Chewing Activities and Milk Production of Dairy Cows Fed Alfalfa as Hay, Silage, or Dried Cubes of Hay or Silage[1]

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ABSTRACT

The objective of this research was to compare the effects of dried cubed hay or silage and long hay or silage on chewing activities and milk production of dairy cows. Second-cutting alfalfa was preserved as hay or wilted silage, and a portion of each forage was dried (hay at 80°C; silage at 175°C) and cubed (5 × 3 × 3 cm). The crude protein effective degradability of forages measured in sacco was (dry matter basis) hay, 69%; hay cubes, 70%; silage, 87%; and silage cubes, 82%. Forages were fed in a replicated 4 × 4 Latin square to eight lactating Holstein cows. The diets, consisting of 45% forage (dry matter basis), were fed in a 2 × 2 factorial arrangement; hay or silage was unprocessed or cubed. The dry matter intake were about 2.6 kg/d lower for cows fed silage than for cows fed hay, but the method of preservation did not affect production or fat content of milk or chewing times. Cubing decreased dry matter intakes of both forages by about 1.5 kg/d (2.90%), resulting in a 3.5 to 4.3% reduction in milk production and a 52 to 62% reduction in rumination time. The milk fat content was unexpectedly low for cows fed long hay (2.90%); therefore, cubing only decreased the milk fat content of cows fed silage (silage, 3.34%; silage cubes, 2.86%). Silage offers a viable alternative to hay for cubing. However, for dairy cows receiving high concentrate diets, cubed hay or silage as the sole source of forage might lower intake and reduce milk production compared with effects of uncubed hay or silage.
(**Key words**: forage processing, silage, hay, chewing)

INTRODUCTION

Alfalfa processing is a multimillion dollar industry in North America, and much of the product is exported as pellets and cubes. The industry processes direct-cut forage during the growing season and sun-cured, baled hay during the remainder of the year. Using hay to prolong the production season increases the output of a plant; however, supplies of high quality hay can be limited because of unfavorable weather conditions during harvesting. In comparison, forage to be ensiled is removed from the field soon after it is cut, storage and harvesting are easily mechanized, and high milk production by dairy cows can be supported when silage is fed as the sole source of forage (7, 20). Silage could provide the processing industry with a year-round source of high quality forage.

In the first step of the cubing process, the particle length of the forage is reduced, which decreases the effective fiber content of the original forage. Reduction of forage particle length reduces the time that cattle spend chewing (27), increases ruminal acidity (14), increases the rate of particulate passage from the rumen (22), depresses fiber digestion (22), depresses fat content of milk (14), and, in some cases, increases the incidence of left displaced abomasum (12). These effects increase as the mean particle length of the forage decreases. Because the particle length of cubed forage is considerably greater than that of pelleted forage, effective fiber content is probably reduced less during cubing than during pelleting. However, few studies have been conducted to determine the chewing time, ruminal function, and milk production of dairy cows fed cubed hay as the sole source of forage.

The second step in the cubing process is drying, which may enhance the utilization of forage protein by dairy cattle. Although alfalfa is generally high in protein, most of this protein is in the form of soluble and ruminally degradable protein (18). Moderate drying of freshly cut forage and hay improves protein utilization by cattle by decreasing N solubility and ruminal degradation of protein (30), although overheating increases ADIN and reduces DM digestibility (8). Most of the protein in silage is in the form of NPN because of proteolysis during harvest and storage (10). It is unknown whether the effects of

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dehydration on forage protein degradability are similar for silage and hay.

The first objective of this study was to determine the effects of dried cubed hay or silage compared with those of long hay or coarsely chopped silage on forage protein degradability, chewing activities, and milk production of dairy cows. A second objective was to compare the nutritional value of alfalfa hay with that of alfalfa silage.

MATERIALS AND METHODS

Forages

Alfalfa was harvested during the second cutting in an early flowering stage (approximately 10% bloom) and preserved as hay in small rectangular bales (40 tonnes) or as wilted silage in a silo bag (100-tonne capacity). The hay was subjected to 11 mm of precipitation during the 6 d preceding baling. A forage harvester (model 1060; Gehl, West Bend, WI), equipped with a 37-tooth sprocket and 8 knives, was used to obtain silage chopped at a theoretical length of 10 mm.

The hay was stored in a barn, and, approximately 7 mo later, portions of the hay and silage were transported to a commercial forage processing plant (Alberta Dehydrating Co. Ltd., Vauxhall, AB, Canada) for dehydration and cubing (5 × 3 × 3 cm). The hay was coarsely chopped; then, each forage was pneumatically conveyed into a single-pass rotary drum drier. The drier outlet temperature was set at 80°C for hay and at 175°C for silage. Four passes through the drier were required to dry the silage to the 10% moisture content required for the cubing process. Product residence time within the drier during each pass was approximately 2 min. Heat transfer coefficients and flow dynamics within the drier were dependent on shapes, sizes, temperatures, and moisture contents of forage particles (21). Because the forages contained a mixture of particle shapes and sizes, the flow rate and particle temperatures could not be measured on-line.

Cows and Diets

Eight lactating, multiparous Holstein cows with a mean BW of 650 kg (SD = 24) were used in an experiment designed as a replicated 4 × 4 Latin square; rows (cows) and periods were blocking factors. Both squares were run simultaneously. At the start of the experiment, the mean number of DIM for cows in square 1 was 78 (SD = 4) and for cows in square 2 DIM was 134 (SD = 3).

Cows in each square received one of four diets during each 21-d experimental period. Diets were a 2 × 2 factorial arrangement: two methods of forage preservation (hay and silage) were combined with two levels of processing (unprocessed or cubed). Diets

TABLE 1. Composition of diets (DM basis).

	Diet			
Ingredient[1]	Hay	Hay cubes	Silage	Silage cubes
	(%)			
Barley, steam-rolled	20.50	20.50	20.50	20.50
Barley, ground	3.96	3.96	3.96	3.96
Corn gluten meal	9.36	9.36	9.36	9.36
Blood meal	9.36	9.36	9.36	9.36
Corn distillers dried grains	8.80	8.80	8.80	8.80
Monosodium phosphate	0.15	0.15	0.15	0.15
Dicalcium phosphate	0.35	0.35	0.35	0.35
Calcium carbonate	0.09	0.09	0.09	0.09
Vitamin and mineral premix[2]	0.87	0.87	0.87	0.87
Pellet binder	0.64	0.64	0.64	0.64
Molasses	0.92	0.92	0.92	0.92
Alfalfa hay	45.00	...	...	...
Alfalfa hay cubes	...	45.00	...	...
Alfalfa silage	...	...	45.00	...
Alfalfa silage cubes	...	...	...	45.00

[1]All ingredients, excluding rolled barley and forages, were pelleted.

[2]Supplied per kilogram of premix DM: 173,650 IU of vitamin A, 21,720 IU of vitamin D_3, 208 IU of vitamin E, 932 g of NaCl, 5.7 g of Mg, 9.4 g of K, 9.3 g of Zn, 7.03 g of Mn, 1.70 g of Cu, and 29.9 mg of Se.

consisted of (DM basis) 45% forage and 55% steam-rolled barley concentrate (Table 1). All diets were formulated to provide NRC (19) requirements for vitamins and minerals.

Cows were fed forage for ad libitum intake and had access to forage throughout the day, except when concentrate was offered. Concentrate was provided in two equal portions at 0600 and 1500 h and usually was consumed within 1 h. The quantity of concentrate offered was adjusted regularly to maintain desired forage to concentrate ratios. Orts were weighed daily, composited weekly, subsampled, and retained for chemical analysis to determine DMI and NDF intake.

Cows were housed in tie stalls bedded with wood shavings to minimize the consumption of additional fiber. The cows were milked in their stalls at 0800 and 1800 h, and mean milk production was determined during the last 8 d of each period. Weighted means for fat, protein, and lactose contents of milk, 4% FCM, and SCM were determined from milk that was sampled during the morning and evening on 2 d of the last week of each period (26). Feed efficiency was calculated as the quantity of milk or FCM per kilogram of DMI. Cows were weighed at the beginning and end of each experimental period. The BW of cows during each period was obtained by weighing cows at the end of the period; BW change (kilograms per day) was calculated as the difference in BW obtained at the beginning and end of the period divided by 21.

Chewing Activities

Chewing activities were monitored for 4 d during the last week of each period using a strain gauge transducer linked to a computerized data acquisition system (6). In addition to computer records, analog signals from the transducers were recorded continuously using a multichannel chart recorder. Computer records were verified with chart tracings to ensure accurate assessment of eating and ruminating activities. Chewing activities per unit of DMI and NDF intake were calculated by dividing minutes or number of chews by the mean daily nutrient intake.

In Sacco Measurements

Two dairy cows, fitted with ruminal cannulas at a mean 261 DIM (SD = 25) and consuming 13.0 kg of concentrate and 10.0 kg of long alfalfa hay, were used to determine the digestion kinetics of DM and CP in sacco. Composite samples of each forage were ground to pass through a 2-mm screen, and 5 g of DM were weighed into small bags (10 × 20 cm) made of monofilament Pecap® polyester (pore size, 52 ± 2 μm; B. & S. H. Thompson, Ville Mont-Royal, QC, Canada). Bags were heat-sealed and placed in large (20 × 30 cm) mesh retaining sacs with 3 × 5-mm pores that permitted ruminal fluid to flow freely. The large sacs were soaked in water for 10 min and were placed in the rumen of each cow over time; when removed at the same time, bags had been incubated for 4, 6, 8, 12, 24, 36, 48, 72, or 96 h. The 0-h bags were incubated in warm water for 30 min. Upon removal, bags were placed in an automatic washer. Using the delicate cycle, bags were washed in cold water until the effluent was clear. Bags were dried at 60°C for 48 h, bags and contents were weighed, and residues were ground through a 1-mm screen and analyzed for DM and CP concentrations.

The kinetics of DM and CP disappearance in sacco were estimated for each feed and cow. The following model was fitted to the percentage of disappearance of DM and CP:

$$y = a + b(1 - e^{-c(t-L)}) \text{ for } t > L$$

where

a = soluble fraction (percentage),
b = digestible fraction (percentage),
e = base of the natural system of logarithms,
c = fractional rate of disappearance (percentage per hour),
t = time of incubation (hours), and
L = lag time (hours).

Parameters a, b, c, and L were estimated using the NLIN procedure of SAS (24), and extent of disappearance (percentage) was calculated as a + b. Protein solubility was estimated as the soluble fraction, and effective ruminal degradability (D) was estimated using the model proposed by Mertens (16):

$$D = a + b \times [c/(c + k)] \times e^{(-k \times L)/100}.$$

The rate of particulate passage (k) was assumed to be 4%/h, reflecting a mean residence time of 25 h in the rumen.

Feed Analyses

A composite sample of each feed was obtained for each experimental period. The DM was determined by drying at 50°C. The CP was determined by total Kjeldahl N (2); ADF was assessed according to method 973.18 of the AOAC (2). The NDF and ADF lignin (72% H_2SO_4 method) were determined using the method described by Van Soest et al. (28), heat-stable α-amylase was used in the NDF analysis of concentrates, and sodium sulfite was used in the analysis of the protein supplement. Neutral detergent insoluble N and ADIN were determined by performing total Kjeldahl N (2) analysis on NDF and ADF, respectively. Calcium was determined using atomic absorption spectrophotometry according to method 3.015 of the AOAC (2); P was analyzed colorimetrically using an autoanalyzer. Concentrations of all nutrients except DM were expressed as a percentage of DM determined using forced-air oven-drying at 135°C (Table 2).

The NE_L of the concentrate and supplement was calculated using tabular NE_L values for the ingredients (19). The NE_L of forages was estimated using the equation given by Mertens (17): NE_L (megacalories per kilogram) = 2.323 – 0.0216 × NDF (percentage). The particle size of forages was determined by wet sieving using an oscillating sieve shaker (Analysette 3®; Fritsch, Oberstein, Germany) equipped with a stack of sieves (W. S. Tyler, Inc., Mentor, OH) arranged in descending size. For silage, 30 g of wet material from a composite sample were soaked in water for 10 min and then placed on the top screen; the stack of sieves was shaken for 10 min to ensure that distribution of material on the sieves did not change. The fraction of the dry weight of material that was retained on each sieve size was determined in duplicate.

The particle size of silage and hay cubes was determined in quadruplicate. About 80 g of forage, representing two to four cubes, were soaked in 1 L of water with gentle stirring for <30 min until cubes dissociated. The slurry was split and run through the sieves separately to avoid overloading the sieves. Half of the slurry was poured onto the top sieve, the sieves were shaken, and the dry weight of material on each sieve was determined. The remainder of the slurry was sieved, and the particle size distribution of cubed forage was expressed by summing the amount of material on each sieve size for the two determinations and expressing this weight as a percentage of the total weight of the cubes. The geometric mean length was calculated as described by the American Society of Agricultural Engineers (1).

Statistical Analysis

The kinetics of DM and CP disappearance of forages determined for each cannulated cow were analyzed using the GLM procedure of SAS (24). The model included forage preservation, forage processing, and the interaction of preservation and processing; degrees of freedom for the error term were 4.

Data on intake, BW, milk production, and chewing activities were analyzed using the GLM procedure of SAS (24); square, cow within square, period within square, forage preservation, forage processing, and the interaction of preservation and processing were fixed effects in the model (25). Statistical significance was assessed at $P < 0.05$ unless noted otherwise.

TABLE 2. Chemical composition of concentrate, protein supplement, and forages (DM basis).[1]

Measurement	Concentrate mixture		Forage: Hay		Forage: Hay cubes		Forage: Silage		Forage: Silage cubes	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
DM, %	89.1	0.6	92.1	1.2	92.9	0.5	34.6	1.4	91.4	0.8
NE_L,[2] Mcal/kg	1.82	. . .	1.37	0.04	1.40	0.05	1.53	0.04	1.48	0.05
					(% of DM)					
CP	17.3	0.2	20.6	0.9	19.9	1.3	23.3	1.2	18.7	1.2
NDIN,[3] % of N	. . .	. . .	45.0	4.9	35.9	3.1	17.1	1.8	23.2	2.5
ADIN, % of N	. . .	. . .	16.0	1.9	14.5	0.9	11.3	1.2	16.2	2.1
NDF[4]	25.9	0.1	44.0	1.9	42.6	2.2	36.9	1.8	38.9	3.8
ADF	6.3	0.2	32.6	1.7	33.9	2.2	32.3	1.6	35.9	1.8
ADL	. . .	. . .	6.1	0.1	6.5	0.3	5.5	0.2	6.6	0.1
Ca	0.47	0.05	1.63	0.12	1.73	0.09	2.02	0.04	1.90	0.12
P	0.57	0.06	0.28	0.01	0.28	0.01	0.35	0.01	0.29	0.02

[1]Means for each forage are for eight samples composited by period; means for concentrate are for two samples composited by square.

[2]The NE_L of concentrate was estimated from NRC (19) recommendations; the NE_L of forages was estimated using the equation given by Mertens (17): NE_L (megacalories per kilogram) = 2.323 – 0.0216 × percentage of NDF.

[3]Neutral detergent insoluble N.

[4]NDF obtained using sulfite in the analysis was 19.4% (SD = 0.1) for concentrate.

RESULTS

Feed Composition

Chemical composition. The composition of hay and silage used in this study was typical of alfalfa harvested in early (approximately 10%) bloom (Table 2). However, the difference in CP content between hay and silage was greater than expected and greater than that found in another study using the same forages (5). Consequently, feeds were reanalyzed for CP; however, similar values were obtained. The silage fed in the present experiment was that remaining in the silo after removal of silage for cubing and for the previously mentioned study (5). Possibly, forage quality varied within the silo. Drying and cubing decreased CP content of silage and hay, suggesting some leaf loss and possible loss of volatile N.

We expected silage to contain more unavailable N than hay contained (9, 15); however, the higher ADIN value for hay than for silage indicated the reverse. The ADIN content of the hay suggested that it had been exposed to heat damage, but signs of heating in the hay were not observed. The higher ADIN content of hay might have been related to its lower CP content relative to silage. Cubing had no effect on ADIN for hay but increased ADIN of silage, indicating that the higher drying temperature might have caused some heat damage (29). Estimates of NE_L from fiber were higher for silage than for hay, but cubing of forage did not affect estimated NE_L.

The particle size of the silage reflected its coarse theoretical chop length (Table 3). The particle length of silage cubes was substantially less than that of the original forage and similar to that of hay cubes, even though silage was not rechopped before cubing. This notable reduction in particle size during cubing suggested mechanical breakage of forage material during dehydration and cubing.

Digestion kinetics. The extent of DM disappearance was higher for silage than for hay, mainly because of its larger soluble fraction (Table 4). Cubing reduced ($P = 0.07$) the extent of DM disappearance for both hay and silage because of a decrease in the slowly digestible fraction. Rate of DM disappearance was higher for silage than for hay and was not significantly affected by cubing.

As expected, degradability of CP was higher for silage than for hay (84.8% vs. 69.3%). Compared with hay, silage CP included a larger soluble fraction and a smaller slowly digestible fraction. Cubing hay marginally affected CP degradability, but cubing silage decreased CP degradability by five percentage points. For both forages, cubing increased the slowly digestible fraction and decreased CP solubility, although the decrease was greater for hay than for silage. Rate of disappearance was variable among forages, as indicated by the large standard deviation, and no effect of preservation method or cubing was evident.

Intake and BW

Cows fed cubed forages ate less DM and, consequently, less NDF and NE_L than did those fed un-

TABLE 3. Particle distribution of forages.[1]

Item	Hay cubes		Silage		Silage cubes	
	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
Geometric mean length, mm						
With soluble fraction	0.65	0.07	3.18	0.97	0.58	0.07
Without soluble fraction	1.42	0.14	17.48	4.37	1.58	0.27
	(% of DM retained)					
Screen size, mm						
13.20	...	...	24.64	6.80	...	...
6.70	2.16	1.08	17.27	1.41	5.22	2.93
4.75	...	...	10.13	1.09	...	...
3.35	6.93	0.38	3.46	1.18	7.71	0.33
2.36	6.83	1.16	2.09	0.51	5.17	0.47
1.70	8.02	0.31	...	...	5.16	0.80
1.18	9.37	0.77	3.19	1.08	7.03	1.52
0.60	11.38	0.51	2.25	0.30	8.13	0.31
0.30	13.83	0.99	...	...	12.77	0.93
0.15	12.11	1.73	3.36	0.45	12.48	2.24
Not retained	29.37	2.28	33.61	2.67	36.34	1.40

[1]Determined by wet sieving using an oscillating sieve shaker. Particles retained on the top sieve measured 21, 100, and 25 mm for hay cubes, silage, and silage cubes, respectively.

TABLE 4. Effects of cubing hay or silage on forage digestion kinetics.

Variable	Hay	Hay cubes	Silage	Silage cubes	SEM	Effect[1] P	C	INT
						P		
DM Disappearance								
Soluble, %	30.4	32.8	40.2	40.7	0.3	<0.001	0.005	0.03
Slowly digestible, %	44.3	39.8	37.2	35.9	0.7	0.002	0.02	0.09
Extent of disappearance, %	74.7	72.6	77.3	76.7	0.6	0.004	0.07	0.26
Rate of disappearance, %/h	5.61	6.44	7.48	7.62	0.45	0.03	0.34	0.49
Lag, h	0.2	0.7	0.5	0.7	0.4	0.74	0.45	0.70
CP Disappearance								
Soluble, %	49.0	44.9	79.5	68.6	0.4	<0.001	<0.001	0.002
Slowly digestible, %	35.5	42.0	12.5	20.7	0.6	<0.001	0.005	0.55
Extent of disappearance, %	84.5	86.9	92.0	89.4	0.2	0.01	0.91	0.05
Rate of disappearance, %/h	11.29	6.15	7.56	14.53	4.92	0.61	0.84	0.23
Lag, h	5.7	0.4	0.6	3.3	2.5	0.65	0.59	0.14
Degradability,[2] %	68.7	69.9	87.4	82.2	0.3	<0.001	0.03	0.007

[1]P = Main effect of method of forage preservation, C = main effect of cubing forage, and INT = interaction of preservation and cubing.

[2]Assumed rate of passage of 4%/h.

processed forages (Table 5). No interaction between method of preservation and processing was observed for DMI; the effect of cubing forage on intake was similar for both silage and hay. Because DMI was lower for cows fed silage than for cows fed hay, the lowest mean DMI were observed for cows fed silage cubes.

Cows consumed approximately 41.4% of DMI as forage, which was slightly less than the formulated level of 45% (Table 1). This difference in forage to concentrate ratio reflected the difficulties of maintaining targeted ratios when feeds are offered separately. Intake of NDF averaged 31.8% of DMI, and intake of NDF from forage averaged 16.6%.

The method of preservation did not affect BW change; cows fed hay or silage gained BW. In contrast, for cows fed hay, cubing resulted in no change in BW, and, for cows fed silage, cubing resulted in a loss in BW.

Milk Production and Composition

Milk production was similar for cows fed silage and for cows fed hay, but cubed forages decreased production by approximately 4% (Table 6). Although FCM and SCM were unaffected by dietary treatment, a significant interaction between preservation and processing was observed for the fat content of milk. Milk fat was lower for cows fed silage cubes than for cows fed silage, but, because of the unexpectedly low milk fat of cows fed hay, milk fat content was similar for cows fed both hay and hay cubes. Protein content of milk was higher for cows fed hay diets than for cows fed silage diets, but protein was not affected by forage processing. Lactose content of milk was unaffected by diet.

Feed efficiency, expressed as kilograms of milk or FCM per kilogram of DMI, was lower for cows fed hay

TABLE 5. Effects of cubing hay or silage on BW and intake means.

Variable	Hay	Hay cubes	Silage	Silage cubes	SEM	Effect[1] P	C	INT
						P		
BW, kg	683	664	666	658	7	0.11	0.07	0.42
BW Change, kg/d	0.94	0	0.20	−0.27	0.30	0.12	0.04	0.55
DMI, kg/d	23.9	22.2	21.1	19.9	0.5	<0.001	0.01	0.61
Forage intake, % of DMI	43.4	41.3	40.8	40.2	0.5	0.003	0.02	0.15
NE_L Intake,[2] Mcal/d	39.1	36.5	36.0	33.8	0.8	0.004	0.01	0.82
NDF Intake, % of DMI	33.5	32.8	30.3	30.7	0.3	<0.001	0.60	0.07
NDF Intake, kg/d	8.0	7.3	6.4	6.1	0.2	<0.001	0.005	0.07
Forage NDF, % of DMI	18.8	17.6	14.9	15.2	0.4	<0.001	0.006	0.07
Forage NDF, kg/d	4.5	3.9	3.2	3.0	0.1	<0.001	0.005	0.07

[1]P = Main effect of method of forage preservation, C = main effect of cubing forage, and INT = interaction of preservation and cubing.

[2]Calculated from estimated NE_L provided in Table 2.

TABLE 6. Effects of cubing hay or silage on milk production and composition.

Variable	Hay	Hay cubes	Silage	Silage cubes	SEM	Effect[1] P	C	INT
						P		
Production, kg/d								
Milk	31.2	30.1	30.3	29.0	0.6	0.11	0.05	0.80
FCM	25.7	25.7	26.9	24.3	1.0	0.93	0.22	0.20
SCM	25.7	25.9	26.6	24.5	0.9	0.81	0.30	0.19
Composition, %								
Fat	2.90	2.98	3.34	2.86	0.13	0.19	0.15	0.05
Protein	3.19	3.21	3.14	3.11	0.02	0.006	0.73	0.28
Lactose	4.66	4.63	4.67	4.69	0.04	0.36	0.87	0.52
Efficiency								
Milk/DMI	1.28	1.34	1.42	1.41	0.02	0.002	0.19	0.35
FCM/DMI	1.06	1.15	1.25	1.19	0.05	0.04	0.76	0.20

[1]P = Main effect of method of forage preservation, C = main effect of cubing forage, and INT = interaction of preservation and cubing.

than for cows fed silage, but was not affected by cubing.

Chewing Activities

The total number of chews during eating was lower for cows fed silage diets than for cows fed hay diets, but method of forage preservation had little effect on time spent eating (Table 7), even though cows consuming silage diets ate less forage than those fed hay diets (Table 5). Consequently, cows spent a longer time eating per unit of NDF from silage than from hay (Table 7). Cows also chewed silage NDF more than they chewed hay NDF during eating.

The time spent ruminating and the number of ruminating chews were similar for cows fed silage or hay diets. However, adjustment of these variables for differences in NDF intake indicated a significant interaction between preservation and cubing. Fiber from silage, which was coarsely chopped, was ruminated longer and subjected to more ruminating chews than fiber from long hay, but there were fewer differences between hay and silage when forages were cubed.

Cubed forage decreased eating time by about 0.5 h/d and decreased the number of eating chews by about 3500. The decrease in eating activity appeared to be caused by lower DMI for cows fed the cubed diets rather than increased ease of ingestive mastication, because chews per kilogram of forage NDF and minutes spent eating per kilogram of forage NDF were unaffected by cubing.

TABLE 7. Effects of cubing hay or silage on daily chewing activities.

Variable	Hay	Hay cubes	Silage	Silage cubes	SEM	Effect[1] P	C	INT
						P		
Eating								
min/d	330	293	310	274	12	0.16	0.01	0.96
min/kg of DM	14.0	13.4	14.9	14.2	0.7	0.25	0.40	0.96
min/kg of NDF	41.7	40.8	49.5	46.6	2.3	0.01	0.44	0.67
min/kg of forage NDF	75.5	73.9	100.9	95.0	5.5	0.001	0.71	0.52
chews/d ($\times 10^3$)	22.2	18.0	18.9	16.0	1.1	0.04	0.01	0.61
chews/kg of forage NDF	4.96	4.62	6.16	5.49	0.4	0.03	0.24	0.70
Ruminating								
min/d	398	190	399	151	18	0.33	<0.001	0.30
min/kg of DM	17.1	9.0	19.4	8.4	1.1	0.45	<0.001	0.23
min/kg of NDF	51.0	27.5	64.3	27.1	3.3	0.08	<0.001	0.06
min/kg of forage NDF	90.5	51.6	131.3	54.5	6.6	0.007	<0.001	0.02
chews/d ($\times 10^3$)	23.5	10.6	23.7	8.4	1.2	0.42	<0.001	0.33
chews/kg of forage NDF	5.33	2.88	7.77	3.02	0.4	0.006	<0.001	0.02

[1]P = Main effect of method of forage preservation, C = main effect of cubing forage, and INT = interaction of preservation and cubing.

TABLE 8. Effects of cubing hay or silage on rumination behavior.

Variable	Hay	Hay cubes	Silage	Silage cubes	SEM	Effect[1] P	C	INT
						P		
Rumination periods								
Periods/d	15.4	8.9	14.8	7.8	0.7	0.28	<0.001	0.75
Duration, min	26.0	22.0	27.6	20.0	1.0	0.80	<0.001	0.10
Chews per period	1527	1229	1622	1112	62	0.87	<0.001	0.13
Rumination boluses								
Boluses/d	394	187	399	147	16	0.31	<0.001	0.20
Chews per bolus	59.1	55.6	58.2	55.8	1.2	0.78	0.03	0.67
Duration of bolus, s	57.0	56.7	56.1	57.6	1.0	0.98	0.58	0.41

[1]P = Main effect of method of forage preservation, cubing = main effect of cubing forage, and INT = interaction of preservation and cubing.

The most striking effect of cubed forage on chewing activities was decreased rumination. The time spent ruminating decreased from a mean of 6.6 h/d for long hay and silage to 2.8 h/d for cubed hay and silage, and a commensurate decrease in the number of chews per day also was observed. Minutes of rumination and chews per kilogram of forage fiber were greatly reduced by cubing. This effect of cubing was most evident for silage, because ruminating activity per unit of fiber was higher for unprocessed silage than for hay.

Decreased ruminating activities of cows fed cubes were manifested in fewer, shorter rumination periods daily (Table 8). Fewer boluses were regurgitated per day, and each bolus was chewed more slowly, as was evidenced by fewer chews per bolus, but chewing for the same duration per bolus.

DISCUSSION

Use of processed forages is usually greatest when home-grown forages are in short supply, in which case, the amount of forage offered would probably be minimal because of its high cost relative to concentrates. Thus, in this experiment, the effectiveness of cubed forages as roughage sources was determined using dairy cows fed diets that were relatively high in concentrate. For most of the variables measured (except milk fat content), including intake, chewing, and milk production, the effects of cubing were similar for silage and hay. However, silage or hay cubes as the sole source of forage for dairy cows fed a diet that is relatively high in concentrate may decrease milk production because of lower DMI compared with DMI of long hay or coarsely chopped silage.

Cows fed cubed forages had lower DMI, rumination times, and milk production than cows fed unprocessed forages. In addition, only cows fed unprocessed forages gained BW during the experimental periods. The low DMI of cows fed cubed forage did not appear to be due to the hardness of the cube because chewing during eating per unit of forage fiber was unaffected by cubing. The lower DMI of cows fed cubed forage contradicted a previous report that claimed that lactating cows ate about 20% more DM in the form of alfalfa cubes than in the form of baled hay of the same quality (23). The discrepancy between these studies might be related to the proportion of concentrate in the diet. A study by Bath et al. (3) indicated that, as the proportion of concentrate in the diet increased, forage intake decreased, and this decrease was more rapid for cubed forage than for long hay. Thus, for cows fed diets that were high in concentrate, DMI would be expected to be lower when forage was cubed than when long forage was fed. This effect was presumably the result of insufficient effective fiber, because reduction of particle length could increase ruminal acidity (14) and decrease intake (13). Unfortunately, ruminal pH was not measured in our experiment to confirm this effect.

With alfalfa hay cubes as the sole source of forage in the diet of dairy cows, some cows have been observed to go off feed, consume inconsistent amounts of forage, or bloat (11). Although bloat was not recorded in our study, at the start of the period, several cows seemed reluctant to consume cubed hay or silage. Christensen (1990, personal communication) observed that, when given a choice of cubes or barley silage, four of eight cows would eat hay cubes only after the cubes were soaked in water to create a mash.

Concentrations of dietary NDF were above NRC (19) recommendations of 28%, but only about half of the fiber was from forage sources. Previous studies

(4) using barley concentrates demonstrated that between 25 and 28% NDF from forage sources was required to maintain a milk fat content of 3.5%. Thus, the relatively low fat content of milk in the present experiment was expected.

Based on rumination time, processing decreased the effective fiber content of forage by 52 to 62% although fat content of milk was only reduced for cows fed silage. This apparent discrepancy occurred because milk fat content was lower than expected for cows fed long hay. These results indicated that milk fat content itself was not a suitable indicator of effective fiber. Reduction in rumination time and chews, even after adjustment for fiber intakes, indicated that particle size breakdown was easier in processed forages.

The particle length of forage likely was more critical in maintaining ruminal function and promoting high milk fat content when high concentrate diets were fed (5), as was done in this experiment. In diets containing greater proportions of forage or in diets containing some long hay or silage, lower effective fiber content of cubed forage than of unprocessed forage likely would not be as great a concern.

Cubing decreased protein degradability of silage by five percentage units. This effect was presumably due to more extensive heating of the silage cubes because the cubing process had little effect on CP degradability in the case of hay. Moderate heating of forage can improve protein utilization, although overheating reduces forage digestibility (15, 30). Although we did not measure total tract digestibility, the kinetics of ruminal digestion indicated a possible decrease in DM digestibility because of cubing. The extent of DM disappearance in the rumen for hay and silage was lower after cubing. Although cubing did not affect feed efficiency, measured as kilograms of milk or FCM per kilogram of DMI, cows fed cubed forages did not gain BW, unlike cows fed unprocessed forages.

For alfalfa that was harvested in an early flowering stage of maturity, the method of forage preservation had only minor effects on milk production of dairy cows. These findings agreed with other studies (7, 20) that examined digestive and productive differences between dairy cows fed silage or hay. Although milk production was slightly lower ($P \leq 0.11$) for cows fed silage diets than for cows fed hay diets, FCM was not affected by method of forage preservation because of the unexpectedly low fat content of milk produced by cows fed long hay. Because cows fed silage ate less DM than did cows fed hay, feed efficiency was higher for cows fed silage. In addition, coarsely chopped alfalfa silage was an effective roughage source in high grain diets, as measured by chewing activities and milk fat content (9). For the formulation of practical diets, effective fiber content of alfalfa hay and coarsely chopped alfalfa silage can be considered equal, although the present study suggests that silage fiber may be slightly more effective than fiber from long hay. Cows spent a longer time eating equivalent amounts of fiber from silage than from hay because they chewed silage fiber more than hay fiber. Despite the increased chewing of silage NDF during eating, the extent of particle size reduction might not have been any greater for silage than for hay, because NDF from silage was also ruminated longer and was subjected to many more ruminating chews than fiber from long hay.

The most important nutritional difference between unprocessed forages was the higher CP degradability of silage than that of hay. The observed effective degradability values of 68.7% for alfalfa hay and 87.4% for silage were similar to those reported by the NRC (19). Apparently, after compensation for differences in CP degradability, alfalfa silage diets were equal to alfalfa hay diets in supporting milk production.

CONCLUSIONS

The preservation of alfalfa either as baled hay or coarsely chopped silage had only minor effects on the milk production of dairy cows. Additionally, silage can be used as an alternative to hay for the production of cubed forages. The effects of cubing on intake, chewing time, and milk production were similar for both silage and hay, although the fat content of milk was reduced only when silage was fed because the milk fat content was lower than expected for cows fed long hay. In addition, cubing decreased protein degradability of silage by five percentage units, likely because of heating.

Silage or hay cubes as the sole source of forage for dairy cows fed diets that were relatively high in concentrates decreased milk production compared with the effects of long hay or silage in the diet. Cows fed cubed forages had lower DMI, rumination times, and milk production than did cows fed unprocessed forages, probably as a result of insufficient effective fiber. Reduction of forage particle length might have increased ruminal acidity, which is associated with decreased intake and reduced fiber digestion. Forage particle length is critical to maintain ruminal function and to promote normal milk fat content, especially when diets contain minimal forage fiber, as in this experiment. Further research is required to determine whether particle length of cubed forages can be increased. Alternatively, a minimum amount of unprocessed forage, such as long hay or silage, could be included in diets that contain forage cubes to increase effective fiber content.

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