Nutrient Intake and Feeding Behavior of Growing Dairy Heifers: Effects of Dietary Dilution

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ABSTRACT

The objective of this study was to determine how the addition of straw to a total mixed ration offered to growing dairy heifers affects their nutrient intake and feeding behavior. Six prepubescent Holstein heifers (226.2 ± 6.3 d old and weighing 250.1 ± 17.7 kg), fed once per day for 1.0 kg/d of growth, were subjected to each of 3 treatment diets using a replicated 3×3 Latin square design. The treatment diets were 1) control (17.0% corn silage, 52.1% grass silage, 30.9% concentrate), 2) control diet with 10% straw, and 3) control diet with 20% straw. Dry matter intake and feeding behavior were monitored for 7 d for each animal on each treatment. Fresh feed andorts were sampled on the last 3 d of each treatment period for each heifer and were then subjected to particle size analysis. The particle size separator contained 3 screens (19, 8, and 1.18 mm) and a bottom pan, resulting in 4 fractions (long, medium, short, and fine). Sorting activity for each fraction was calculated as actual intake expressed as a percentage of the predicted intake. Heifers sorted against long particles and for short particles on all 3 diets. On the 10 or 20% straw diets the heifers sorted for medium particles. Heifers also sorted for fine particles on the 20% straw diet. There was a linear increase in sorting for medium, short, and fine particles with increased straw in the diet. Dry matter intake linearly decreased with increased straw in the diet. Feeding time and meal duration increased linearly with the addition of straw to the diet, whereas feeding rate, meal size, and meal frequency decreased with the addition of straw. Requirements for maintenance and growth of 1.0 kg/d were sufficiently met when the animals consumed the control and 10% straw diet. On the 20% straw diet the animals consumed sufficient nutrients to achieve a 0.9 kg/d growth rate. These results indicate that the addition of straw to the diet of prepubescent

heifers strongly influences their sorting behavior. Despite this sorting, the results suggest that a low-quality feedstuff may be included in the diet to target nutrient intake and reduce feed costs without negatively affecting feeding behavior or growth potential.

Key words: heifer, dietary dilution, straw, sorting

INTRODUCTION

As replacement heifers represent the future potential of the dairy industry, heifer rearing programs have been receiving more attention in recent years. On many dairy farms it is common practice to feed the TMR refusals from the lactating herd to the replacement heifers (Boterman and Bucholtz, 2005). This type of heifer feeding management may be an area of concern because this feed is not balanced to meet the specific nutrient requirements of the growing dairy heifer. With increased emphasis in recent years on targeting growth rates, improving feed efficiency, and reducing feed wastage, researchers have been investigating new ways of managing the nutrition of replacement dairy heifers.

One feeding strategy for replacement heifers that has received increased attention is limit feeding. In this management practice the feed intake of the animal is limited, slowing the rate of passage, which results in greater retention time and ultimately causes increased ruminal degradation and nutrient utilization (Tamminga et al., 1979; Loerch, 1990). Feeding a more nutrient dense diet at a restricted intake, without affecting production, has been successfully used in beef heifers (Wertz et al., 2001) and cows (Loerch, 1996). Limit-fed animals, however, do show behavioral signs of being hungry: Loerch (1996) found that some cows resorted to consuming bark from trees present in their dry lot. In a recent study with gravid dairy heifers, Hoffman et al. (2007) limited the intake of a more nutrient dense diet and found that these heifers had increased feed efficiency with no adverse effects on growth or future production. These researchers, however, also found that the eating and lying time of limit-fed heifers were reduced, resulting in these animals spending more time

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standing while not eating. Increased time spent standing, particularly on hard flooring surfaces, may increase the risk of hoof pathologies (Cook et al., 2004; Vanegas et al., 2006). Further, Hoffman et al. (2007) found that those heifers limited to 80% of ad libitum DMI vocalized far more during the first 5 wk after exposure to treatment than those fed at greater levels of DMI. Increased vocalization has been interpreted as a sign of frustration, hunger, and compromised welfare (Watts and Stookey, 2000; Valizadeh et al., 2008). It can, therefore, be hypothesized that the changes in behavior associated with limit feeding come as a result of the animals not having achieved satiety.

An alternative to limiting the amount of feed provided would be to limit the nutrient density of a feed offered ad libitum (Hoffman et al., 1996). The addition of a low-quality feedstuff may help reduce feed costs, target nutrient and energy intake, and prevent displays of hunger due to lack of gut fill. It is also important to remember that cattle are foragers and, as such, under natural grazing conditions, would engage in foraging behavior for 4 to 9 h of their day (Hafez and Bouissou, 1975). Thus, increasing the time required to feed by adding a low-quality feedstuff to the diet may help satisfy the natural feeding behavior of these animals. One concern, however, with the addition of a low-quality feedstuff to the heifer diet is increased sorting against the feedstuff. Dairy cows have been shown to discriminate against the longer, forage components of their TMR (Leonardi and Armentano, 2003; DeVries et al., 2007). To date, there is limited knowledge on sorting behavior of growing dairy heifers. Based on previous work with adult dairy cattle, we hypothesized that increasing the amount of a low-quality feedstuff in the TMR of growing heifers would increase sorting behavior. We also hypothesized that the animals would be able to meet their nutrient requirements for maintenance and 1.0 kg/d of growth while consuming a nutrient-diluted ration. The objective of this study was, therefore, to determine how the addition of a low-quality feedstuff to the TMR of growing dairy heifers affects their nutrient intake and feeding behavior.

MATERIALS AND METHODS

Animals and Housing

Six Holstein dairy heifers were used in this study. The animals were (mean $\pm$ SD) 226.2 $\pm$ 6.3 d old, weighed 250.1 $\pm$ 17.7 kg, and measured 119.0 $\pm$ 4.2 cm high at the withers at the beginning of the experiment. Over the 21 d of the experiment, the animals, on average, gained 0.97 $\pm$ 0.51 kg/d and grew 0.09 $\pm$ 0.13 cm/d. The heifers were housed in 2 pens in the heifer research barn at the University of British Columbia Dairy Re-

Table 1. Ingredient composition of the treatment diets (DM basis) fed to growing heifers¹

Ingredient	Control	10% straw	20% straw
Corn silage	17.0	15.3	13.6
Grass silage	52.1	47.0	41.9
Concentrate ²	30.9	27.9	24.9
Rye straw	—	9.8	19.6

¹10% straw = control diet with 10% rye straw; 20% straw = control diet with 20% rye straw.

²Supplied by Unifeed Ltd. (Chilliwack, BC, Canada), containing (on as-is basis): 15.0% flattened corn, 14.0 canola meal, 12.9% ground wheat, 11.6% soymeal, 10.2% mixed grains, 9.0% flattened oats, 8.4% millrun, 7.0% flattened barley, 4.8% molasses, 2.3% calcium carbonate, 1.6% ground barley, 1.3% salt, 0.7% dicalcium phosphate, 0.6% ground alfalfa pellets, 0.3% ground corn, 0.2% trace mineral/vitamin premix, 0.07% lasalocid sodium (Bovatec, Alpharma Canada Corp., Mississauga, ON, Canada).

search and Education Centre (Agassiz, BC, Canada) and were managed according to the guidelines set by the Canadian Council on Animal Care (1993). The pens consisted of a sawdust bedded-pack area (4.6 $\times$ 9.0 m; width $\times$ depth) and a standing alley (4.6 $\times$ 3.05 m) that divided the pack from the feeding area. The animals had ad libitum access to feed (TMR) using roughage intake control feed bins (Insentec B.V., Marknesse, the Netherlands). Within each pen, each heifer was trained to eat from one bin assigned to her. Orts were cleaned out of bins at 0800 h each day, with new feed delivered once daily at 0900 h. Water was available ad libitum to the heifers through a water bowl in each pen.

Experimental Design and Diets

The number of animals required per treatment was determined through power analysis (Morris, 1999) for the primary response variables, including DMI, feed sorting, and feeding time. Estimates of variation for these variables were based on previously reported values (Kertz and Chester-Jones, 2004; Hoffman et al., 2006, 2007; DeVries et al., 2007). Heifers were divided into 2 groups of 3 and exposed to 3 dietary treatments using a replicated 3 $\times$ 3 Latin square design. One week before exposure to the experimental diets, the heifers were housed in their respective pens and trained to access feed only from their assigned feed bin. During this period all heifers were fed the control TMR consisting of 17.0% corn silage, 52.1% grass silage, and 30.9% concentrate on a DM basis. This ration was formulated according to the NRC (2001) nutrient requirement recommendations for a 250-kg nonbred Holstein heifer growing at 1.0 kg/d. Following this period, heifers in each pen were exposed to each of the 3 dietary treatments (see Table 1 and Table 2) in 3 successive 7-d treatment periods using a Latin square design. The

Table 2. Nutrient composition of the treatment diets (DM basis) fed to growing dairy heifers

Item	Experimental diet ¹			SE	Effects (<i>P</i> -value)	
	Control	10% straw	20% straw		Linear	Quadratic
Chemical composition ²						
DM, %	49.3	51.9	54.3	0.6	0.004	NS ³
CP, %	16.7	14.2	13.3	0.4	0.005	NS
ADF, %	26.5	31.2	32.3	1.2	0.01	NS
NDF, %	42.8	49.7	50.4	2.1	0.02	0.15
OM, %	91.8	92.5	92.7	0.2	0.02	NS
Ether extract, %	3.03	2.37	2.03	0.16	0.002	NS
NFC, ⁴ %	29.3	26.2	26.9	1.9	NS	NS
Ca, %	0.67	0.57	0.58	0.04	0.04	0.09
P, %	0.40	0.32	0.31	0.02	0.007	0.09
Calculated nutrients ⁵						
TDN ⁶	69.6	65.7	64.7	1.1	0.006	0.14
ME, Mcal/kg	2.52	2.37	2.34	0.04	0.005	0.13
NE _G , Mcal/kg	1.01	0.90	0.87	0.03	0.007	NS
NE _M , Mcal/kg	1.62	1.50	1.46	0.03	0.007	NS

¹Control = 17.0% corn silage, 52.1% grass silage, 30.9% concentrate; 10% straw = control diet with 10% rye straw; 20% straw = control diet with 20% rye straw.

²Values were obtained from chemical analysis of TMR samples.

³NS = $P > 0.15$.

⁴NFC = $100 - (\% \text{ NDF} + \% \text{ CP} + \% \text{ ether extract} + \% \text{ ash})$.

⁵Calculated according to NRC (2001) equations.

⁶Total digestible nutrients (calculated from ingredients).

treatment diets were 1) control, 2) 10% straw (control diet with 10% rye straw added), and 3) 20% straw (control diet with 20% rye straw added).

Each day of the experiment the silages (Table 3) were mixed in a mixer wagon and delivered into each feed bin. The appropriate amount of the concentrate component was then added manually into each bin. For the 10 or 20% straw diets, the appropriate amount of rye straw (Table 3) was also weighed into the bins. The feed was then removed and placed onto the cement floor in front of each bin and thoroughly mixed by hand for 10 min. Feed was then placed back into its original bin. The amount of feed offered to each animal was adjusted daily to ensure approximately 10% orts. The actual orts averaged (mean $\pm$ SD) $12.5 \pm 8.5\%$ DM of offered feed over the course of the experiment.

Measuring Feed Intake and Behavior

The Insentec feed bins (Insentec B.V.), as validated by Chapinal et al. (2007), continuously measured the feeding behavior as well as individual feed intake for all experimental animals. From the recorded data, we were able to determine the duration of each visit to the feed bin, the amount of feed consumed (start weight – end weight) during each visit, and the rate of consumption for each visit. These data were then summarized to calculate daily DMI (kg/d), daily time spent feeding (min/d), and average feeding rate (kg/min).

Meal Analysis

Visits to the feed intake system were separated into meals using a meal criterion (minimum time interval that a heifer is away from the feed bin to be considered a meal). This meal criterion was calculated to be 21.0 min using a mixed distribution model, as outlined by DeVries et al. (2003). Using this criterion, meal frequency, duration, and size were calculated.

Feed Sampling and Analysis

Representative samples of the 3 treatment diets were collected for particle size separation on d 5, 6, and 7 of each treatment period at the time of feed delivery (i.e., after feed mixing was complete). A duplicate sample of each of the experimental diets was taken on d 5 for DM and chemical analysis. Orts samples for particle size separation and subsequent chemical analysis were taken from each feed bin at the end of d 5, 6, and 7 during each treatment period. Additionally, on d 5 of each treatment period, duplicate samples of the dietary components were taken for particle size analysis and chemical analysis. All samples were immediately frozen until they were further analyzed.

Samples for particle size separation were thawed at a later date and separated using the 3-screen (19, 8, and 1.18 mm) Penn State Particle Separator (PSPS; Kononoff et al., 2003a). This separated the particles into 4 fractions: long (>19 mm), medium (<19, >8 mm),

Table 3. Chemical composition and particle size distribution of the forages (mean $\pm$ SD; DM basis)

Item	Corn silage	Grass silage	Rye straw
Chemical composition ¹			
DM, %	30.5 $\pm$ 1.3	34.9 $\pm$ 4.0	93.1 $\pm$ 0.6
CP, %	9.0 $\pm$ 0.9	17.7 $\pm$ 1.7	6.6 $\pm$ 1.5
ADF, %	30.0 $\pm$ 3.7	32.2 $\pm$ 1.0	45.7 $\pm$ 4.4
NDF, %	47.7 $\pm$ 5.1	49.9 $\pm$ 1.7	68.0 $\pm$ 5.2
OM, %	94.2 $\pm$ 0.5	89.7 $\pm$ 1.2	94.6 $\pm$ 0.7
Ether extract, %	2.33 $\pm$ 0.1	3.03 $\pm$ 0.1	0.23 $\pm$ 0.4
NFC, ² %	35.1 $\pm$ 4.5	19.1 $\pm$ 2.4	19.9 $\pm$ 3.6
Particles, %			
>19.0 mm	23.3 $\pm$ 2.7	52.7 $\pm$ 7.5	77.8 $\pm$ 4.2
<19.0, >8.0 mm	64.8 $\pm$ 2.7	36.7 $\pm$ 6.3	14.7 $\pm$ 4.5
<8.0, >1.18 mm	11.1 $\pm$ 0.4	9.0 $\pm$ 1.1	5.9 $\pm$ 0.03
<1.18 mm	0.8 $\pm$ 0.2	1.6 $\pm$ 0.5	1.6 $\pm$ 0.4
pef ³	0.88 $\pm$ 0.001	0.89 $\pm$ 0.02	0.93 $\pm$ 0.004
peNDF, ⁴ %	42.0 $\pm$ 0.3	44.6 $\pm$ 0.8	62.9 $\pm$ 0.3

¹Values were obtained from chemical analysis of feed component samples.

²NFC = 100 - (% NDF + % CP + % ether extract + % ash).

³pef = physical effectiveness factor determined as the proportion of particles retained by top 2 sieves of the Penn State Particle Separator (Lammers et al., 1996).

⁴peNDF = measured as the NDF content of the TMR (DM basis) multiplied by the pef.

short (<8, >1.18 mm), and fine (<1.18 mm) particles. After separation, the DM of each separated fraction was determined by oven drying at 55°C for 48 h. The physical effectiveness factor (**pef**) was determined as the DM proportion of particles retained by the top 2 sieves of the PSPS (Lammers et al., 1996). The physically effective NDF (**peNDF**) was calculated by multiplying the NDF content of the feed by the pef.

Dry matter content of those samples taken for chemical analysis was determined by drying samples in a forced-air oven at 55°C for 48 h. These samples, plus the separated ort fractions, were then ground to pass through a 1-mm screen (Brinkmann mill, Brinkmann Instruments Co., Westbury, NY). Following grinding, the separated ort fractions for each sample were reconstituted back into a single ort sample. Samples were then shipped to Cumberland Valley Analytical Services Inc. (Maugansville, MD) for analysis of DM (135°C), ash (535°C), ADF (AOAC, 2000), NDF with heat-stable α -amylase and sodium sulfite (Van Soest et al., 1991), CP (N $\times$ 6.25; AOAC 2000; Leco FP-528 Nitrogen Analyzer, Leco, St. Joseph, MI), and fat (AOAC, 1990).

Calculations and Statistical Analysis

Sorting was calculated as the actual DMI of each fraction of the PSPS expressed as a percentage of the predicted DMI of that fraction (Leonardi and Armentano, 2003). The predicted intake for each individual fraction was calculated as the product of the DMI of the total diet multiplied by the DM percentage of that fraction in the fed TMR. Values equal to 100% indicate no sorting, <100% indicate selective refusals (sorting

against), and >100% indicate preferential consumption (sorting for).

To test whether sorting of the experimental diets occurred, data for each PSPS fraction were averaged across the last 3 d of each treatment period for each heifer and tested for a difference from 100 using *t*-tests. The DMI and feeding behavior data were averaged across 7 d of each treatment period for each heifer. The nutrient and energy intake data were averaged across the last 3 d of each treatment period for each heifer. To test for the effect of treatment, all of these data were analyzed using the MIXED procedure of SAS (SAS Institute, 2003). The model included the fixed effect of treatment, the random effects of period and square, and the residual error. Linear and quadratic orthogonal contrasts were tested using the CONTRAST statement of SAS.

Data for DMI, feeding time, and feeding rate were also summarized on an hourly basis for each animal on each treatment. Differences among treatments in the distribution of these variables over a 24-h period were analyzed using the MIXED procedure of SAS treating hour as a repeated measure. The model included the fixed effects of hour, treatment, and hour by treatment interaction, the random effects of period and square and the residual error. Heifer within square was included in the model as the subject of the repeated statement. Heterogeneous compound symmetry was selected as the covariance structure on the basis of best fit according to Schwarz's Bayesian information criterion. All values reported are least squares means. Significance was declared at $P \leq 0.05$, and a trend was reported if $0.05 < P \leq 0.15$.

Table 4. Particle size distribution of the treatment diets fed to growing dairy heifers

Item	Experimental diets ¹			SE	Effects (<i>P</i> -value)	
	Control	10% straw	20% straw		Linear	Quadratic
Particles, % of DM retained						
>19.0 mm	26.8	31.3	43.3	4.5	0.03	NS ²
<19.0, >8.0 mm	45.2	42.1	33.6	3.4	0.01	NS
<8.0, >1.18 mm	23.4	21.6	18.8	1.0	0.04	NS
<1.18 mm	4.6	5.0	4.3	0.4	NS	NS
pef ³	0.72	0.73	0.77	0.01	0.06	NS
peNDF, ⁴ % of DM	30.8	36.5	38.8	2.0	0.02	NS

¹Control = 17.0% corn silage, 52.1% grass silage, 30.9% concentrate; 10% straw = control diet with 10% rye straw; 20% straw = control diet with 20% rye straw.

²NS = $P > 0.15$.

³pef = physical effectiveness factor determined as the proportion of particles retained by 2 sieves of the Penn State Particle Size Separator (Lammers et al., 1996).

⁴peNDF = measured as the NDF content of the TMR (DM basis) multiplied by the pef.

RESULTS

Dietary Composition

Nutrient composition of the dietary treatments is reported in Table 2. Addition of the rye straw resulted in the experimental diets having greater DM, ADF, NDF, and OM content compared with the control diet. Conversely, the greater proportion of concentrate in the control diet resulted in greater CP, Ca, and P content. As a result, the total digestible nutrients (TDN), ME, NE_G, and NE_M all decreased with the addition of straw to the control diet. The straw also changed the particle size distribution of the treatment diets (Table 4). With the addition of straw, there was a linear increase in the DM retained on the 19-mm sieve and a linear decrease in the DM retained on the 8- and 1.18-mm screens. The addition of straw to the diets caused the peNDF to increase linearly and a tendency for the pef to increase in the same manner.

Sorting

Heifers tended to sort against long particles (>19 mm) when fed the control diet ($P = 0.07$) and the 10% straw diet ($P = 0.06$) and sorted against long particles when fed the 20% straw diet ($P = 0.01$). The extent of sorting against long particles was similar across the experimental diets (Table 5). When provided the control diet heifers did not sort for or against medium-length particles (<19 mm, >8 mm; $P = 0.4$), whereas on the 10 and 20% straw diets they did sort for medium-length particles ($P \leq 0.01$). Overall, there was a linear increase in sorting for medium particles when straw was added to the diet (Table 5). Heifers sorted for short particles (<8 mm, >1.18 mm) when fed all 3 experimental diets ($P < 0.05$). There was a linear increase in the sorting for short particles with the addition of straw to the diet

(Table 5). Further, a quadratic tendency revealed that the extent of sorting was much greater for the 20% straw diet. For both the control and 10% straw diets, heifers did not sort for or against fine particles (<1.18 mm; $P = 0.3$). Heifers did sort for fine particles when fed the 20% straw diet ($P = 0.02$). Overall, there was a linear increase in the sorting for fine particles with the addition of straw to the diet (Table 5).

DMI and Feeding Behavior

There was a linear decrease in DMI of the heifers with the addition of straw to the diet (Table 6). As a result, there were linear decreases in the consumption of CP, ADF, NDF, NFC, TDN, ME, NE_M, and NE_G with the added straw. Despite the lower DMI, feeding time increased linearly with the addition of straw. This translated into a linear decrease in the rate of intake with the addition of straw to the diet. A quadratic tendency indicated that the rate of intake was more similar for the 10 and 20% straw diets compared with the control diet.

Analysis of the diurnal pattern of feeding behavior showed differences in DMI between the 3 treatments (SE = 0.05, $P < 0.001$; Figure 1A). We observed a treatment by hour interaction for DMI ($P < 0.001$) indicating that differences in hourly intake were affected by time of day. Of note is the reduction in DMI during the period of peak feeding activity when heifers consumed the 20% straw diet and the consistently greater DMI of the control diet for the second half of the day. We also noted a tendency for differences in hourly feeding time (SE = 1.48, $P = 0.13$; Figure 1B). Feeding time was consistently greater during the daytime hours for the straw diets compared with the control diet. These differences in hourly DMI and feeding time translated into heifers consuming the control diet at a much greater feeding

Table 5. Effect of treatment diets on the sorting (%) of long, medium, short, and fine particles by growing dairy heifers¹

Particle size ²	Experimental diet ³			SE	Effects (<i>P</i> -value)	
	Control	10% straw	20% straw		Linear	Quadratic
Long	92.0	91.4	87.1	3.8	NS ⁴	NS
Medium	100.7	102.9	105.5	0.9	0.003	NS
Short	104.6	103.9	110.3	1.8	0.05	0.14
Fine	96.7	103.2	107.8	2.6	0.003	NS

¹Sorting (%) = $100 \times (\text{actual DM intake of particle fraction} / \text{predicted DM intake of particle fraction})$. Data are averaged over 3 d for 6 heifers on each treatment.

²Particle size determined by Penn State Particle Separator: long = >19 mm, medium = <19, >8 mm, short = <8, >1.18 mm and fine = <1.18 mm.

³Control = 17.0% corn silage, 52.1% grass silage, 30.9% concentrate; 10% straw = control diet with 10% rye straw; 20% straw = control diet with 20% rye straw.

⁴NS = $P > 0.15$.

rate throughout the day (SE = 0.004, $P < 0.001$; Figure 1C). A treatment by hour interaction ($P < 0.001$) for feeding rate was noted, likely due to the consistently greater rate of intake of the control diet during the daytime hours.

The addition of straw resulted in a quadratic decrease in the number of meals consumed per day by the heifers, with the fewest meals per day consumed on the 10% diet (Table 7). We also noted a linear increase in the length and size of the meals with the addition of straw to the diet.

DISCUSSION

Despite the aim of providing feed as a homogeneous mixture in TMR, dairy cattle will selectively consume (sort) the more desirable components of the TMR, often causing animals to consume an imbalanced diet. Al-

though sorting behavior has been shown by several researchers to occur in lactating dairy cattle (Kononoff et al., 2003b; Leonardi and Armentano, 2003; DeVries et al., 2007), it is not known whether prepubescent growing dairy heifers engage in this behavior. This experiment was designed to test whether heifers engage in sorting behavior and to determine to what extent this occurs when heifers are fed diets containing varied amounts of a low-quality feedstuff (rye straw). Further, we aimed to test whether the growth and maintenance requirements of these animals could be met when consuming a nutrient-diluted diet. Given the addition of 10 and 20% rye straw to the control diet, the 3 treatment diets were not designed to have similar composition, but rather vary in particle size distribution and nutrient density. As the quantity of straw was increased, the diets contained an increased percentage of DM, ADF, NDF, and OM and a decreased percentage of CP, TDN,

Table 6. Effect of treatment diets on nutrient and energy intake of growing dairy heifers¹

Item	Experimental diet ²			SE	Effects (<i>P</i> -value)	
	Control	10% straw	20% straw		Linear	Quadratic
Nutrient intake						
DM, kg/d	8.12	7.08	6.18	0.28	<0.001	NS ³
CP, kg/d	1.42	1.04	0.85	0.06	<0.001	NS
ADF, kg/d	2.20	2.22	1.93	0.10	0.08	NS
NDF, kg/d	3.57	3.54	3.02	0.20	0.05	NS
NFC, kg/d	2.40	1.90	1.69	0.17	<0.001	NS
Energy intake						
TDN, ⁴ kg/d	5.80	4.75	4.03	0.24	<0.001	NS
ME, Mcal/d	20.98	17.19	14.56	0.86	<0.001	NS
NE _M , Mcal/d	13.55	10.88	9.17	0.58	<0.001	NS
NE _G , Mcal/d	8.45	6.59	5.54	0.42	<0.001	NS

¹DMI data are averaged over 7 d for 6 heifers on each treatment. Data for all other nutrients and energy intake are averaged over 3 d for 6 heifers on each treatment.

²Control = 17.0% corn silage, 52.1% grass silage, 30.9% concentrate; 10% straw = control diet with 10% rye straw; 20% straw = control diet with 20% rye straw.

³NS = $P > 0.15$.

⁴Total digestible nutrients.

Figure 1. Hourly averages for A) DMI (kg), B) feeding time (min), and C) feeding rate (kg/min) for growing dairy heifers fed 1) control diet (17.0% corn silage, 52.1% grass silage, 30.9% concentrate), 2) control diet with 10% rye straw, and 3) control diet with 20% rye straw. Data are averaged over 7 d for 6 animals on each treatment.

Table 7. Effect of treatment diets of the feeding behavior of growing dairy heifers¹

Item	Experimental diet ²			SE	Effects (<i>P</i> -value)	
	Control	10% straw	20% straw		Linear	Quadratic
Feeding time, min/d	180.24	193.30	199.24	13.38	0.05	NS ³
Feeding rate, kg/min	0.060	0.044	0.041	0.004	0.002	0.12
Meal frequency, no./d	9.62	8.39	8.71	0.92	0.03	0.03
Meal duration, min/meal	38.46	41.95	43.39	3.45	0.03	NS
Meal size, kg/meal	0.89	0.88	0.73	0.09	0.04	NS

¹Data are averaged over 7 d for 6 heifers on each treatment.

²Control = 17.0% corn silage, 52.1% grass silage, 30.9% concentrate; 10% straw = control diet with 10% rye straw; 20% straw = control diet with 20% rye straw.

³NS = *P* > 0.15.

ME, NE_G, and NE_M. According to the NRC (2001) requirements for a 250-kg nonbred Holstein heifer with a target gain of 1.0 kg/d, neither the 10 and 20% straw diets contained sufficient CP, TDN, or ME. Given their formulation, the 10 and 20% straw diets would be able to sustain growth rates of 0.9 and 0.8 kg/d, respectively. The addition of straw also changed the particle size distribution of the diets, with increased DM retained on the 19-mm screen and a decrease in DM found on the 8- and 1.18-mm screens. These changes, along with increased NDF, resulted in greater pef and peNDF in the 10 and 20% straw diets.

Regardless of the type of diet consumed, the heifers sorted against long particles and for short particles. The heifers also sorted for medium particles when fed the 10 and 20% straw diets. The main components contributing to the medium-length particles were flattened corn and short forage particles, whereas the pellets and other grain portions of the concentrate were the main contributors to the short particles. Clearly, the animals were preferentially sorting for the highly palatable concentrate components and against the longest forage particles. Other researchers have found similar sorting behavior in lactating dairy cows (Leonardi and Armentano, 2003; DeVries et al., 2007) and gravid dairy heifers (Hoffman et al., 2006). To our knowledge, this is the first evidence of such sorting behavior in prepubescent dairy heifers. We observed no difference in the extent of sorting against long particles between treatments. This result is not surprising because most research on feed sorting has reported that cattle sort extensively against long particles, regardless of the substrate making up the bulk of the long particle fraction (Leonardi and Armentano, 2003; Hoffman et al., 2006; DeVries et al., 2007).

With increased straw in the diet there was a linear increase in sorting for medium, short, and fine particles. This supported our initial hypothesis that heifers would sort more with increasing amounts of straw in the diet. There are several possible explanations for this in-

crease in sorting. Given the lower nutrient and energy density of the 10 and 20% straw diets, such sorting may indicate that the animals were attempting to compensate for this by increasing their consumption of the elements greatest in nutrient and energy content. It is well documented that ruminants will often selectively consume feedstuffs in an effort to meet their nutritional and energy requirements (Kyriazakis and Oldham, 1993; Cooper et al., 1994; Villalba and Provenza, 1999).

Another possible explanation for the increased sorting of the straw diets is the greater DM content of these diets. Leonardi et al. (2005) found that lactating cows sorted more against long particles when they were fed a dry diet. The DM content of the experimental diets in the present study was much lower than that tested by Leonardi et al. (2005). The main difference, however, between our experimental diets was the amount of rye straw, which has a very high DM content. This dry feedstuff does not have the same adhesion properties as the other, wetter forage components of the TMR. As a result, the smaller particles in the straw diets may have been more easily discriminated against. Similarly, it is also possible that the increased proportion of long, dry forage in the straw diets encouraged increased sorting behavior. Leonardi and Armentano (2003) demonstrated that increasing the proportion of dry alfalfa hay and decreasing the proportion of alfalfa silage resulted in increased sorting of smaller particles by lactating dairy cattle.

As the amount of straw in the diet was increased, the DMI of the heifers decreased and the time the animals spent eating increased. These differences were particularly noticeable during the periods of peak feed-bunk activity. As a result, there was a linear decrease in the rate of intake with increasing amounts of straw in the diet. The rate of intake was consistently lower throughout the daytime when the majority of eating activity occurred. This is likely the result of increased straw in the diet, and hence effective fiber, resulting in a greater amount of time needed for chewing and subsequent

rumination. Robles et al. (2007) found that feeding barley straw to heifers, in addition to a high concentrate diet, resulted in a slower feeding rate. In that study, the slower feeding rate is explained by the large amount of time the animals spent consuming the forage component of the diet. Allen (2000) suggested that dietary components that increase eating time (i.e., straw) could decrease the time available for ruminating and, thus, increase the filling effect of the diet. Our results would support this hypothesis in that the increased straw likely increased the rumen filling effect of the diets and, thus, resulted in lower DMI. NRC (2001) requirements suggest that the 10 and 20% straw diets were limiting in essential nutrients and energy. Lower DMI on these diets, therefore, could potentially limit growth and development. Interestingly, however, given the DMI levels of the heifers, all requirements were sufficiently met when the animals consumed the control and 10% straw diets. This finding supports our secondary hypothesis that the animals would be able to meet their nutrient requirements for maintenance and 1.0 kg/d of growth while consuming a nutrient-diluted ration. Crude protein and ME intakes were slightly below requirements for the targeted growth rate when the heifers were provided the 20% straw diet. This would indicate that there are limits to the quantity of straw or other low-quality feedstuffs that can be added to dairy heifer diets to achieve certain target growth rates. The nutrient intakes on the 20% straw diet, however, were sufficient to meet a growth rate of 0.9 kg/d. Therefore, dietary dilution with high levels of low-quality feedstuffs is possible, but will decrease the maximum growth rate achievable.

In a limit-feeding situation, animals are often fed insufficient quantities to allow for continuous feeding throughout the day. Hoffman et al. (2007) found some potentially detrimental effects of limit feeding gravid heifers, including increased vocalization, decreased time spent feeding, and increased time spent standing while not eating. Such effects of limit feeding may be indicative of reduced well-being of these animals. Increased time spent standing, particularly on hard flooring surfaces, may increase their risk of hoof pathologies (Cook et al., 2004; Vanegas et al., 2006). Further, the increased vocalization can be interpreted as a sign of frustration, hunger, and compromised welfare (Watts and Stookey, 2000; Valizadeh et al., 2008). It is not clear whether ad libitum feeding of a diluted diet would have either a positive or detrimental effect on these behaviors, and we encourage future work in this area. However, it is clear from our results that ad libitum feeding of a diluted diet to growing dairy heifers does promote longer feeding times and decreased rates of intake as opposed to limit-fed animals (e.g., Hoffman

et al., 2007). Based on the DMI and feeding behavior results, it is evident that the ad libitum-fed animals in our study were achieving satiety. Therefore, similar to limit feeding, diluting the nutrient density of the TMR by adding straw is an effective method of reducing overall DMI without compromising nutrient intake and growth requirements. Unlike limit feeding, dietary dilution achieved this without negatively affecting feeding behavior.

CONCLUSIONS

Heifers sorted against long particles regardless of diet composition. There was a linear increase in sorting for medium, short, and fine particles with increased straw in the diet. Dry matter intake, feeding rate, meal size, and meal frequency decreased with increased straw in the diet, whereas feeding time and meal duration increased. All requirements for maintenance and growth of 1.0 kg/d were sufficiently met when animals consumed the control and 10% straw diets. On the 20% straw diet the animals consumed sufficient nutrients to achieve a growth rate of 0.9 kg/d. Our results indicate that straw may be included in the diet to reduce DMI and target nutrient intake without negatively affecting feeding behavior or growth potential. Therefore, the addition of an inexpensive, low-quality feedstuff may help reduce feed costs and enable producers to target caloric intake for desirable weight gain and development. Furthermore, the ad libitum feeding of a diluted diet also provides increased opportunity for these animals to express their natural foraging behavior.

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