriculture and Agri-Food Canada, Dion Machineries and Rhône-Poulenc Animal Nutrition. They thank Philippe Savoie for initiating this project and providing scientific advice.

REFERENCES

- Arambel, M. J., E. E. Bartley, J. L. Camac, S. M. Dennis, T. G. Nagaraja, and A. D. Dayton. 1987. Rumen degradability and intestinal availability of a protected methionine product and its effects on rumen fermentation, and passage rate of nutrients. *Nutr. Rep. Int.* 35:661–672.
- ASAE. 1999. Standards, 46th Edition. American Society of Agricultural Engineers, St. Joseph, MI.
- Association of Official Analytical Chemists. 1990. Official Methods of Analysis. 15th ed. AOAC, Arlington, VA.

Figure 3. Blood alpha-amino nitrogen concentration after morning milking in cows fed processed (PCS) or unprocessed corn silage (UCS) supplemented (AA) or not (AA0) with ruminally protected amino acids after 10 wk of treatment.

- Bal, M. A., R. D. Shaver, A. G. Jirovec, K. J. Shinnors, and J. G. Coors. 2000. Crop processing and chop length of corn silage: Effects on intake, digestion, and milk production by dairy cows. *J. Dairy Sci.* 83:1264–1273.
- Balcells, J., J. A. Guada, and J. M. Peiró. 1992. Simultaneous determination of allantoin and oxypurines in biological fluids by high-performance liquid chromatography. *J. Chromatogr.* 575:153–157.
- Bassett, J. M. 1975. Dietary and gastrointestinal control of hormones regulating carbohydrate metabolism in ruminants. Pages 383–398 in *Digestion and Metabolism in the Ruminant*. I. W. McDonald and A. C. I. Warner, eds. Proc. 4th International Symposium on Ruminant Physiology. The University of New England Publishing Unit, Armidale, Australia.
- Broderick, G. A. 1985. Alfalfa silage or hay versus corn silage as the sole forage for lactating cows. *J. Dairy Sci.* 68:3262–3271.
- Chapoutot, P., P. Schmidely, D. Sauvant, J. C. Robert, and B. Sloan. 1992. Influence of ruminally protected blend of methionine and lysine (ML) on the dairy cow nutrition and production. *J. Dairy Sci.* 75:199. (Abstr.)
- Chiquette, J., P. Savoie, and A. Lirette. 1994. Effects of maceration at mowing on digestibility and ruminal fermentation of timothy hay in steers. *Can. J. Anim. Sci.* 74:235–242.
- CPM-Dairy. 1997. Version 1.0. Copyright 1997 by The Center for Animal Health and Productivity, School of Veterinary Medicine, University of Pennsylvania, Philadelphia.
- Danfær, A. 1994. Nutrient metabolism and utilization in the liver. *Livest. Prod. Sci.* 39: 115–127.
- Demarquilly, C. 1994. Facteurs de variation de la valeur nutritive du maïs ensilage. *INRA Prod. Anim.* 7:177–189.
- Dewar, W. A., and P. McDonald. 1961. Determination of dry matter in silage by distillation with toluene. *J. Sci. Food Agric.* 12:790–795.
- Dhiman, T. R., M. A. Bal, Z. Wu, W. R. Moriera, R. D. Shaver, L. D. Satter, K. J. Shinnors, and R. P. Walgenbach. 2000. Influence of mechanical processing on utilization of corn silage by lactating dairy cows. *J. Dairy Sci.* 83:2521–2528.
- Gawehn, K., and H. U. Bergmeyer. 1974. D-Lactate. Page 1492 in *Methods of Enzymatic Analysis*. 2nd English ed. Vol. 3. H. U. Bergmeyer, ed. Academic Press, Inc., New York.
- Gutmann, I., and A. W. Wahlefeld. 1974. L-(+)-Lactate: Determination with lactate dehydrogenase and NAD. Page 1464 in *Methods of Enzymatic Analysis*. 2nd English ed. Vol. 3. H. U. Bergmeyer, ed. Academic Press, Inc., New York.
- Harrison, J. H., L. Johnson, S. Xu, and C. W. Hunt. 1996. Managing corn silage for maximum nutritive value. Pages 29–37 in *Proc. Cornell Nutrition Conf.*, Rochester, NY.
- Hintz, R. W., R. G. Koegel, T. J. Kraus, and D. R. Mertens. 1999. Mechanical maceration of alfalfa. *J. Anim. Sci.* 77:187–193.
- Huntington, G. B. 1984. Net absorption of glucose and nitrogenous compounds by lactating Holstein cows. *J. Dairy Sci.* 67:1919–1927.
- Huntington, G. B., and R. L. Prior. 1985. Net absorption of amino acids by portal-drained viscera and hind half of beef cattle fed a high concentrate diet. *J. Anim. Sci.* 60:1491–1499.
- Johnson, L. 1996. Characterization of the relationship between duodenal flow of rumen microbial nitrogen production and purine metabolites in urine and milk. M. S. Thesis, Washington State University, Pullman.
- Johnson, L. M., J. H. Harrison, D. Davidson, W. C. Mahanna, and K. Shinnors. 2003. Corn silage management: Effects of hybrid, maturity, inoculation, and mechanical processing on fermentation characteristics. *J. Dairy Sci.* 86:287–308.
- Johnson, L. M., J. H. Harrison, D. Davidson, W. C. Mahanna, K. Shinnors, and D. Linder. 2002a. Corn silage management: Effects of maturity, inoculation, and mechanical processing on pack density and aerobic stability. *J. Dairy Sci.* 85:434–444.
- Johnson, L. M., J. H. Harrison, D. Davidson, M. Swift, W. C. Mahanna, and K. Shinnors. 2002b. Corn silage management: Effects of hybrids, maturity, and mechanical processing on digestion and energy content. *J. Dairy Sci.* 85:2913–2927.
- Johnson, L., J. H. Harrison, C. Hunt, K. Shinnors, C. G. Doggett, and D. Sapienza. 1999. Nutritive value of corn silage as affected by maturity and mechanical processing; a contemporary review. *J. Dairy Sci.* 82:2813–2825.
- Johnson, L. M., J. H. Harrison, K. A. Loney, D. Bengen, R. Bengen, W. C. Mahanna, D. Sapienza, W. Kezar, C. Hunt, T. Sawyer, and M. Bieber. 1996. Effect of processing of corn silage prior to ensiling on milk production, component yield, and passage of corn grain into manure. *J. Dairy Sci.* 79(Suppl. 1):149. (Abstr.)
- Miller, C. N., C. E. Polan, R. A. Sandy, and J. T. Huber. 1969. Effect of altering the physical form of corn silage on utilization by dairy cattle. *J. Dairy Sci.* 52:1955–1960.
- Muck, R. E., and B. J. Holmes. 1999. Factors affecting bunker silo densities. Pages 278–279 in *Proc. XIIth International Silage Conference*, Uppsala, Sweden.
- National Research Council. 1989. *Nutrient Requirements of Dairy Cattle*. 6th rev. ed. Natl. Acad. Sci., Washington, DC.
- National Research Council. 2001. *Nutrient Requirements of Dairy Cattle*. 7th rev. ed. Natl. Acad. Sci., Washington, DC.
- Nocek, J. E., and S. Tamminga. 1991. Site of digestion of starch in the gastrointestinal tract of dairy cows and its effect on milk yield and composition. *J. Dairy Sci.* 74:3598–3629.
- Ørskov, E. R., and I. McDonald. 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. *J. Agric. Sci. (Camb.)* 92:499–503.
- Petit, H. V., R. Rioux, and D. R. Ouellet. 1997. Milk production and intake of lactating cows fed raw or extruded peas. *J. Dairy Sci.* 80:3377–3385.
- Playne, M. J., and P. McDonald. 1966. The buffering constituents of herbage and of silage. *J. Sci. Food Agric.* 17:264–268.
- Roberge, M., P. Savoie, and E. Norris. 1998. Evaluation of a crop processor in a pull-type forage harvester. *Trans. Am. Soc. Agric. Eng.* 41(4):967–972.
- Robert, J. C., and P. E. V. Williams. 1997. Influence of forage type on the intestinal availability of methionine from a rumen protected form. *J. Dairy Sci.* 80(Suppl. 1):248. (Abstr.)
- Rogers, J. A., S. B. Peirce-Sandner, A. M. Papas, C. E. Polan, C. J. Sniffen, T. V. Muscato, C. R. Staples, and J. H. Clark. 1989. Production responses of dairy cows fed various amounts of rumen-protected methionine and rumen-protected lysine. *J. Dairy Sci.* 72:1800–1817.
- Rulquin, H., R. Vérité, G. Guinard, and P. M. Pisulewski. 1995. Dairy cows' requirements for amino acids. Pages 143–160 in *Animal science research and development: Moving toward a new century*. M. Ivan, ed. Centre for Food and Animal Research, Ottawa, Ontario, Canada.
- SAS User's Guide: Statistics, Version 6.12 Edition. 1996. SAS Inst., Inc., Cary, NC.
- Satter, L. D., Z. Wu, V. R. Moreira, M. A. Bal, and R. D. Shaver. 1999. Processing corn silage. Pages 49–56 in *Proc. of 24th Annual Minnesota Forage Conference*, Rochester, MN.
- Savoie, P., G. F. Tremblay, and H. V. Petit. 1999. Ruminal degradability of alfalfa and corn after processing or maceration. *Can. J. Anim. Sci.* 79:361–368.
- Schwab, C. G., L. D. Satter, and A. B. Clay. 1976. Response of lactating dairy cows to abomasal infusion of amino acids. *J. Dairy Sci.* 59:1254–1270.
- Schwab, C. E., R. D. Shaver, K. J. Shinnors, J. G. Lauer, and J. G. Coors. 2002. Processing and chop length effects in brown-midrib corn silage on intake, digestion, and milk production by dairy cows. *J. Dairy Sci.* 85:613–623.
- Siddons, R. C., R. T. Evans, and D. E. Beever. 1979. The effect of formaldehyde treatment before ensiling on the digestion of wilted grass silage by sheep. *Br. J. Nutr.* 42:535–545.
- Thomson, D. J. 1972. Physical form of the diet in relation to rumen fermentation. *Proc. Nutr. Soc.* 31:127–134.
- Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74:3583–3597.
- Weiss, W. P., and D. J. Wyatt. 2000. Effect of oil content and kernel processing of corn silage on digestibility and milk production by dairy cows. *J. Dairy Sci.* 83:351–358.
- Woodford J. A., N. A. Jorgensen, and G. P. Barrington. 1986. Impact of dietary fiber and physical form on performance of lactating dairy cows. *J. Dairy Sci.* 69:1035–1047.