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Effect of Dietary Choline and Diet Fermentability on Feeding Behavior and Performance of Postpartum Dairy Cows

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Summary

The objective of this study was to evaluate the effects of diet fermentability (DF) and rumen-protected choline (RPC) on postpartum feeding behavior and performance. Sixty-five multiparous Holstein cows were enrolled 21 days prepartum and supplemented with RPC (C+; 30 g/d) or without RPC (C-). Postpartum, cows (n = 55) were randomly assigned to a 2 × 2 factorial arrangement of starch fermentability (low [dry rolled corn; LFERM] vs. high [wheat; HFERM]) and corresponding prepartum RPC treatment ([C-] vs. [C+; 30 g/d]) and were fed for 21 days in a tie-stall. Feeding behaviors, dry matter intake (DMI), and milk yield were recorded daily, and milk components were collected at six consecutive milkings weekly. Prepartum, C+ decreased DMI compared with C- (32.6 vs. 37.7 kg), whereas no treatment differences were detected for postpartum DMI. Postpartum, there was no evidence of a treatment difference in total DMI. The HFERM increased milk yield after day 3 compared with LFERM, but reduced milk fat concentration and milk true protein yield and concentration; milk fat yield was unchanged. Supplementation with RPC decreased plasma beta-hydroxybutyrate (BHB) concentration and tended to increase plasma glucose concentration compared to C-. In conclusion, RPC at a low inclusion rate reduced DMI prepartum and decreased postpartum plasma BHB concentrations, suggesting the product improved metabolic status. Diet fermentability and RPC did not interact to affect feeding behavior, likely reflecting the relatively lesser-than-anticipated differences in starch digestibility between treatments.

Introduction

Dry matter intake of postpartum dairy cows is variable and depressed in the immediate postpartum period. Strategies to maximize DMI during this critical period are important to drive milk production and to alleviate metabolic diseases that plague cows postpartum. In particular, feeding rapidly fermentable diets (high-moisture corn, wheat) can depress feed intake through oxidation of fatty acid intermediates within the liver, which accumulate due to rapid body fat mobilization. Appropriate feed sources are needed to ensure cows can maximize feed intake; however, rapid fermentation narrows the array of starch sources that are practical for feeding postpartum cows compared with cows in other stages of lactation.

Another important nutritional strategy for peripartum cows is the supplementation of rumen-protected choline (RPC). The use of RPC helps the liver export fat, preventing the accumulation of lipids in the liver. This also reduces the intermediates of incomplete fatty acid oxidation (ketone bodies) and substrates that are oxidized within meals, which can reduce feed intake when highly fermentable starch sources are fed. Feeding RPC to postpartum dairy cows to export liver fat may also help cows overcome DMI depression when fed highly fermentable starch sources. Therefore, the objective of this study was to evaluate the interaction of diet fermentability and RPC supplementation in postpartum dairy cows. We hypothesized that more fermentable diets would depress postpartum DMI, but this depression would be mitigated in cows fed RPC.

Experimental Procedures

This study was conducted at the Kansas State University Dairy Cattle Research and Teaching Center. All experimental procedures were approved by the Kansas State University Institutional Animal Care and Use Committee. Multiparous Holstein cows (n = 65) were enrolled on a rolling basis and blocked by expected calving date (ECD), body condition score (BCS; cows within a block differed by ≤ 1-unit on a 5-point scale), and previous lactation 305-d mature equivalent milk yield (≤ 5,000 kg).

Prepartum

Cows were enrolled 21 days before ECD and fed a common prepartum diet with RPC (C+; 30 g/d; ReaShure, Balchem) or without RPC (C-). Treatments were mixed into a total mixed ration (TMR). Ingredient composition and actual chemical composition of the prepartum experimental diets are described in Table 1. Animals were housed in a bedded pack barn and fed individually using a Roughage Intake Control (RIC) computerized feeding system. Feed refusals were removed once daily and cows were fed twice daily to permit *ad libitum* intake.

Postpartum

After calving, cows (n = 55) were randomly assigned to one of four postpartum treatments in a randomized complete block design with a 2 × 2 factorial arrangement, including starch fermentability (low [dry rolled corn; LFERM] vs. high [dry rolled wheat; HFERM]) and corresponding prepartum RPC treatment (0 g/d [C-] vs. 30 g/d [C+]). Ingredient composition and actual chemical composition of the postpartum experimental diets are described in Table 2. Postpartum cows were housed in a tie-stall barn and individually fed their assigned treatment diet *ad libitum* for 21 days. Feed refusals were removed once daily, and cows were fed twice daily for 110% of expected intake. Cows were milked three times daily in a milking parlor. Milk yield was recorded daily and milk samples were collected at six consecutive milkings weekly for component analysis. Blood samples were collected via coccygeal venipuncture on days 3, 7, 14, and 21 and analyzed for glucose, insulin, free fatty acids, blood urea nitrogen, and BHB. Body weight and BCS were recorded at enrollment (-21 day relative to ECD), at calving, and 21 days in milk (DIM).

Statistical analysis

Data were analyzed using the MIXED procedure of SAS (version 9.4). Data were analyzed as a split-plot design, with cow as the whole plot and DIM as the subplot. The model included the fixed effects of DF, RPC, time, and their interactions, and the random effects of block and cow nested within block × treatment. Results are reported as least square means with 95% confidence intervals. Treatment effects and interactions were declared significant at $P \leq 0.05$ and tendencies at $0.5 < P \leq 0.10$.

Results and Discussion

Prepartum

Supplementation of C+ decreased prepartum DMI compared to C- (32.6 lbs/d [30.4, 35.1] vs. 37.7 [35.3, 40.1]; Table 3). Our study contrasts with the larger body of work that has evaluated RPC in prepartum dairy cow diets and reported either no difference or increased prepartum DMI. In previous studies, RPC was top-dressed on the feed, whereas our project incorporated the RPC into the TMR. It is unclear if this difference in delivery may have contributed to the depression in overall DMI; further investigation may be required if other studies support this result.

A tendency existed for an interaction between time and RPC for meal size ($P = 0.08$), with C+ decreasing meal size more rapidly over time compared to C-. Similarly, C+ decreased eating rate (0.20 lbs/min [0.19, 0.22] vs. 0.22 [0.21, 0.24]; $P = 0.02$; Table 3), while there was no evidence of difference in the number and duration of meals. This pattern suggests that the reduced intake was not driven by fewer or shorter feeding events, but by a reduction in the quantity of feed consumed per meal. These responses may reflect differences in RPC palatability when mixed in a TMR, or they could suggest that other mechanisms are relaying satiety signals within a meal for cows offered RPC. The exact mechanism remains unclear and merits further investigation.

Postpartum

Postpartum DMI increased with DIM ($P < 0.001$; Table 4), as expected during early lactation, but was not affected by DF, RPC, or their interaction ($P > 0.19$). The absence of treatment effect on postpartum DMI aligns with previous studies that supplemented RPC during the transition period, which typically reported no differences in postpartum DMI. Furthermore, there was no observed treatment effect of diet fermentability on postpartum DMI, which contrasts with expectations and previous reports showing rapidly fermentable starch sources depressed intake through enhanced ruminal starch degradation and propionate production. The absence of DMI reduction in HFERM may be partially explained by the lesser divergence in the dietary 7-hr starch fermentability achieved in the present study than anticipated (~5% vs. targeted 15%). The lesser starch digestibility rate may have been a byproduct of coarser particle size of the dry-rolled wheat used in the present study compared with the 1-mm ground wheat used in the *in vitro* assay that informed the diet formulation. Taking these factors into consideration, there may not have been sufficient fermentation differences between diets to induce a DMI response.

Milk yield and composition responses are summarized in Table 5. Time and DF interacted to influence milk yield ($P = 0.02$), where HFERM progressively increased milk yield more with time than LFERM. As mentioned previously, the 7-hr digestibility rates of the experimental diets in our study (~5%) were less divergent than anticipated. These data indicate that moderately increased dietary starch fermentability can enhance milk yield during early lactation under conditions where DMI is not depressed. For milk components, cows fed HFERM had reduced milk fat content (4.4 % [4.0, 4.8] vs. 4.8 [4.4, 5.2]; $P < 0.01$) compared to LFERM, but there was no treatment effect on milk fat yield ($P = 0.16$). This reduction in milk fat concentration reflects a dilution effect from the increased milk yield in HFERM rather than the induction of milk fat depression. Similar relationships between greater starch fermentability, increased milk yield, and reduced milk fat concentration have been reported in early-lactation cows. Furthermore, HFERM decreased the milk net energy (NE) compared to LFERM (1.7 Mcal/lb

[1.6, 1.8] vs. 1.8 [1.7, 1.9]; $P = 0.02$), while there was no evidence of treatment effect for energy-corrected milk (ECM) or fat-corrected milk (FCM; $P = 0.20$).

Blood metabolite responses are presented in Table 6. Supplementation of C+ decreased plasma BHB concentration compared to C- (1.02 mmol/L [0.87, 1.19] vs. 1.31 [1.12, 1.52]; $P = 0.02$). Mean BHB concentrations for C+ cows remained below the subclinical ketosis threshold of 1.2 mmol/L, whereas C- cows exceeded this value, indicating a meaningful reduction in ketosis risk. In a corresponding manner, C+ tended to increase plasma glucose concentration compared to C- (49.0 mg/dL [46.4, 51.5] vs. 46.0 [43.5, 48.5]; $P = 0.07$), while there was no evidence of treatment differences in plasma insulin or serum free fatty acid (FFA) concentrations ($P > 0.44$). Few studies have evaluated choline doses at or below the dose supplemented within the present study. The reduction in BHB observed herein at 30 g/d of RPC supports that even minimal supplementation can enhance hepatic lipid metabolism in high-producing postpartum cows.

Conclusions

Supplementing RPC reduced the DMI prepartum, which requires further investigation to elucidate mechanisms underlying similar responses in TMR-fed cows. Diet fermentability and RPC supplementation did not interact for postpartum DMI or feeding behavior, which may reflect lesser differences in starch digestibility between treatments. Feeding a more fermentable diet increased milk yield over time. Supplementation of RPC decreased the plasma BHB concentration postpartum below subclinical ketosis thresholds. Overall, these findings suggest that moderate increases in starch fermentability can enhance milk yield without compromising intake, and that RPC supports metabolic adaptation when fed at moderate levels in high-producing cows. Future studies should evaluate greater contrasts in starch fermentability and increased choline supply to determine potential interactive effects on feed intake, feeding behavior, and performance.

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Table 1. Ingredients and nutrient composition of prepartum experimental diets for multiparous Holstein cows fed a control (C-) or diet containing rumen-protected choline (C+; RPC)

	Treatment[1]			
	C-		C+	
Item	**Week 1-12**	**Week 13-34**	**Week 1-12**	**Week 13-34**
Ingredient, % of DM				
Corn silage	17.64	13.66	17.64	13.66
Wet corn gluten feed	15.51	13.84	15.51	13.84
Grass hay	46.11	46.10	46.11	46.10
Grain mix				
Common grain mix ingredients[2]	20.52	26.20	20.52	26.20
RPC	-	-	0.22	0.20
Soyhulls	0.22	0.20	-	-
Nutrient, % of DM				
DM	55.48	57.45	55.53	57.58
CP	13.83	13.72	14.35	14.25
aNDFom	43.96	42.89	43.69	42.91
Starch	10.63	12.89	10.43	12.24
EE	3.19	3.04	3.26	3.16

[1] C = 0 g/d of RPC; C = 30 g/d of RPC (ReaShure, Balchem Corp., Montvale, NJ)
[2] Common grain mix (average % of DM): 7.92% soybean meal, 7.11% dry ground corn, 7.42% SoyChlor (Landus Cooperative, Jefferson, IA), 0.12% NutriTek (Diamond V, Cedar Rapids, IA), 0.17% salt, 0.13% NiaShure (ReaShure, Balchem Corp., Montvale, NJ), 0.04% Zinpro 4 Plex C (Zinpro, Eden Prairie, Minnesota), 0.02% Zinpro Avail Zn 120 (zinc amino acid complex; Zinpro, Eden Prairie, Minnesota), 0.07% magnesium oxide, 0.02% selenium, 0.01% Rumensin (Elanco Animal Health, Greenfield, IN), 0.01% Biotin, 0.28% Vitamin E 20,000 IU/lb, 0.03% Vitamin A 30,000 IU/gram, 0.01% Vitamin D 30,000 IU/gram

Table 2. Ingredients and nutrient composition of postpartum experimental diets fed to multiparous Holstein cows, formulated with low (LFERM; dry rolled corn) or high (HFERM; dry rolled wheat) starch fermentability, with (C+) or without (C-) rumen-protected choline (RPC)

	Treatment[1]							
	LFERM C-		LFERM C+		HFERM C-		HFERM C+	
Item	Week 1-12	Week 13-34	Week 1-12	Week 13-34	Week 1-12	Week 13-34	Week 1-12	Week 13-34
Ingredient, % of DM								
Corn silage	25.32	22.52	25.24	22.41	25.41	22.54	25.27	22.42
Alfalfa hay	19.65	20.25	19.52	20.15	19.66	20.26	19.55	20.16
Grass hay	7.29	7.19	7.27	7.15	7.32	7.19	7.28	7.15
Wet corn gluten feed	3.45	3.51	3.44	3.50	3.46	3.52	3.44	3.50
Cottonseed	3.95	3.88	3.94	3.86	3.96	3.88	3.94	3.86
Base mix[2]	24.92	27.63	24.85	27.50	25.02	27.65	24.88	27.51
Top dress								
Dry rolled corn	15.28	14.88	15.62	15.30	3.90	3.84	4.02	3.96
Dry rolled wheat	-	-	-	-	11.13	10.97	11.49	11.31
RPC[3]	-	-	0.14	0.13	-	-	0.13	0.13
Soyhulls	0.15	0.14	-	-	0.14	0.14	-	-
Nutrient, % of DM[4]								
DM	60.47	64.95	60.80	65.49	60.10	64.83	60.66	65.42
CP	17.18	16.16	17.11	16.08	17.71	16.67	17.64	16.62
aNDFom	27.88	28.39	27.67	27.85	28.34	28.51	27.99	28.25
Starch	25.05	25.09	23.83	25.52	23.42	25.01	23.33	24.85
IVSD7	50.18	44.53	48.21	44.81	56.43	51.94	55.21	52.45
EE	4.72	4.59	4.72	4.59	4.52	4.31	4.53	4.39

[1] LFERM C- = low fermentability, no RPC; LFERM C+ = high fermentability, RPC; HFERM C- = low fermentability, no RPC; HFERM C+ = high fermentability, RPC

[2] Base mix (average % of DM): 9.53% dry ground corn, 9.45% Soy Plus (Landus Cooperative, Ralston, IA), 3.38% soybean meal, 0.62% Megalac (Arm and Hammer Nutrition, Princeton, NJ), 0.41% blood meal, 0.06% Smartamine (Adisseo Inc., Antony, France), 1.12% micromineral and vitamin premix (MKC Cooperative, Moundridge, KS), 0.99% sodium bicarbonate, 0.68% calcium carbonate

[3] ReaShure (Balchem Corp., Montvale, NJ)

[4] aNDFom = amylase NDF OM; IVSD7 = in-vitro starch digestibility 7 hr; EE = ether extract

Table 3. Dry matter intake and feeding behavior of multiparous Holstein cows during the last 3 weeks prepartum fed a control (C-) or diet containing rumen-protected choline (C+; RPC)

	Treatment[1]		*P*-value		
Item	C[2]	C[3]	Trt	Time	Trt × Time
DMI, lbs/d	37.70 [35.27, 40.12]	32.63 [30.42, 35.05]	<0.01	<0.001	0.22
Meals, n/d	10.5 [9.97, 11.04]	10.5 [9.92, 10.98]	0.86	0.51	0.35
Meal interval, min	117.0 [110.6, 122.8]	118.0 [111.8, 123.9]	0.77	0.42	0.95
Meal size, lbs	3.75 [3.33, 4.01]	3.09 [2.84, 3.46]	0.01	<0.001	0.08
Eating rate, lbs/min	0.22 [0.21, 0.24]	0.20 [0.19, 0.22]	0.02	0.05	0.59

[1] Treatment means are presented as least square means with 95% confidence intervals
[2] C = 0 g/d of RPC (ReaShure, Balchem Corp., Montvale, NJ)
[3] C = 30 g/d of RPC (ReaShure, Balchem Corp., Montvale, NJ)

Table 4. Dry matter intake and feeding behavior of multiparous Holstein cows during the first 3 weeks postpartum fed a low (LFERM; dry rolled corn) or high (HFERM; dry rolled wheat) fermentable diet, with (C+) or without (C-) rumen-protected choline (RPC)

	Treatment[1, 2]				*P*-value						
Item	LFERM C-	LFERM C+	HFERM C-	HFERM C+	Ferm	Chol	DIM	F×C	F×D	C×D	F×C×D
DMI, lbs/d	42.1 [38.6, 45.4]	41.7 [38.1, 45.2]	45.0 [41.4, 48.5]	42.1 [38.4, 45.6]	0.28	0.29	<0.001	0.40	0.30	0.19	0.87
Feed efficiency[3]	2.5 [2.3, 2.6]	2.5 [2.4, 2.7]	2.4 [2.3, 3.6]	2.4 [2.3, 3.6]	0.35	0.75	<0.001	0.97	0.96	0.73	0.70
Meals, n/d	13.9 [12.9, 14.8]	14.3 [13.3, 15.2]	13.9 [12.9, 14.8]	13.9 [12.9, 14.9]	0.73	0.61	<0.001	0.71	0.95	0.92	0.92
Meal size, lbs	5.3 [4.6, 6.0]	5.1 [4.4, 5.7]	5.7 [5.1, 6.4]	5.3 [4.6, 6.0]	0.17	0.35	<0.001	0.69	0.41	0.04	0.68
Meal interval, hr	1.4 [1.3, 1.5]	1.4 [1.3, 1.5]	1.5 [1.4, 1.6]	1.4 [1.3, 1.5]	0.67	0.61	<0.001	0.92	0.92	0.98	0.95

[1] LFERM C- = low fermentability, no RPC; LFERM C+ = high fermentability, RPC; HFERM C- = low fermentability, no RPC; HFERM C+ = high fermentability, RPC
[2] Treatment means are presented as least square means with 95% confidence interval
[3] Feed efficiency = ECM/DMI

Table 5. Milk yield and components of multiparous Holstein cows during the first 3 weeks postpartum fed a low (LFERM; dry rolled corn) or high (HFERM; dry rolled wheat) fermentable diet, with (C+) or without (C-) rumen-protected choline (RPC)

	Treatment[1, 2]				*P*-value						
Item	LFERM C-	LFERM C+	HFERM C-	HFERM C+	Ferm	Chol	Wk	F×C	F×W	C×W	F×C×W
Milk, lbs/d	86.6 [79.4, 93.7]	85.8 [78.5, 93.0]	94.6 [87.5, 101.9]	88.4 [80.9, 95.7]	0.04	0.15	<0.001	0.26	0.02	0.61	0.44
Fat, %	4.8 [4.3, 5.2]	4.9 [4.4, 5.3]	4.3 [3.9, 4.7]	4.4 [4.0, 4.9]	0.01	0.50	<0.001	0.89	0.86	0.78	0.85
Fat, lbs	4.2 [3.5, 4.6]	4.2 [3.7, 4.6]	4.0 [3.5, 4.4]	3.7 [3.3, 4.4]	0.16	0.61	<0.001	0.42	0.77	0.41	0.71
True protein, %	3.2 [3.1, 3.4]	3.2 [3.1, 3.4]	3.2 [3.1, 3.4]	3.1 [3.0, 3.3]	0.36	0.48	<0.001	0.29	0.04	0.50	0.97
True protein, lbs	2.9 [2.6, 3.1]	2.9 [2.6, 3.1]	3.1 [2.9, 3.3]	2.9 [2.6, 3.1]	0.17	0.09	0.04	0.27	0.05	0.33	0.81
Milk NE, Mcal/lb	1.8 [1.7, 1.9]	1.8 [1.7, 1.9]	1.7 [1.6, 1.8]	1.7 [1.6, 1.8]	0.02	0.69	<0.001	0.94	0.98	0.56	0.91
ECM, lbs/d	103.4 [94.1, 112.9]	103.2 [93.7, 114.6]	106.9 [97.4, 116.2]	100.3 [90.8, 109.8]	0.92	0.20	<0.001	0.26	0.35	0.23	0.73
FCM, lbs/d	103.8 [94.1, 113.8]	103.8 [94.1, 113.5]	105.8 [95.9, 115.5]	100.1 [90.2, 110.0]	0.73	0.31	<0.001	0.30	0.54	0.33	0.64

[1] LFERM C- = low fermentability, no RPC; LFERM C+ = high fermentability, RPC; HFERM C- = low fermentability, no RPC; HFERM C+ = high fermentability, RPC
[2] Treatment means are presented as least square means with 95% confidence intervals

Table 6. Concentrations of blood β-hydroxybutyrate (BHB), glucose, free fatty acid (FFA), and insulin of multiparous Holstein cows during the first 3 weeks postpartum fed a low (LFERM; dry rolled corn) or high (HFERM; dry rolled wheat) fermentable diet, with (C+) or without (C-) rumen-protected choline (RPC)

	Treatment[1, 2]				*P*-value						
Item	LFERM C-	LFERM C+	HFERM C-	HFERM C+	Ferm	Chol	DIM	F×C	F×D	C×D	F×C×D
BHB, mmol/L	1.44 [1.16, 1.79]	1.08 [0.87, 1.34]	1.19 [0.96, 1.47]	0.96 [0.77, 1.20]	0.16	0.02	0.14	0.73	0.75	0.23	0.23
Glucose, mg/dL	43.76 [40.39, 47.12]	48.79 [45.57, 52.11]	48.22 [44.89, 51.55]	49.17 [45.71, 52.62]	0.14	0.07	<0.001	0.21	0.27	0.45	0.57
FFA, mmol/L	0.30 [0.25, 0.36]	0.32 [0.27, 0.39]	0.29 [0.24, 0.36]	0.30 [0.24, 0.36]	0.54	0.64	<0.001	0.72	0.61	0.58	0.76
Insulin, µg/L	0.09 [0.07, 0.11]	0.09 [0.07, 0.11]	0.08 [0.06, 0.10]	0.08 [0.07, 0.11]	0.48	0.78	<0.001	0.52	0.44	0.48	0.51

[1] LFERM C- = low fermentability, no RPC; LFERM C+ = high fermentability, RPC; HFERM C- = low fermentability, no RPC; HFERM C+ = high fermentability, RPC
[2] Treatment means are presented as least square means with 95% confidence interval