Canadian Journal of Animal Science
Revue canadienne de science animale

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Journal:	<i>Canadian Journal of Animal Science</i>
Manuscript ID	CJAS-2017-0123.R1
Manuscript Type:	Short Communication
Date Submitted by the Author:	25-Oct-2017
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Keywords:	automated milking system, concentrate, dairy cow, milking frequency

RUNNING HEAD: CONCENTRATE AND AMS**Does the Location of Concentrate Provision Affect Voluntary Visits, and Milk and Milk Component Yield for Cows in an Automated Milking System?**

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ABSTRACT

Eight Holstein cows were used in a cross-over design test whether concentrate allocation in an automated milking system (AMS) affects DMI and milk production. Cows were fed a high-energy partial mixed ration (HE-PMR) with 0.5 kg of AMS concentrate or a low-energy PMR (LE-PMR) with 5.0 kg of AMS concentrate. AMS concentrate intake was greater and PMR intake was reduced for LE-PMR than HE-

PMR. Milk, fat, and protein yields were not affected by treatment. In a guided traffic flow barn, providing a PMR with greater energy density increases DMI, but has no effect on milk and milk component yield.

Key words: automated milking system, concentrate, dairy cow, milking frequency

INTRODUCTION

Based on survey data, dairy producers utilizing automated milking systems (AMS) typically feed between 1.8 to 7.7 kg of concentrate daily to entice cows to visit the milking unit (Rodenburg 2011). While the reported feeding rates have a substantial range, a more recent survey utilizing data arising from mostly free-traffic flow AMS barns (93% of the observations; Tremblay et al., 2016) reported a mean feeding rate of 1.59 kg of concentrate/10 kg of milk produced, equating to feeding rates of 4.8 to 7.2 kg/d for cows producing 30 to 45 kg of milk/d. Thus, the data of Tremblay et al. (2016) support the feeding rates summarized by Rodenburg (2011) and indicate little change in practices over time.

There are several challenges when feeding high concentrate allowances in an AMS. Firstly, increasing the amount of concentrate offered to cows does not guarantee consumption as other factors such as maximum AMS meal size and milking frequency may constrain the amount actually provided (Bach and Cabrera 2017). For example, Bach et al. (2007) compared providing 3 vs. 8 kg of AMS concentrate in the AMS; however, cows only consumed 2.6 and 6.8 kg/d, respectively. In another study, Halachmi et al. (2005) offered either 1.2 kg/milking or a maximum of 7 kg/d. In that study, cows that were theoretically provided with 7 kg/d

only consumed 5.2 kg/d emphasizing that the concentrate allocation may not equate to that offered and consumed in the AMS. The discrepancy between the amount offered and that consumed in the above-listed studies suggests that the implementation of a feeding strategy with high AMS concentrate allocation is often not successful.

A second challenge with high concentrate allocation in the AMS is that increasing the concentrate delivered in the AMS results in a substitution effect, where the increased concentrate consumed is offset by a reduction for the intake of the partial mixed ration (**PMR**; Bach et al., 2007). Only 1 study known to the authors has considered the impact of how AMS concentrate provision strategies affect PMR intake. However, the substitution of PMR for AMS concentrate can have a large impact on the nature of the diet consumed as Bach et al. (2007) reported that for every 1 kg/d increase in AMS concentrate consumed, cows decreased PMR intake by 1.14 kg/d.

Lastly, while it has been suggested that providing more concentrate in the AMS may encourage voluntary visits and milk yield, the amount of concentrate offered in the AMS in guided-traffic flow systems have not been reported to improve milking frequency or milk and milk component yield (Halachmi et al., 2005; Migliorati et al., 2005; Bach et al., 2007). While most studies have evaluated the effect of providing additional concentrate in the AMS, it is not clear whether iso-caloric dietary scenarios will affect performance (Bach et al., 2007). These data are necessary to help establish optimal quantities of concentrate provided in an AMS. Moreover, while there are several previous studies evaluating concentrate feeding

strategies in AMS, none to date have been successful in achieving targeted AMS concentrate intake.

Nevertheless, given the challenge in delivering the targeted concentrate provision to dairy cattle milked in an AMS, the substitution effect reducing PMR intake when increased AMS concentrate is provided, and that milk yield and milk component yield are not improved, we set out to test whether location of concentrate provision, under iso-caloric dietary conditions, would affect voluntary attendance and milk and milk component yield for cows milked in an AMS. We hypothesized that increasing concentrate provision for cows in a guided traffic flow AMS will not improve voluntary attendance, and milk yield and composition when total dietary energy is balanced.

MATERIALS AND METHODS

The study was conducted at the Rayner Dairy Research and Teaching Facility at the University of Saskatchewan (Saskatoon, SK, Canada) using 8 lactating Holstein-Friesian cows. At the start of the study, the three primiparous heifers were, on average, 123 ± 71 DIM and the five multiparous cows were 227 ± 25 DIM. The average starting BW was 689 kg with a standard error of 19.0 kg. All experimental procedures were pre-approved by the University of Saskatchewan Research Ethics Board (protocol 20100021) and cows were cared for in accordance with the Canadian Council of Animal Care guidelines (CCAC, 2009).

The study was designed as a randomized crossover design consisting of 2 dietary treatments and two, 26-d periods. The first 19 d of each treatment period served as an adaptation period, followed by a 7-d sampling period. Prior to the start

of the study, cows were trained to use the AMS (DeLaval International, Tumba, Sweden) and automated feed bins (Roughage Intake Control System, Insentec, Marknesse, Netherlands) validated by Chapinal et al. (2007).

Housing and Cow Traffic Flow

Cows were housed in a feed-first guided-traffic flow barn with 12 free stalls. Eight automated feed bins (Roughage Intake Control System, Insentec, Marknesse, Netherlands) were accessible within the feeding area and one cow was assigned to each feed bin such that cow was considered as the experimental unit, and so that PMR intake and sorting behaviour could be determined. Cows gained access to a holding area if they met milking permission criteria, otherwise they were directed to the free-stall area. Milking permission for primiparous and multiparous cows was granted, respectively, when predicted milk yield exceeded 9 and 10 kg or when 4 and 5 h had elapsed since the previous milking.

Dietary Treatments

Diets were formulated to meet the nutritional requirements for a 680-kg cow producing 43 kg of milk with 3.8% milk fat and 3.3% protein using the Nutritional Dynamic System software (Sant' Ambrogio, Italy). Treatments consisted of a high-energy PMR (**HE-PMR**) with a target of 0.5 kg of concentrate (DM basis) provided in the AMS or a low-energy PMR (**LE-PMR**) with a target of 5.0 kg of concentrate (DM) consumed in the AMS (Table 1). The concentrate supplement provided in the AMS and PMR were the same. To achieve the 0.5 kg and 5.0 kg of concentrate provision in the AMS, a total of 0.54 and 5.20 kg of concentrate (DM basis) were

provided in the AMS. The maximal meal size of AMS concentrate was set at 2.5 kg/visit on an as fed basis.

When combining the PMR and AMS concentrate allocation, diets were formulated to be similar in the forage-to-concentrate ratio, and to be iso-caloric and iso-nitrogenous. Thus, this study design allowed for the investigation of whether AMS attendance in a feed-first guided-traffic system is stimulated by concentrate provision in the PMR or AMS. The PMR was fed twice daily at 1000 and 1700 h into the automated feed bins that continuously measured and recorded the weight of feed (at visit start and end), and visits to the feed bunks such that feeding time, eating rate, and meal parameters could be calculated. The PMR was fed ad libitum targeting refusals of 5 to 10% relative to the amount of feed offered (as fed basis). Prior to the morning feeding on each day, the refusals were weighed to facilitate calculation of DMI (described below). Feed bins were calibrated after removal of feed refusals if the scale displayed a value other than 0.00 kg.

Data Collection and Laboratory Analysis

Cows were weighed on 2 consecutive days prior to the start of the study and at the end of each period to calculate BW change. From d 20 to 26, data from the feed bins were used to calculate feeding behaviour, as described by DeVries et al. (2003). In addition, the AMS recorded amount of concentrate offered per visit.

Feed ingredient (ingredients in PMR and AMS concentrate) and refusal samples (PMR) were collected each day during the data collection period and pooled to prepare a composite for each treatment period. All samples were stored at -20°C until the end of each experimental period. Samples were then thawed at room

temperature and analyzed for DM content using a forced-air convection oven at 55°C until achieving a constant weight. Individual feed ingredients were ground through a 1-mm screen using a hammer mill (Christy and Norris Ltd., Chelmsford, UK), and sent to Cumberland Valley Analytical (Hagerstown, MD) for chemical analysis as described by Rosser et al. (2013).

In addition, all feed samples (daily ration, feed ingredients, robot concentrate, and feed refusals) were analyzed, in duplicate, for particle size distribution using a 4-tiered (3 sieves and 1 pan) Penn State Particle Separator (Nasco, Fort Atkinson, WI). Pore sizes of the upper, middle, and lower sieves were 18 mm, 8 mm, and 1.18 mm, respectively. The difference between the PMR and refusal particle size distribution were analyzed on an as fed basis to determine the feed sorting behaviour according to Leonardi and Armentano (2003). Values greater than 1.0 were interpreted as selective consumption, whereas values less than 1.0 indicated selective refusal.

Milking behaviour (including milking frequency, milk yield, and milking duration) was determined from data collected by the AMS. Data were downloaded and average milking frequency, milk yield, milking duration, and inter-milking interval were determined over each 7-d collection period. In conjunction, from d 23 to d 26, milk samples were collected at each milking. Milk samples were stored at 4°C until the end of each study period, were composited (proportionally to milk yield at each milking) by cow and day. Samples were sent to Dairy Herd Improvement (Edmonton, AB, Canada) and analyzed for fat, protein, and lactose concentrations, and MUN. The 4-d milk composition data were combined with the 7-d milk yield values to determine milk component yield.

Statistical Analysis

All data were confirmed to be normally distributed based on graphical representation and a Shapiro-Wilk P value > 0.05 . Data for each cow were averaged by period and analyzed as a cross-over design using the Proc Mixed of SAS (Version 9.3, Cary, NC) with fixed effects of treatment, parity, and period and the two-way interaction between treatment and parity. Cow was included in the model as a random effect. Significance was declared when $P < 0.05$ and trends were discussed when $0.10 > P > 0.05$.

To evaluate whether sorting indices for each treatment differed from one, a 2-tailed t-test was used using SAS. Differences were declared significant when $P < 0.05$.

RESULTS AND DISCUSSION

It has been suggested that feeding greater quantities of concentrate in the AMS will result in greater milk production and improve efficiency of the AMS by improving voluntary visits (Rodenburg 2011). However, this recommendation is based on the evaluation of practices employed by dairy producers (de Jong et al. 2003; Salfer and Endres 2014), rather than from conclusions drawn from controlled studies. Moreover, a recent observational study further challenged the notion that increased AMS concentrate provision always enhances milk yield, as they noted a negative relationship between the amount of concentrate offered in the AMS and milk yield (Tremblay et al. 2016). Thus, research is needed to evaluate feeding strategies for cows milked with AMS (Jacobs and Siegford 2012).

As designed with the treatments in the present study, AMS concentrate intake was greater for cows fed the LE-PMR than the HE-PMR (5.0 vs. 0.5 kg/d; Table 2). Contrary to AMS concentrate intake, PMR intake was greater for cows fed the HE-PMR compared to LE-PMR, and the corresponding changes resulted in a 2.7 kg/d lower total DMI for cows fed LE-PMR than HE-PMR ($P = 0.05$). These findings support the work of Bach et al. (2007) indicating that AMS concentrate functions as a partial substitute for PMR. Specifically, they noted that for every 1 kg/d increase in concentrate intake, there was a 1.14 kg/d reduction in PMR intake. In the present study, we observed a substitution rate of 1.58 kg PMR/kg AMS concentrate, further supporting the concept that increasing the AMS concentrate provision leads to a reduction in PMR intake and will further alter the forage-to-concentrate ratio of the diet consumed. Using the data in the present study, cows fed the LE-PMR consumed a diet containing 45.8% forage compared to 47.6% for cows fed the HE-PMR and a target of 47.4% for the LE-PMR treatment. There was no effect of parity on feed intake. While we were able to detect changes in PMR intake and AMS concentrate intake, based on retrospective analysis, it is evident that statistical power is limiting for this study. With the observed differences among treatments for total DMI and the measured standard deviation, retrospective power analysis using the Proc Power statement in SAS (SAS Institute, Cary, NC) indicated that 15 cows would have been needed to have an 80% power to detect differences ($\alpha = 0.05$).

Cows fed the HE-PMR spent 29 min/d more eating PMR, had a faster PMR eating rate (0.14 vs. 0.12 kg/min), and consumed larger PMR meals (3.2 vs. 2.3 kg PMR/meal) than cows fed the LE-PMR (Table 2). The inter-meal interval, meal

frequency, and meal duration were not affected by treatment. Cows fed the LE-PMR selectively consumed more particles retained on the 8-mm sieve and refused more particles retained in the pan when compared to the HE-PMR. The sorting index values for the 8-mm sieve and the pan were different than 1 for cows fed LE-PMR and were different than 1 on the pan for cows fed the HE-PMR. No differences were detected for sorting of particles retained on the 19-mm or 1.18-mm sieves. The increased sorting behaviour for cows fed the LE-PMR likely explains why eating rate and meal size were less than cows fed HE-PMR. While we cannot confirm, we speculate that the change in PMR eating behaviour, PMR sorting, and consequently greater AMS concentrate may have resulted in reduced ruminal pH when cows were fed the LE-PMR, and thus avoidance of small particles may have been a strategy to increase effective fibre intake (DeVries et al. 2008). Future work is need to evaluate how feeding strategies for cows in AMS affects ruminal fermentation, as no published data are currently available.

Despite differences in total DMI, milk and milk component yield was not affected (Table 2). Likewise, milk composition was not affected and again power was limited in this study. Milking duration and inter-milking interval were not different between treatments. The lack of a milk yield response is likely due to the tendency for HE-PMR cows to gain more weight than LE-PMR (27.0 vs. 19.0 kg/26 d, SEM 3.62 kg; $P = 0.10$; data not shown). These data suggest that increasing the amount of concentrate offered in the AMS, without corresponding changes in the total dietary energy supply does not affect milk yield or composition. Others have also attempted to maintain total dietary energy supply and found that increasing concentrate

provision in the AMS did not enhance milking frequency or milk yield (Bach et al., 2007). Interestingly, increasing concentrate provision in the AMS without changes in PMR energy density has also been shown not to improve milking frequency or milk yield (Migliorati et al. 2005; Halamachi et al. 2005). The findings of the current study and previous studies challenge the notion that increasing the provision of concentrate in the AMS will improve voluntary visits and milk and milk component yield in guided traffic systems.

CONCLUSIONS

Results of this study indicate that in a feed-first, guided traffic flow barn, providing a PMR with greater energy density, while limiting the quantity of concentrate in the AMS, may improve DMI, increase the PMR eating rate and meal size, and may reduce sorting of the PMR when compared to feeding a low-energy PMR coupled with high AMS concentrate allocation. Moreover, for every 1 kg increase in concentrate provision in the AMS, we observed a 1.57 kg reduction in PMR intake. Thus, providing a greater proportion of the dietary nutrient supply in the PMR, rather than the AMS, may improve the ability of dairy producers to manage nutrient supply for cows milked in a guided traffic flow AMS.

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Table 1. Dietary composition and particle size distribution of the low-energy PMR (LE-PMR) coupled with high AMS concentrate allowance (5 kg/d) or a high-energy PMR (HE-PMR) coupled with a low AMS concentrate allowance (0.5 kg/d).

Variable	LE-PMR	HE-PMR
Ingredient composition, % DM		
PMR		
Barley silage	31.6	31.8
Alfalfa hay	15.8	15.9
Concentrate supplement ¹	31.3	47.3
Palmitic acid ²	1.6	1.6
Canola meal	1.4	1.4
AMS Concentrate ¹	18.4	1.9
Forage, % DM	47.4	47.7
Chemical composition of the complete diet, % DM		
DM	49.8	49.6
OM	91.1	91.3
CP	15.8	15.9
NDF	21.0	21.3
ADF	31.2	31.1
Lignin	4.2	4.1
Starch	23.0	22.1
Ethanol soluble carbohydrates	4.4	4.5
Ether extract	5.5	5.3
Calcium	0.9	0.9
Phosphorous	0.4	0.4
NE _L , Mcal/kg	1.66	1.66
PMR particle size distribution, %		
> 18mm	41.07	36.73
9 to 18mm	24.44	21.99
1.18 to 9mm	29.31	35.44
Pan	5.45	5.87

¹Concentrate supplement contained 45.8% barley grain, 17.6% corn grain, 7.4% pea grain, 7.4% canola meal, 8.2% soybean meal, 1.9% corn gluten meal, 3.22% corn dist medium spirits, 2.38% U of S premix, 1.39% palmitic acid, 1.45% molasses cane, 0.07% biotin, 0.42% R-choline, 0.16% potassium/magnesium/sulfate, 1.01% sodium bicarbonate, 1.08% limestone, 0.04% niacin, 0.02% santoquin, 0.44% salt; chemical composition: 6.658 kIU/kg of Vitamin A, 2.130 kIU/kg of Vitamin D₃, 53.27 IU/kg Vitamin E, 23.58 ppm of Cu, 111.93 ppm of Fe, and 96.46 ppm of Zn.

²Energizer RP10 (Scothorn Nutrition, Grand Pré, Nova Scotia, Canada)

Table 2. Effect of providing a low-energy PMR (LE-PMR) coupled with high AMS concentrate allowance (5 kg/d) or a high-energy PMR (HE-PMR) coupled with a low AMS concentrate allowance (0.5 kg/d) on BW, DMI, and eating behaviour of dairy cattle.

Parameter	Treatment			Parity			P-value		
	LE-PMR	HE-PMR	SEM	Primi	Multi	SEM	Treatment	Parity	Treatment × parity
DMI, kg/d	23.6	26.3	1.17	23.5	26.30	1.64	0.049	0.23	0.11
AMS concentrate, kg/d	5.0	0.5	0.11	2.7	2.8	0.13	< 0.001	0.69	0.86
PMR, kg/d	18.6	25.7	1.16	20.8	23.6	1.63	0.012	0.23	0.12
PMR eating behaviour									
Eating time, min/d	154	183	16.7	168	169	25.1	0.038	0.99	0.11
PMR feeding rate, kg/min	0.12	0.14	0.014	0.11	0.15	0.020	0.041	0.24	0.74
Meal frequency, meals/d	6.8	7.2	0.41	7.2	6.8	0.57	0.46	0.64	0.47
Intermeal interval, min	196	179	12.5	181.0	194.0	17.9	0.18	0.58	0.22
Meal duration, min/meal	30.4	31.4	1.48	28.9	32.8	2.13	0.46	0.20	0.57
Meal size, kg	2.3	3.3	0.23	2.5	3.1	0.30	0.015	0.20	0.94
Sorting Index ¹									
19-mm sieve	1.00	1.02	0.014	1.01	1.01	0.016	0.27	0.97	0.75
8-mm sieve	1.04 ^z	0.99	0.013	1.02	1.02	0.015	0.011	0.97	0.99
1.18-mm sieve	0.99	1.00	0.008	1.00	0.99	0.010	0.33	0.39	0.88
Pan	0.86 ^z	0.94 ^z	0.025	0.90 ^z	0.91 ^z	0.028	0.080	0.70	0.30
Milking frequency, no./d	2.9	3.0	0.21	3.2	2.8	0.29	0.62	0.26	0.85
Milking duration, min/milking	8.95	9.43	0.448	9.90	8.49	0.588	0.38	0.11	0.50
Inter-milking interval, min	493	497	28.4	455	534	40.5	0.89	0.18	0.65

Yield, kg/day									
Milk	36.4	35.6	2.89	31.9	40.1	4.36	0.64	0.19	0.61
Fat	1.43	1.48	0.092	1.29	1.61	0.130	0.55	0.11	0.63
Protein	1.22	1.22	0.093	1.06	1.39	0.135	0.98	0.10	0.68
Milk Composition, %									
Fat	3.98	4.18	0.149	4.14	4.02	0.202	0.24	0.67	0.86
Protein	3.37	3.43	0.080	3.35	3.45	0.116	0.38	0.50	0.66
Lactose	4.63	4.57	0.050	4.62	4.58	0.074	0.15	0.65	0.99
Milk Urea Nitrogen, mg/dL	12.3	13.2	0.42	12.2	13.3	0.47	0.17	0.10	0.91

Note: For sorting index, values denoted with a superscript z differ from 1.0.

¹Sorting indices were calculated as the proportion of actual particle intake in relation to the theoretical particle intake. Indices greater than 1.00 indicate selective consumption, while less than 1.00 indicate selective refusal. Sorting index equal to 1.00 indicate no selection.