Effect of Quantity, Quality, and Length of Alfalfa Hay on Selective Consumption by Dairy Cows

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ABSTRACT

Twenty-four lactating Holstein cows were used in a replicated 6×6 Latin square design. Experimental periods were 6 or 7 d. Cows were housed in tie-stalls, and diets were fed ad libitum twice daily at 1100 and 1600 h. Diets contained 60% concentrate and either 40% alfalfa hay or 20% alfalfa hay and 20% alfalfa silage (dry matter basis). The effect of quantity, quality, and length of hay on sorting behavior was determined. Treatments consisted of 20% lower or higher quality long alfalfa hay, 20% lower or higher quality chopped alfalfa hay, and 40% lower or higher quality chopped alfalfa hay. Variation of sorting among cows was also determined. Particle size distribution of samples of as-fed total mixed rations andorts were determined using the Wisconsin particle size separator. Screens have square holes with diagonals of 26.9, 18, 8.98, 5.61, and 1.65 mm (screens Y_1 to Y_5 , respectively). Sorting was calculated as the actual intake of each fraction expressed as a percentage of the predicted intake. Increasing the proportion of dry hay increased sorting. Quality of alfalfa hays that were offered did not affect sorting activity. Feeding long alfalfa hay increased selective consumption of fine particles. However, feeding long alfalfa hay also increased intake of longer particles because a higher percentage of long particles was offered. Across treatments, animals consistently sorted against longer particles in favor of finer particles. In particular, intake of Y_1 as a percentage of the predicted intake was the most variable. Average Y_1 intake, across the six treatments for each cow, was between 60 and 70% of predicted intake for four cows, 71 to 80% for 11 cows, 81 to 90% for five cows, 91 to 100% for two cows, and 101 to 110% for two cows. On one diet a cow failed to consume any of the Y_1 portion of the total mixed ration. This variation among animals in sorting of very long feed particles may have practical significance.

(**Key words:** sorting, selection, alfalfa hay)

Abbreviation key: AM = a.m. sampling 21 h after feeding; **20HQC** = 20% higher quality chopped alfalfa hay, **40HQC** = 40% higher quality chopped alfalfa hay, **20HQL** = 20% higher quality long alfalfa hay, **20LQC** = 20% lower quality chopped alfalfa hay, **40LQC** = 40% lower quality chopped alfalfa hay, **20LQL** = 20% lower quality long alfalfa hay, **NFC** = nonfibrous carbohydrate; **PAN** = bottom pan; **PM** = p.m. sampling 4 h after feeding.

INTRODUCTION

Various chemical and physical dietary factors such as NDF concentration and particle size can affect rumen fermentation, and consequently milk production and composition. The NRC (2001) recommends feeding dairy cattle a minimum of 25% dietary NDF with 19% of dietary DM from forage NDF to avoid milk fat depression. The NRC (2001) also suggests increasing dietary NDF concentration when < 19% of dietary DM is forage NDF or when forage mean particle size is < 3 mm. Many studies have shown that a reduction in dietary particle size decreases milk fat concentration (Grant et al., 1990; Beauchemin et al., 1994; LeLiboux and Peyraud, 1999), chewing activity (Grant et al., 1990; Beauchemin et al., 1994; LeLiboux and Peyraud, 1999), and rumen pH (Beauchemin et al., 1994; LeLiboux and Peyraud, 1999). Therefore, it is important to consider both NDF and particle size in diet formulation.

A further complication exists when cows sort, and therefore, do not ingest feeds in proportion to dietary concentration. In particular, when diets are formulated close to minimum recommendations, sorting could reduce intake of long particles and thereby possibly decrease chewing activity, rumen pH, and milk fat test.

No data are available on sorting activity of lactating dairy cattle fed a TMR, containing either corn silage or alfalfa silage. However, several studies have shown that cattle are capable of selecting among different anatomical portions present in grain stovers (Osafo et al., 1997; Methu et al., 2001). Increasing the amount of unchopped corn stover offered to dairy cattle increased the intake of more palatable plant parts such as leaf, sheath, and husk without changing the intake of the

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less palatable stems even though feed refusals were always at least 10% for all diets (Methu et al., 2001).

Physical processing can also affect sorting by dairy cattle. Osafo et al. (1997) fed chopped or unchopped sorghum stover to steers. Chopping decreased stem DMI, without affecting leaf plus sheath DMI. Therefore, chopping the sorghum stovers increased the stover leaf plus sheath intake expressed as a fraction of total intake, compared to feeding unchopped plants.

We hypothesized that dairy cattle could sort TMR diets resulting in reduced intake of long particles in the diet consumed relative to the abundance of these particles in the TMR offered. In most cases, the longer particles contain higher NDF concentration than the TMR. Therefore, sorting against long particles also reduces NDF concentration of the consumed diet compared to the diet offered. The net effect would be a reduction in both long fiber and total NDF intake. We also hypothesized that cows would sort more with diets containing lower quality hay and containing more hay and less silage. Therefore, the primary objective of this study was to investigate the effects of feeding different quantity, quality, and length of alfalfa hay as a TMR on sorting behavior of lactating dairy cattle.

Simultaneously, we wanted to determine how a sudden dietary change would impact sorting. In farms, cows often change diet during their lactation. This usually takes place by moving the animal from one pen to another; therefore, dietary changes happen quite rapidly. Also within a day, dairy cattle show different eating patterns (Beauchemin, 1991; Tolkamp et al., 2000). Therefore, a secondary objective was to measure sorting that occurred during the first day that a new diet was fed, after a period of adaptation, and at different times within the day.

We also hypothesized that animals could behave differently from each other in both a qualitative and quantitative manner. For example, a diet that is not sorted at all by any animal would likely perform differently than one for which half of the animals selectively consumes long particles, while the other half rejects long particles for an average of no sorting. An estimate of cow variability in sorting could help us understand why in some farms where all recommendations are followed, some cows may still have health problems associated with finely ground diets. Therefore, an additional objective of this study was to measure variability in feed sorting among animals.

MATERIALS AND METHODS

Animals

Twelve multiparous and 12 primiparous lactating Holstein cows were utilized in a replicated 6 × 6 Latin

square design. At the beginning of the study, multiparous cows averaged ($\pm$ SD) 153 $\pm$ 7 DIM and produced ($\pm$ SD) 42.1 $\pm$ 2.0 kg of milk daily; primiparous cows averaged 160 $\pm$ 19 DIM and produced 34.2 $\pm$ 3.6 kg of milk daily. Two squares consisted of multiparous cows, and two squares of primiparous cows. Cows were randomly assigned to squares within parity. Treatment sequences were ordered to minimize carryover effects of any treatment in the succeeding period. Cows were housed individually in tie-stall facilities and had free access to water. The Animal Care Committee of the College of Agriculture and Life Sciences of the University of Wisconsin-Madison approved all procedures involving animals.

Experimental Diets

Diets were fed for ad libitum intake twice daily at 1100 and 1500 h. The amount of feed offered was adjusted daily to obtain approximately 10% oforts (as-fed basis). Approximately 40% of the diet was offered at 1100 h and the remaining 60% at 1500 h. Cows were fed at 1100 h to follow barn schedule and at 1500 h, because at 1500 h animals were milked. Therefore, at 1500 h, refusals samples could be taken without disturbing the cows' eating pattern. After the morning milking, cows were allowed to exercise daily from 0800 until 1100 h. Therefore, cows had access to feed for approximately 19 h. Cows were milked twice daily, but milk production is not reported due to short experimental periods. Diets contained 40% forage and 60% concentrate (DM basis). Diets were formulated to be isonitrogenous, isoenergetic, and have similar NDF concentrations. Forage was either alfalfa hay or a mixture of 50% alfalfa hay and 50% alfalfa silage (Table 1). Treatments consisted of different quantity, quality, and length of alfalfa hay: 20% higher quality long alfalfa hay (**20HQL**), 20% lower quality long alfalfa hay (**20LQL**), 20% higher quality chopped alfalfa hay (**20HQC**), 20% lower quality chopped alfalfa hay (**20LQC**), 40% higher quality chopped alfalfa hay (**40HQC**), and 40% lower quality chopped alfalfa hay (**40LQC**).

Lower and higher quality hay had the same CP concentration (18.8%) but different NDF concentration, which averaged 44.5 and 34.5% for lower and higher quality alfalfa hay, respectively. Therefore, diets did not have similar forage NDF (FNDF) concentrations (Table 2). Chopped alfalfa hay was obtained weekly by processing it for 15 min in a TMR wagon (184-mixer, Roto-mix, Dodge City, KS). Diets were mixed in the TMR wagon and successively fed with Data Ranger (American Calan, Northwood, NH). Long alfalfa hay was added to the Roto-mix last to minimize particle size reduction and mixed for 2 to 3 min.

Table 1. Ration composition.

Ingredient	Treatments ¹			
	20HQ	20LQ	40HQ	40LQ
	(g/100g of DM)			
Alfalfa silage ²	20.0	20.0	—	—
Alfalfa hay ²	20.0	20.0	40.0	40.0
Corn grain ground	36.5	39.8	37.2	42.1
Soybean meal	4.2	6.6	4.2	8.1
Soybean roasted	6.4	2.8	5.4	0.8
Soy hulls	11.9	9.8	12.2	8.0
Blood meal	0.2	0.2	0.2	0.2
Limestone	0.3	0.3	0.3	0.3
Ca 23%: P 18%	0.3	0.3	0.3	0.3
Minerals-vitamins mix ³	0.2	0.2	0.2	0.2

¹Treatments: 20HQ = 20% higher quality hay, 20LQ = 20% lower quality hay, 40HQ = 40% higher quality hay, and 40LQ = 40% lower quality hay.

²Chemical composition of alfalfa silage, lower and higher quality alfalfa hay was 35.7, 88.9 and 90.4% for DM; 31.8, 44.6 and 34.5% for NDF (DM basis); 20.1, 18.8 and 18.8% for CP (DM basis); 10.5, 8.4 and 7.8% ash (DM basis), respectively.

³Contained 0.55% Mn, 0.55% Zn, 0.35% Fe, 0.14% Cu, 0.008% I, 0.006% Se, 0.002% Co, 3304 IU/g of vitamin A, 1101 IU/g of vitamin D, and 11 IU/g of vitamin E.

Sampling and Laboratory Analysis

Habituation to a new feeding schedule takes 3 to 4 d in rats, mice, and rabbits (Mistelberger, 1994). In two experiments where dairy cattle had the possibility to choose between two diets with different metabolizable protein concentrations, after 3 d the level of diet selection was similar to the remaining experimental days

Table 2. Chemical composition of the diets.

Diet component	Treatments ¹			
	20HQ	20LQ	40HQ	40LQ
	(g/100g of DM)			
DM, g/100g (as fed)	69.5	69.1	89.9	89.9
NE _L , Mcal/kg, DM ²	1.61	1.58	1.59	1.57
	(g/100g of DM)			
CP	16.7	17.0	16.7	16.4
NDF	23.8	23.3	23.6	25.3
FNDF ³	13.3	15.3	13.8	17.9
ADF	17.2	16.4	17.1	16.8
NFC ⁴	48.5	49.6	50.3	49.2
FA ⁵	4.1	3.2	3.1	2.6
Ash ⁶	5.9	5.9	5.3	5.5

¹Treatments: 20HQ = 20% higher quality hay, 20LQ = 20% lower quality hay, 40HQ = 40% higher quality hay, and 40LQ = 40% lower quality hay.

²NE_L were calculated based on NRC (2001) values for individual feedstuffs.

³FNDF = forage NDF.

⁴NFC = Nonfiber carbohydrates. $NFC = 100 - (FA + 1 + NDF + CP + \text{ash})$.

⁵FA = Fatty acids. Represented the sum of C₁₄ to C₁₈.

⁶Diets contained 0.81% Ca, and 0.41% P calculated based on NRC (2001) values for individual feedstuffs.

(Tolkamp and Kyriazakis, 1997; Tolkamp et al., 1998). Therefore, short experimental periods of either 7 d (periods 1 to 4) or 6 d (periods 5 and 6) were chosen for the present study.

Orts and diets were sampled on the first and last 2 d of each experimental period. Day 1 was sampled to study feeding behavior immediately following a diet change. Orts samples were collected twice daily, at 1500 (PM) and 0800 h (AM), 4 and 21 h after the morning feeding, respectively. Sorting activity was determined 4 and 21 h after feeding, in order to better understand sorting activity across the day, especially because eating patterns vary during the day (Beauchemin, 1991; Tolkamp et al., 2000). However, our major interest was to determine how sorting affects total consumption. Data collected 21 h after morning feeding represent the entire day, and these data include sorting of the first 4 h as well as sorting from 4 through 21 h. During the PM sampling, Orts were weighed, sampled, and returned to the manger; while at the AM sampling, Orts were weighed, sampled, and discarded. Sorting and DMI at 21 h were calculated taking in consideration Orts samples amounts collected during the previous PM sampling. Samples of Orts were taken while the cows were either in the milking parlor or outside, to avoid interference of the sampling with the eating behavior. Particle size distribution of diets and Orts were determined using the Wisconsin particle size separator, according to the ASAE S424.1 protocol (ANSI, 1998), and geometric mean particle length was calculated assuming a mean length of 48 mm for the material retained on the top screen. The separator has five square-hole screens (Y₁ to Y₅) with nominal diagonal openings of Y₁ = 26.90 mm, Y₂ = 18.00 mm, Y₃ = 8.98 mm, Y₄ = 5.61 mm, Y₅ = 1.65 mm, and a bottom pan (PAN).

Diets were adjusted weekly to account for forage DM fluctuation. Feed samples were collected during the last day of each experimental period, dried at 60°C for 48 h, ground to pass through a 1-mm screen (Wiley mill, Arthur H. Thomas, Philadelphia, PA), and analyzed for DM, CP, NDF, ADF, ash, and fatty acids. The CP concentration was determined by micro-Kjeldahl analysis (AOAC, 1990). Neutral detergent fiber was determined using α -amylase (Sigma no. A3306: Sigma Chemical Co., St. Louis, MO), sodium sulfite and corrected for ash concentration according to Van Soest et al. (1991), adapted for Ankom²⁰⁰ Fiber Analyzer (Ankom Technology, Fairport, NY). Acid detergent fiber was determined using the method described by Goering and Van Soest (1970), adapted for Ankom²⁰⁰ Fiber Analyzer (Ankom Technology, Fairport, NY). Fatty acids were determined following the procedure described by Sukhija and Palmquist (1988) and represented the sum of C₁₄ to C₁₈. The nonfibrous carbohydrate (NFC) com-

ponent was calculated as $100 - (\text{NDF} + \text{ether extract} + \text{CP} + \text{ash})$, where ether extract was calculated as fatty acids plus one (NRC, 2001).

Calculations and Statistical Analysis

Sorting was calculated as the actual intake of each fraction (Y_1 to PAN) expressed as a percentage of the predicted intake, where predicted intake of Y_i equals the product of as-fed intake and as-fed fraction of Y_i in the TMR. Values $<100\%$ indicate selective refusals, $>100\%$ is preferential consumption, and $=100\%$ is no sorting. Data from the last 2 d of the sampling period were averaged prior to analysis and are labeled as d 6. All analyses were performed using the mixed procedure of SAS (SAS, 1998).

Data were originally analyzed as a single dataset (d 1 and 6, and 4 and 21 h). There was a significant ($P < 0.05$) day $\times$ hour $\times$ treatment interaction for Y_2 , Y_3 , Y_5 , and PAN. Therefore, least squares means of d 1 at 4 h and at 21 h, and d 6 at 4 h and at 21 h are reported in Table 3. For simplicity, significance of treatment effects for sorting and intake are only reported at 21 h during d 6, which are probably most indicative of long-term behavior. Treatment effects were tested, including in the final model: period, treatment, parity, and parity $\times$ treatment interaction. Square within parity and cow within square $\times$ parity were included in the random statement. Parity $\times$ treatment, period $\times$ treatment, and period $\times$ parity interactions were tested in the initial model and were not significant ($P > 0.25$); therefore, they were dropped from the analysis. Orthogonal contrasts were built to test the effect of different quantity (40HQC and 40LQC vs. 20HQC and 20LQC), quality (40HQC, 20HQC, and 20HQL vs. 40LQC, 20LQC, and 20LQL), and length (20HQL and 20LQL vs. 20HQC and 20LQC) of alfalfa hay on feeding behavior. The interactions between quantity and quality (40HQC and 20LQC vs. 40LQC and 20HQC), and quality and length (20HQC and 20LQL vs. 20LQC and 20HQL) were also tested.

Another objective was to test differences due to adaptation over time and to measure daily sorting patterns; therefore, data has been divided into two smaller datasets consisting of d 1 and 6 at 4 h and d 1 and 6 at 21 h. Data were analyzed by day as repeated measures, utilizing a first-order auto regressive covariance structure. The final model for sorting activity included period, day, treatment, parity and the interaction of day $\times$ treatment. Interactions also tested in the initial model were parity $\times$ treatment, period $\times$ treatment, period $\times$ parity, day $\times$ period, and day $\times$ parity. Interactions not reported in the final models were not significant ($P > 0.25$) and were dropped from the analysis. Square

within parity, cow within square $\times$ parity, and treatment $\times$ period $\times$ cow within square $\times$ parity were the terms of the random statement. Significance was declared at $P \leq 0.05$.

RESULTS AND DISCUSSION

Diet Composition

Dietary chemical composition is reported in Table 2. The four diets with 20% alfalfa hay had similar DM concentration (69.3%), while the 40% alfalfa hay diets had higher DM concentration (89.9%). Ash, CP, ADF, and NFC were similar across all diets. Diets were balanced to have similar NDF concentration; however, 40LQC had a numerically higher NDF concentration compared to the remaining diets. Dietary geometric mean length was 4.70 mm for 20HQL, 4.59 mm for 20LQL, 4.03 mm for 20HQC, 3.88 mm for 20LQC, 3.29 mm for 40HQC, and 3.35 mm for 40LQC. Distribution of forages particles, as percentage of total mass, on the five screens and the pan, was 5.1, 18.6, 38.3, 13.0, 17.3, and 7.7 for alfalfa silage; 15.3, 13.4, 17.8, 11.2, 16.9, and 25.4 for LQC alfalfa hay; 17.5, 10.9, 14.3, 10.1, 18.6, and 28.6 for HQC alfalfa hay; 56.1, 6.7, 9.8, 8.5, 11.7, and 7.2 for LQL alfalfa hay; and 49.3, 5.4, 11.5, 9.9, 14.8, and 9.1 for HQL alfalfa hay. Dietary particles distribution is a result of forages and grain particles distribution; therefore, diets with 20% long hay had more material retained on Y_1 compared to 20% chopped hay (Figure 1). Doubling the amount of chopped hay in the diet (40 vs. 20% alfalfa hay) increased the amount of material retained on Y_1 , even though the geometric mean length of 20% chopped hay diets was greater than the 40% chopped hay diets. There were no general differences in particle size distribution for diets with different alfalfa hay quality.

Cow Variability

Cow variability is reported by averaging sorting activity at 21 h after morning feeding of d 1 and 6, across all treatments (Figure 2), combining a total of 18 daily measurements per cow. Generally, cows sorted against longer particles ($Y_1 < 100\%$). Only two animals (4459 and 3930) did not sort or sorted in favor of longer particles ($Y_1 \geq 100\%$). Intake of Y_1 as a percentage of predicted intake was $< 70\%$ for four cows (3894, 4156, 4454, and 4460), between 71 and 80% for 11 cows (3816, 3968, 4273, 4275, 4327, 4438, 4442, 4448, 4466, 4469, and 4470), between 81 and 90% for five cows (4075, 4180, 4202, 4424, and 4444), and between 91 and 100% for two cows (4178 and 4422). Sorting by a single cow can be quite extreme as observed for one cow fed 40LQC who consumed no Y_1 particles on d 1 and during the 2

Figure 1. Dietary particles retained on each screen (as-fed basis). Screens are labeled from left (long material) to right (fine material) as Y₁, Y₂, Y₃, Y₄, Y₅, and PAN, respectively. Treatments consisted of 20HQL = 20% higher quality long hay, 20LQL = 20% lower quality long hay, 20HQC = 20% higher quality chopped hay, 20LQC = 20% lower quality chopped hay, 40HQC = 40% higher quality chopped hay, and 40LQC = 40% lower quality chopped hay. Standard deviations for Y₁, Y₂, Y₃, Y₄, Y₅, and PAN were: 3.5, 0.8, 1.0, 1.3, 2.6, 3.2 for 20HQL; 3.2, 1.5, 1.5, 0.7, 2.9 for 20LQL; 1.7, 0.4, 1.1, 1.1, 1.6, 1.9 for 20HQC; 1.9, 1.4, 1.3, 0.8, 2.5, 2.5 for 20LQC; 2.8, 1.2, 1.4, 1.8, 1.1, 6.5 for 40HQC; and 3.3, 1.2, 1.3, 0.9, 2.4, 3.6 for 40LQC.

d represented in d 6 (data not shown). Sorting of Y₂ and Y₃ followed the same pattern of Y₁ but to a lesser extent. Intakes of Y₂ and Y₃ as a percentage of predicted intakes ranged from 80 to 100%. Intake of Y₄ was al-

ways about 100% of predicted intake. Contrary to long particles, fine particles were always preferentially selected (Y₅ and PAN >100%). Therefore, animals tended to selectively consume finer particles (Y₅ and PAN) and sort against longer particles (Y₁, Y₂, and Y₃). Both Y₅ and PAN were constituted of grain mixture, of which approximately 95% was retained on these two finest screens (data not shown), and fine particles of alfalfa hay.

Figure 2. Cow variability for sorting (as-fed basis) 21 h after morning feeding. Data are averaged across d 1 and 6 and also across diets, by cow. Screens are labeled from the top (long material) to the bottom (fine material) as Y₁ (◇), Y₂ (■), Y₃ (▲), Y₄ (●), Y₅ (□), and PAN (○), respectively.

Time and Dietary Effects

Time effects and its interaction with treatment.

There were significant ($P < 0.05$) day $\times$ hour $\times$ treatment and day $\times$ hour interactions for Y₂, Y₃, Y₅, and PAN (Table 3). For the 4-h data, day had a significant main effect for all screens except Y₁ with less sorting of diets early on the first day of exposure to the new diet compared to early in the day after adaptation. An interaction of day $\times$ treatment occurred for the 4-h data for Y₅ and PAN due to much more pronounced selection on the 40% hay diets following adaptation.

Although the 4-h data provides an interesting insight into cow behavior, daily consumption measured at 21

Table 3. Least squares means of sorting measured feeding different quantity, quality, and length of alfalfa hay within day (d 1 and 6) and hour (4 and 21 h).

Screens ²	Treatments ¹						SEM
	20HQL	20LQL	20HQC	20LQC	40HQC	40LQC	
Day 1 at 4 h	(% ³)						
Y ₁	88.0	82.2	97.1	95.5	87.6	85.7	7.7
Y ₂	97.9	92.2	94.7	95.4	90.3	86.3	4.2
Y ₃	97.5	98.1	96.6	97.3	86.0	91.6	2.8
Y ₄	95.8	98.5	96.8	95.8	93.0	92.4	1.6
Y ₅	102.3	105.1	104.3	100.0	106.6	101.1	2.0
PAN	108.5	110.8	107.9	106.5	109.1	109.2	2.8
Day 1 at 21 h							
Y ₁	88.1	86.5	89.2	101.9	52.2	69.0	7.9
Y ₂	95.9	92.3	96.0	90.0	80.4	75.8	4.4
Y ₃	97.8	96.3	97.3	95.6	82.9	82.1	2.9
Y ₄	100.1	99.4	99.9	100.3	99.9	102.6	1.6
Y ₅	103.1	103.7	102.1	101.4	107.8	107.3	2.1
PAN	104.4	106.3	102.9	104.3	112.4	110.9	2.9
Day 6 at 4 h							
Y ₁	97.9	83.7	82.2	80.7	79.0	62.3	9.6
Y ₂	99.1	83.9	79.2	84.0	81.6	58.9	4.1
Y ₃	89.7	88.6	88.4	87.0	77.2	70.3	2.7
Y ₄	93.7	93.9	97.9	93.4	88.0	88.8	1.6
Y ₅	101.3	105.4	106.7	103.3	113.4	119.6	2.0
PAN	110.2	119.6	117.7	117.9	114.9	135.6	2.8
Day 6 at 21 h							
Y ₁	85.3	85.4	84.3	90.7	61.1	59.0	8.0
Y ₂	92.7	94.0	94.6	90.8	85.1	84.3	4.2
Y ₃	95.5	96.3	96.6	95.6	85.3	87.4	2.8
Y ₄	99.8	99.3	99.2	99.2	99.5	101.0	1.6
Y ₅	104.3	103.6	102.6	102.2	107.3	107.1	2.0
PAN	107.6	106.4	105.2	104.6	110.2	110.3	2.9

¹Treatments: 20HQL = 20% higher quality long hay, 20LQL = 20% lower quality long hay, 20HQC = 20% higher quality chopped hay, 20LQC = 20% lower quality chopped hay, 40HQC = 40% higher quality chopped hay, and 40LQC = 40% lower quality chopped hay. There was a significant ($P < 0.05$) day $\times$ hour $\times$ treatment interaction for Y₂, Y₃, Y₅ and PAN.

²Screens: the particle separator has five square-hole screens with nominal diagonal openings of Y₁ = 26.90 mm, Y₂ = 18.00 mm, Y₃ = 8.98 mm, Y₄ = 5.61 mm, Y₅ = 1.65 mm, and a pan (PAN).

³ Sorting by screen (Y_i) was calculated on as-fed basis as $(100 \times (Y_i \text{ intake} / Y_i \text{ predicted intake}))$.

h is more likely to impact rumen function and animal performance. In contrast to the 4-h data, the 21-h data show a day effect only for screen Y₄ ($P < 0.05$), with a slight increase in sorting against this screen or less preferential consumption following adaptation. The impact of this change is probably minor given that consumption for this screen was always very close to predicted intake. Day by treatment interactions at 21 h were significant ($P < 0.05$) only for screens Y₂ and Y₃. For the 40% chopped hay diets that had the most sorting against longer particles, screens Y₂ and Y₃ were less extensively sorted on d 6 compared to d 1. These moderately long particles seemed less prone to sorting than the longest particles, and this difference was magnified as cows adapted to the diets.

Dietary effects. Day-6 data are the best indication of chronic sorting activity. There were no significant quantity $\times$ quality or quality $\times$ length interactions in these data.

Quantity. Across treatments, cows sorted against longer particles and in favor of finer particles (Figure 2). This behavior was most evident when cows were fed 40% chopped hay. Cows fed 40% chopped hay reduced Y₁ intake by 40.2 percentage units and increased PAN intake by 10.0 percentage units compared to their predicted intake (Figure 3). Feeding 20% chopped hay and 20% alfalfa silage reduced the extent of sorting compared to 40% hay ($P < 0.0001$). It is not possible to distinguish if this was due to the change in particle size distribution offered or if it was the result of the lower moisture content. Methu et al. (2001) reported increased sorting due to increasing the amount of corn stover offered above requirements. Therefore, the increased sorting activity could have resulted from an increased percentage of long particles offered. No data are available regarding sorting when feeding diets with different DM contents. When dry feeds are mixed, the feeds generally tend to separate into fine, high-density

Table 4. Effect of quantity, quality, length, the interaction of quantity by quality, and the interaction of quality by length on DMI and as-fed intake of individual screens (Y_i) measured at 21 h after morning feeding during d 6.

	Treatments ¹							Effects ²				
	20HQL	20LQL	20HQC	20LQC	40HQC	40LQC	SEM	Quantity	Quality	Length	Qt × Ql	L × Ql
	(kg DM/d)							(P-values)				
DMI by screen ³	24.4	24.0	24.0	24.7	24.3	25.2	0.5	0.20	0.20	0.76	0.74	0.19
	(kg as-fed/d)											
Y ₁	3.38	3.29	1.87	1.36	1.48	1.29	0.11	0.02	0.0006	<0.0001	0.08	0.02
Y ₂	1.71	1.81	2.08	2.49	1.32	1.8	0.06	<0.0001	<0.0001	<0.0001	0.45	0.001
Y ₃	5.1	5.19	5.04	5.16	1.73	2.41	0.11	<0.0001	<0.0001	0.61	0.002	0.88
Y ₄	3.87	3.4	4.06	3.63	2.45	2.16	0.08	<0.0001	<0.0001	0.0009	0.26	0.76
Y ₅	9.01	9.53	9.43	10.09	8.36	8.01	0.21	<0.0001	0.02	0.001	0.001	0.64
PAN	9.26	9.4	9.74	10.43	10.41	11.1	0.24	<0.0001	<0.0001	0.0003	0.98	0.1

¹Treatments: 20HQL = 20% higher quality long hay, 20LQL = 20% lower quality long hay, 20HQC = 20% higher quality chopped hay, 20LQC = 20% lower quality chopped hay, 40HQC = 40% higher quality chopped hay, and 40LQC = 40% lower quality chopped hay.

²Effects: Quantity = (40HQC and 40LQC) vs. (20HQC and 20LQC), Quality = (40HQC, 20HQL, and 20HQC) vs. (40LQC, 20LQL, and 20LQC), Length = (20HQL and 20LQL) vs. (20HQC and 20LQC), Qt × Ql = Quantity × Quality interaction = (40HQC and 20LQC) vs. (40LQC and 20HQC), and L × Ql = Length × Quality interaction = (20HQC and 20LQL) vs. (20LQC and 20HQL).

³Screens: the particle separator has five square-hole screens with nominal diagonal openings of Y_1 = 26.90 mm, Y_2 = 18.00 mm, Y_3 = 8.98 mm, Y_4 = 5.61 mm, Y_5 = 1.65 mm, and a pan (PAN).

particles at the bottom of the manger and longer, lower density particles on top. Cows have little ability to nibble; therefore, they utilize their tongues and noses to gather and sort their feed (Beauchemin, 1991). Therefore, if dry diets are fed, cows can use their tongues to selectively eat the fine particles and their noses to push away the longer particles.

Feeding 40 vs. 20% alfalfa hay did not affect DMI, but it affected intake (as-fed basis) of the various screens (Table 4). It is not possible to make DMI com-

parisons by screen, because feed retained on different screens probably had different DM concentration. However, it is reasonable to compare Y_1 intakes, considering that Y_1 of all diets was primarily alfalfa hay. Therefore, even though cows fed 40% hay had 2.2 percentage units (as-fed basis) more Y_1 offered compared to 20% alfalfa hay diets, Y_1 intake was actually lower for 40% chopped hay than 20% chopped hay diets. This was a result of increased sorting activity on the 40% hay diets.

Quality. There were no significant differences for sorting activity between the two alfalfa hay qualities. Therefore, our results do not support the concept that lower-quality hay will increase the likelihood of sorting on as-fed basis. However, as hay quality decreases and the concentration of NDF in long particles increases, equal sorting on as-fed basis or DM basis will result in greater sorting against forage NDF and total NDF. This would result in a greater decrease of forage NDF consumed related to forage NDF offered with lower-quality vs. higher-quality forages. Therefore, sorting may not be greater with higher fiber forages, but the impact of sorting might be.

In this experiment, diets were not balanced for forage NDF but for total NDF. As a result, increasing the quality of alfalfa hay corresponded to replacing forage NDF with nonforage NDF (Tables 1 and 2). Because preferential consumption of the finer screens must accompany relative rejection of the coarser screens, it is very possible that the composition of the finer screens affected sorting behavior. Small differences in particle size distributions between the two qualities of hay resulted in significantly different intake (as-fed basis) of feed retained on individual screens but similar total DMI (Table 4).

Figure 3. Least squares means for sorting (as-fed basis) of cows fed 40% (■) vs. 20% (□) alfalfa hay measured on d 6 at 21 h. Screens are labeled from left (long material) to right (fine material) as Y_1 , Y_2 , Y_3 , Y_4 , Y_5 , and PAN, respectively. Replacing alfalfa silage with chopped alfalfa hay increased sorting with significant changes occurring on each screen (Y_1 to PAN, $P < 0.05$).

Length. Contrary to the Osafo et al. (1997) study, where chopping increased animal's capability to selectively refuse stems, in this experiment feeding long alfalfa hay significantly increased selective consumption of Y_5 ($P = 0.01$) and PAN ($P = 0.02$), although the increase was small (Figure 3). In the Osafo et al. (1997) experiment, the difference between treatments was chopped vs. intact plant, but in our experiment, forages were mixed with grains, and all diets underwent some mixing and particle size reduction in the TMR mixing wagon. The present results are probably more applicable to TMR feeding system.

Dry matter intake was not different feeding chopped or long alfalfa hay. Y_1 as-fed intake was greater for the long material because more long material was offered. Feeding 20% chopped hay increased intake (as-fed basis) of feed retained on the finest screens (Y_4 , Y_5 , and PAN). Although feeding long hay increased preferential consumption of the finer particles, a higher amount of Y_5 and PAN was offered feeding 20% alfalfa hay diet, resulting in overall higher intakes.

CONCLUSIONS

In each of the six TMR fed in this study, cows sorted most against the longest particles in the diet. Consumption of particles relative to amount offered increased progressively as particle size decreased. Sorting of each screen was similar for long and chopped hay; therefore, feeding long hay increased intake of long particles. However, diets based on long hay are likely to have a larger difference between the TMR offered and that consumed due to the presence of more long particles. In addition, sorting increased when feeding 40 vs. 20% chopped alfalfa hay. This resulted in less absolute intake of long particles on the 40% diet even though the 40% diet had more long particles in the TMR. Hay quality did not affect sorting activity per se, but in practice, reduced hay quality may amplify the impact of sorting by concentrating dietary NDF into the longest, most easily sorted feed particles. It is important to note that cows behave differently and sorted to a different degree. This was true with individually fed animals where a sorting animal has a progressively coarser diet as the day progresses. In a free-stall barn, where sorting cows are free to move to minimally sorted TMR, this sorting behavior could be enhanced.

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REFERENCES

- American National Standards Institute. 1998. Method of determining and expressing particle size of chopped forage materials by screening. ASAE S424.1. p. 578. ASAE, St. Joseph, MI.
- Association of Official Analytical Chemists. 1990. Official Methods of Analysis. Vol. I 15th ed. AOAC, Arlington, VA.
- Beauchemin, K. A. 1991. Ingestion and mastication of feed by dairy cattle. Pages 439–463 in Vet. Clin. North Am. Food Anim. Pract. Vol. 7, No. 2.
- Beauchemin, K. A., B. I. Farr, L. M. Rode, and G. B. Schaalje. 1994. Effects of alfalfa silage chop length and supplementation of long hay on chewing activity and milk production of dairy cows. J. Dairy Sci. 77:1326–1339.
- Goering, H. K., and P. J. Van Soest. 1970. Forage Fiber Analysis. (Apparatus, Reagents, Procedures, and Some Applications). Agric. Handbook No. 379. ARS-USDA, Washington, DC.
- Grant, R. J., V. F. Colenbrander, and D. R. Mertens. 1990. Milk fat depression in dairy cows: Role of particle size of alfalfa hay. J. Dairy Sci. 73:1823–1833.
- LeLiboux, S., and J. L. Peyraud. 1999. Effect of forage particle size and feeding frequency on fermentation patterns and sites and extent of digestion in dairy cows fed mixed diets. Anim. Feed Sci. Technol. 76:297–319.
- Methu, J. N., E. Owen, A. L. Abate, and J. C. Tanner. 2001. Botanical and nutritional composition of maize stover, intakes and feed selection by dairy cattle. Livest. Prod. Sci. 71:87–96.
- Mistelberger, R. E. 1994. Circadian food-anticipatory activity: Formal models and physiological mechanisms. Neurosci. Biobehav. Rev. 18:171–195.
- National Research Council. 2001. Nutrient requirements of dairy cattle. 7th Rev. Ed. Natl. Acad. Sci., Washington, DC.
- Osafo, E. L. K., E. Owen, A. N. Said, M. Gill, and J. Sherington. 1997. Effects of amount offered and chopping on intake and selection of sorghum stover by Ethiopian sheep and cattle. Anim. Sci. 65:55–62.
- SAS User's Guide: Statistics, Release 7th Edition, 1998. SAS Inst., Inc., Cary, NC.
- Sukhija, P. S., and D. L. Palmquist. 1988. Rapid method for determination of total fatty acid content and composition of feedstuffs and feces. J. Agric. Food Chem. 36:1202–1206.
- Tolkamp, B. J., I. Kyriazakis. 1997. Measuring diet selection in dairy cows: Effect of training on choice of dietary protein level. Anim. Sci. 64:197–207.
- Tolkamp, B. J., I. Kyriazakis, J. D. Oldham, M. Lewis, R. J. Dewhurst, and J. R. Newbold. 1998. Diet choice by dairy cows. 2. Selection for metabolizable protein or for ruminally degradable protein? J. Dairy Sci. 81:2670–2680.
- Tolkamp, B. J., D. P. N. Schweitzer, and I. Kyriazakis. 2000. The biologically relevant unit for the analysis of short-term feeding behavior of dairy cows. J. Dairy Sci. 83:2057–2068.
- Van Soest, P. J., J. B. Robertson, and B. A. Lew. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597.