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Effects of particle size and moisture levels in mixed rations on the feeding behavior of dairy heifers

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Two experiments on replacement heifers (175 ± 12 days of age) assessed the effects of forage particle length and moisture on feeding behavior. Both experiments used a replicated 3 × 3 Latin square design, with nine heifers per replication and three periods of 9 days each. Each group of nine heifers was housed in one pen with access to three electronic feed bins. In Experiment 1, hay chopped at different lengths was incorporated into three total mixed rations (TMR) all having the same ingredient and nutrient composition but differing in the percentage of long particles (>19 mm): 60% (Short), 64% (Medium) and 72% (Long). In Experiment 2, heifers were fed a TMR with the same ingredient and nutrient composition but differing in moisture content: 65% DM (Dry), 50% DM (Moderate), and 35% DM (Wet). In both experiments, feeding behavior during the last 5 days of each period was analyzed using a mixed model accounting for the fixed effects of treatment and period, and the random effects of replication and animal. In Experiment 1, dry matter intake (DMI) and eating rate (DMI/min) tended to increase, whereas daily eating time decreased as the feed particle size decreased. Heifers fed the Long diet selected in favor of long particles (>19 mm) and against Short (1.18 to 8 mm) and fine (<1.18 mm) particles; heifers fed the Short diet selected against long particles and in favor of short and fine particles. Heifers fed the Medium diet showed a preference for medium particles with no preference for the other particle sizes. In Experiment 2, heifers fed the Dry diet tended to consume more feed than those fed the Moderate and Wet diets, with no differences in feeding behavior or sorting activity. In conclusion the Medium diet minimized sorting without reducing eating rates and intake, and adding water to TMR to achieve a dry matter less than 65% tended to decrease DMI without reducing sorting.

Keywords: feeding management, dietary preference, TMR, forage, Holstein

Implications

This study examined how forage particle length and the moisture content of the total mixed ration (TMR) affected feed consumption and feed sorting by dairy heifers. A TMR with medium particle size (where 65% of the particles > 19 mm and 6% of particles < 1.18 mm) minimized feed sorting. Adding water to the diet such that dry matter was lower than 65% (DM ≤ 35%) tended to decrease consumption but did not reduce sorting of the TMR. Results of this study will help improve feeding management of heifers raised on high forage diets.

Introduction

Physical attributes of feeds can affect feeding behavior of replacement heifers. Heifers are fed in a variety of ways in the months after weaning; for example, some farms feed concentrate and forage separately, other top-dress forage with concentrates and other feed a total mixed ration (TMR). Feeding methods are intended to meet production goals and minimize health disorders, competition and hunger (Bach and Ahedo, 2008). Feeding a TMR has some advantages over providing concentrate and forage separately. For example, TMR reduces competition at the feed bunk and decreases feed sorting (DeVries and von Keyserlingk, 2009a; Greter *et al.*, 2010).

The distribution of particle size can affect feed intake, feeding behavior, feed sorting, rumination and rumen function (Tafaj *et al.*, 2007; DeVries and von Keyserlingk, 2009a). Research on adult dairy cattle has focused on preventing rumen acidosis by varying particle size (Zebeli *et al.*, 2012), but less work has focused on rations for replacement heifers. These animals are typically fed more forage than adult cows and the risk of rumen acidosis is thought to be low.

Diets for heifers are typically based on hay or straw and thus are relatively low in moisture. Previous work on adult

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dairy cattle and older heifers has shown increased consumption (Lahr *et al*., 1983), reduced sorting (Leonardi and Armentano, 2003; Leonardi *et al*., 2005), less dust (Arzola-Álvarez *et al*., 2010) and lower feed losses due to wind when the moisture content was increased by adding water, but other studies have reported either no effect (Fish and DeVries, 2012), or decreased feed intake (Kellems *et al*., 1991; Felton and DeVries, 2010) and increased sorting (Miller-Cushon and DeVries, 2009; Felton and DeVries, 2010) with greater dietary moisture. Furthermore, wetter rations are prone to spoilage especially at higher environmental temperatures (Felton and DeVries, 2010). Differences in results of previous studies may be due to variation in feed composition (e.g. forage to concentrate ratio, forage sources, and feed particle length), environmental conditions (temperature and humidity), moisture levels and methods used to manipulate moisture (e.g. water addition).

To our knowledge, the effects of feed particle length and moisture content in TMRs fed to younger heifers have not been evaluated. The objectives of this study were to examine the effects of differences in forage particle length and moisture on feeding behavior and sorting by replacement heifers. We hypothesized that heifers would consume more feed, spend less time eating, and sort less when fed a TMR containing small forage particles than one composed of long particles. Furthermore, adding water to a dry TMR would reduce sorting and increase dry matter intake (DMI).

Material and methods

This study was conducted at the UBC Dairy Education and Research Centre in Agassiz, BC, Canada. The Institutional Animal Care Committee (monitored according to CCAC, 2009) approved all procedures described in this study.

Experiment 1: effects of dietary particle size

Eighteen Holstein heifers (initial BW = 203 ± 23 kg and age 191 ± 13 days) were used in a replicated 3 × 3 Latin square design with three periods of 9 days and three treatments (three heifers per treatment and replication). Heifers were housed in a single pen consisting of a sawdust bedded-pack area (4.6 × 9.0 m; width × depth) and alley (4.6 × 3.05 m) that divided the pack from the feeding area. Water was available *ad libitum* from a water bowl in the pen. Feed was provided using three automated feed intake control bins (Insentec BV, Marknesse, The Netherlands). Each individual feed bin was 0.8 m wide, 0.75 m high and had a depth of 0.74 m. The design of the feeding system allowed for each heifer to be assigned to a bin related to a specific feeding treatment. For 7 days before the start of each replicate heifers trained to bins (three heifers per bin) and fed long hay *ad libitum* and restricted amounts of starter (~3 kg/day). In each experiment, treatments (TMR) were switched among three bins rather changing bins for heifers. This allowed for using a shorter adaptation period during each experiment because the heifers were adapted to the pen environment and fed on the same bin throughout the entire study.

Table 1 *Ingredient and nutrient composition and particle size distribution of diets differing in the chop length of hay (Experiment 1)*[1]

	Long	Medium	Short
Ingredients (% of DM)			
Corn silage	13.5	13.5	13.5
Grass hay	58.2	58.2	58.2
Grass silage	10.6	10.6	10.6
Barley	10.9	10.9	10.9
Corn	2.65	2.65	2.65
Distillers dried grains	1.78	1.78	1.78
Canola meal	0.79	0.79	0.79
Soybean meal	0.45	0.45	0.45
Limestone	0.45	0.45	0.45
Molasses	0.36	0.36	0.36
Mineral vitamin premix	0.32	0.32	0.32
Nutrients (DM basis)			
Metabolizable energy (Mcal/kg)[2]	2.06	2.06	2.06
CP (%)	15.1	15.1	15.1
NDF (%)	52	52	52
Particle size distribution (% retained on sieve)			
Long (>19 mm)	72.2	64.2	60.0
Medium (8 to 19 mm)	9.6	13.3	13.5
Short (1.18 to 8 mm)	12.6	16.1	19.3
Fine (<1.18 mm)	4.6	5.5	6.5

Grass hay was chopped using a TMR mixer to attain SHORT (~70% particles > 19 mm), MEDIUM (~65% particles > 19 mm), and LONG (~60% particles > 19 mm) particles. Throughout the experiment, particle size of the diets offered to heifers was kept constant within treatments. For the LONG treatment the CV for long, medium, short and fine particles was 10.2, 16.3%, 17.6% and 16.0%, respectively; for MEDIUM the CV was 11.4%, 17.7%, 19.9% and 14.3%, respectively; and for SHORT the CV was 14.6%, 20.1%, 16.6% and 19.6%, respectively.

[1]All diets were identical in ingredient and chemical composition (calculated) and differed only in particle size distribution.

[2]Estimated following NRC (2001).

Individual feed consumption and feeding behavior were monitored continuously for all heifers. All heifers were weighed at the beginning and at the end of each period.

Nutrient and ingredient composition and particle size distribution of the experimental rations are presented in Table 1. Diets were identical in nutrient and ingredient composition and varied only in particle size of the hay component. Hay was chopped using a TMR mixer (Loewen Horizontal mixer; Loewen Welding & Manufacturing Ltd Matsqui, BC, Canada) at 1900 r.p.m. for 5, 20 and 60 min to achieve long, medium and short particle sizes, respectively. At each feeding, a TMR was prepared by mixing hay of different lengths with silage and concentrate providing three treatments: Long (72% particles > 19 mm), Medium (64% particles > 19 mm) and Short (~60% particles > 19 mm). Orts were removed and heifers fed at 0900, 1500 and 2100 h daily for *ad libitum* intake and 10% refusals.

Representative samples were taken from the orts and the fresh feed on days 6 and 8 of each period. The dry matter (DM) was determined by oven-drying at 55°C for 48 h. The particle size distribution was determined using the 3-screen Penn State Particle Separator (PSPS; Kononoff *et al*., 2003b).

Table 2 *Ingredient and nutrient composition and particle size distribution of diets differing in moisture content (Experiment 2)*[1]

	Dry	Moderate	Wet
Ingredient (% of DM)			
Alfalfa hay	45.4	45.4	45.4
Grass hay	14.2	14.2	14.2
Barley	25	25	25
Corn	6	6	6
Distillers dried grains	4	4	4
Canola meal	1.8	1.8	1.8
Soybean meal	1	1	1
Limestone	1.1	1.1	1.1
Molasses	0.78	0.78	0.78
Mineral vitamin premix	0.72	0.72	0.72
Nutrient (DM basis)			
Metabolizable energy (Mcal/kg)[2]	2.38	2.38	2.38
CP (%)	18.3	18.3	18.3
NDF (%)	36.4	36.4	36.4
Particle size distribution (% retained on sieve)[1]			
Long (>19 mm)	34.1	34.7	33.9
Medium (8 to 19 mm)	22.7	25.9	31.5
Short (1.18 to 8 mm)	33.2	33.6	31.8
Fine (<1.18 mm)	9.9	5.7	2.8

All diets were identical in ingredient and chemical composition (calculated) and differed only in moisture contents.
[1]Differences in moisture were achieved by addition of water. Dry: 65% DM; Moderate: 50% DM; Wet: 35% DM.
[2]Estimated following NRC (2001).

Experiment 2: effects of moisture content of the ration
Following the design of Experiment 1, 18 Holstein heifers (initial BW = 158 ± 17 kg and age 159 ± 11 days) were used in a replicated 3 × 3 Latin square design with three periods of 9 days and three treatments (three heifers per treatment and replication). Heifers were housed in a single pen as described above. Before the start of each replicate heifers were allocated to bins (three heifers per bin), trained for 7 days with long hay fed *ad libitum* and restricted amounts of starter (~3 kg/day). Nutrient and ingredient composition and particle size distribution of the experimental rations is presented in Table 2. In this experiment, each feed had the same TMR but contained different amounts of moisture. Differences in moisture were achieved by adding water at the rate of 0.475, 0.925 and 1.675 l/kg of TMR to obtain three treatments: Dry (65% DM), Moderate (50% DM) and Wet (35% DM). Feeding behavior measures as described in Experiment 1.

Statistical analysis
Analyses were identical for both experiments. The first 4 days of each period were considered as an adaptation period to new diet and data from these days were excluded. A 4-day adaptation period was used because the heifers remained in the same pen and accessed the feed from the same bin throughout the study (diets were switched among bins during the study). Meal criteria (maximum amount of time between visits to the feed bins to consider a visit as a part of the same meal) were calculated using a model composed of two normal distributions resulting from the natural logarithm of time (in seconds) between feed bin visits as described elsewhere (Tolkamp *et al.*, 1998). Meal criteria were calculated for each heifer for the last 5 days of each period and treatment. The duration (min), amount of feed consumed (kg), and feed consumption rate for each visit (kg/min), daily DMI (kg/day), daily time spent feeding (min/day), and average feeding rate (kg/min) for each heifer were calculated. Sorting (per bin) was calculated as the DMI of each fraction of the PSPS expressed as a proportion of the predicted DMI of that fraction (Leonardi and Armentano, 2003). Predicted intake of each fraction was calculated as the product of the total DMI multiplied by the DM percentage of that fraction in the feed provided. Values equal to 1 indicate no sorting, <1 indicate selective refusals (sorting against), and >1 indicate preferential consumption (sorting for).

Initially, a mixed effects model that accounted for the fixed effects of treatment, day, period and the interaction between treatment and day, and the random effects of replication and animal within treatment and period was run. No interaction between treatment and day was present for any of the dependent variables, so data were summarized over the 5 days period yielding one value for each animal and treatment. Feed intake data were analyzed using the MIXED procedure of SAS (SAS Institute, 2009) with a mixed-effects model that accounted for the fixed effects of treatment and period and the random effects of replication and animal within treatment and period ($n = 18$). Sorting activity was analyzed in similar matter, but without the effect of animal. In addition, sorting activity for each particle size fraction within treatment was tested for a difference from 1 using a *t*-test.

Results and discussion

Experiment 1: effects of dietary particle size
Within treatments, particle size of the diets offered was kept relatively constant. For the Long treatment the CV for long, medium, short and fine particles was 10.2%, 16.3%, 17.6% and 16.0%, respectively; for Medium the CV was 11.4%, 17.7%, 19.9% and 14.3%, respectively; and for Short the CV was 14.6%, 20.1%, 16.6% and 19.6%, respectively.

DMI tended ($P = 0.09$) to increase as the particle size decreased (Table 3). Several studies have shown increased DMI with decreasing particle size (Teimouri Yansari *et al.*, 2004; Tafaj *et al.*, 2007; Alamouti *et al.*, 2009). However, when feeding high-concentrate rations (>50% concentrate) particle size seems to have less of an effect on DMI (Allen, 2000; Yang and Beauchemin, 2007). The higher DMI in the current study may have been due to the combined effects of increased passage and digestion rates (Tafaj *et al.*, 2007; Storm and Kristensen, 2010), and the tendency ($P = 0.07$) to increase eating rate as the particle size decreased (Table 3). It is well known that the distension of the reticulorumen could limit feed intake of high-forage diets (Montgomery and Baumgardt, 1965; Allen, 2000). The high-forage diet fed in the current study (~80% of the dietary DM) may have increased the effects of particle size on DMI.

Table 3 *Feed consumption and feeding behavior as affected by particle length of the diet (Experiment 1)*[1]

Parameters	Long	Medium	Short	s.e.	*P*-value
Total intake (kg of DM/day)	6.4	6.8	7.0	0.2	0.09
Total time eating (min/day)	186[a]	178[a]	154[b]	9	0.04
Eating rate (g of DM/min)	35	39	47	3	0.07
Feed sorting (%)					
Long particles (>19 mm)	1.11[a]	0.95[b]	0.19[c]*	0.07	<0.001
Medium particles (8 to 19 mm)	1.25[b]*	1.45[b]*	1.83[ab]*	0.15	0.05
Short particles (1.18 to 8 mm)	0.70[c]*	0.97[b]	1.27[a]*	0.08	<0.001
Fine particles (<1.18 mm)	0.63[c]*	0.97[b]	1.25[a]*	0.09	0.002

Sorting = actual DM intake of particle fraction/predicted DM intake of particle fraction. Values equal to 1 indicate no sorting, <1 indicate selective refusals (sorting against), and >1 indicate preferential consumption (sorting for).
[a,b,c]Values within row with uncommon superscripts differ at $P < 0.05$.
[1]Grass hay was chopped using a TMR mixer to attain Short (~70% particles >19 mm), Medium (~65% particles >19 mm) and Long (~60% particles >19 mm) particles.
*Denotes a value differing ($P < 0.05$) from 1.

Meal criteria did not differ among treatments (3.8 ± 0.27 min). Number of eating bouts (18.4 ± 1.54/day), meal size (371 ± 30.8 g of DM/meal), and meal duration (9.23 ± 0.7 min/meal) also did not vary with treatment. Other studies have reported effects on eating bouts, meal size, and meal duration in heifers fed in a competitive environment (DeVries and von Keyserlingk, 2009b), offered a TMR or separated rations (DeVries and von Keyserlingk, 2009a; Greter *et al*., 2010) or diluting the diet with a forage source (Greter *et al*., 2008). Total eating time (min/day) was lower ($P < 0.05$) for heifers fed Short compared with those fed Long or Medium diets. Increased eating time in response to longer particle sizes has been reported for adult cows in some studies (Maulfair *et al*., 2010) but not others (Kononoff *et al*., 2003a; Yang and Beauchemin, 2006). This discrepancy may be due to differences in other dietary factors i.e. moisture contents, forage NDF and forage DM in TMR.

Sorting behavior was affected ($P < 0.05$) by particle size (Table 3). In all treatments, heifers selected for feed particles classified as medium (8 to 19 mm), but the effect was greatest for heifers that received the Short ration. Previous work reported that cows sort against long particles and in favor of fine particles (Kononoff *et al*., 2003a; Leonardi and Armentano, 2003; DeVries *et al*., 2007). Likewise, Greter *et al.* (2008) reported sorting against long and for short particles in older (226 ± 6 days) heifers. Heifers fed the Long ration did not ($P = 0.72$) select against long (>19 mm) particles, despite selecting ($P < 0.05$) against short (1.18 to 8 mm) and fine (0.63 mm) particles. Differences between our results and those of Greter *et al.* (2010) may be attributed the differences in particle size distributions of the diets. Greter *et al.* (2010) fed rations containing between 26% and 43% of long particles; in current study the TMR contained between 60% and 70% long particles (Table 1). It is possible that the high proportion of long particle sizes in the Long ration prevented heifers from reaching the small proportion of short and fine particles. When the proportion of short particles is low, it is less likely that the animal will be able to preferentially consume these particles as they become increasingly difficult to differentiate. Heifers fed the SHORT ration clearly selected against long particles but heifers fed the Medium ration showed a preference for medium particles with no preference for the other particle sizes. This observation suggests that offering rations with about 64% of forage particles greater 19 mm in length may be ideal.

Reduced sorting is considered beneficial because it diminishes diurnal variation of nutrient intake (DeVries *et al*., 2005). The results of this experiment suggest that a ration with a particle size distribution similar to the Medium ration minimizes sorting activity and does not compromise DMI. A ration similar to Long may compromise intake. A ration similar to Short would not reduce DMI but would result in increased sorting against long particles. Traditionally the dairy heifers are fed diets in which the majority of the nutrients are derived from forages (Zanton and Heinrichs, 2009). Under such feeding systems, DMI could be affected by the type and characteristics (physical and chemical) of forage used (Allen, 1997; Allen, 2000), and any reduction in feed consumption could compromise growth. However, the current studies were not designed to assess the long-term effects on growth performance. Further studies are required to understand the effects of various attributes (physical and chemical) of forage-based TMR on intake and performance of heifers.

Experiment 2: effects of moisture content of the ration

To our knowledge, ours is the first study to evaluate the effect of adding water to TMR for heifers. Heifers that received the Dry ration tended ($P = 0.09$) to consume more DM (5.9 kg/day) than those fed the Moderate (4.8 kg/day) and Wet (5.1 kg/day) rations. Digestive dynamics, as well as the amount of water directly consumed by the heifers, could have been altered by the moisture content of the diet. Water consumption was not measured in the current study but we recommend that this be measured in future work. There were no treatment differences in eating time (165 ± 17.7 min/day), number of eating bouts (12.8 ± 1.68/day), meal size (423 ± 55 g of DM/meal), meal duration (13.0 ± 2.4 min/meal) or eating rate (35.7 ± 2.5 g of DM/min). As in Experiment 1, meal criteria were not affected by treatment, with an average meal criterion of 5.2 ± 0.56 min. Research on the effects of adding water to

Table 4 *Sorting activity of heifers as affected by moisture content of the diet (Experiment 2)*[1]

Parameters (%)	Dry	Moderate	Wet	s.e.	*P*-value
Long particles (>1.9 mm)	0.56*	0.42*	0.66*	0.14	0.22
Medium particles (8 to 1.9 mm)	1.19	1.24*	1.16	0.05	0.55
Short particles (1.18 to 8 mm)	1.28*	1.37*	1.24*	0.13	0.39
Fine particles (<1.18 mm)	1.31	1.58*	1.98*	0.26	0.57

[1]Dry: 65% DM; Moderate: 50% DM; Wet: 35% DM. Sorting = actual DM intake of particle fraction/predicted DM intake of particle fraction. Values equal to 1 indicate no sorting, <1 indicate selective refusals (sorting against), and >1 indicate preferential consumption (sorting for).
*Denotes a value differing ($P < 0.05$) from 1.

the TMR for adult cows has been inconclusive; some studies describe increases in DMI (Lahr *et al.*, 1983) and others report negative effects (Kellems *et al.*, 1991).

Sorting activity was not affected by moisture content of the TMR (Table 4). Overall, heifers selected against long (>19 mm) particles and for short (1.18 to 8 mm) and fine particles (<1.18 mm). Some authors have suggested that adding water to TMR for adult cows diminishes sorting (Shaver, 2002; Leonardi *et al.*, 2005) but others have reported contrary findings (Miller-Cushon and DeVries, 2009; Felton and DeVries, 2010) or no effect (Fish and DeVries, 2012). The results from the current study suggest that adding water to a TMR has no consequences on sorting activity but tends to reduce DMI.

Conclusion

Providing heifers with a TMR containing about 65% of the particles above 19 mm and <6% of particles below 1.18 mm minimizes sorting without affecting intake rates and feed consumption. Adding water to achieve moisture contents of a TMR above 65% is not desirable, as it may decrease feed consumption and fails to reduce sorting against long feed particles.

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