The effect of carbohydrate type on milk and milk component yields in early lactation dairy cows

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ABSTRACT

Providing additional energy to dairy cows in early lactation can increase energy intake, and improve production; however, different energy types may elicit different types of responses. The current study assessed the effect of supplementary feeding of starch, fibre, or sugar on milk and milk component yield. Sixty-eight dairy cows, due to calve over a 21-day period, were randomly assigned to one of four treatments at parturition (n = 17). Treatments consisted of a pasture-only control and pasture with starch, fibre or sugar based supplements. Supplements were formulated using the Cornell Net Carbohydrate and Protein System v6.1 and fed at an isoenergetic rate to supply sufficient metabolisable energy and protein to support a target of 30 kg of potential milk production, assuming cows would consume 13 kg of pasture DM/day; 11 MJ ME/kg DM. The study ran for eight weeks, and data were analysed on a week of lactation basis. Relative to the control, milk and milk protein yields were higher for the starch- and fibre-based supplements, but similar for the sugar ($P < 0.01$). Protein yields were highest in cows supplemented with starch ($P < 0.001$), while fat yields were numerically highest in cows supplemented with fibre. These data confirm that the form of carbohydrate fed affects the types of responses seen when supplementing concentrates in early lactation.

Keywords: pasture; carbohydrate; milk components; milk yield.

INTRODUCTION

An important limitation to dairy cows, in pasture-based systems, is the ability to consume enough energy to meet their genetic potential for milk production (Kolver, 2003). This can be exacerbated in early lactation by the time it takes for the animal to adapt her dry matter intake (DMI) to match the physiological shift from late gestation to lactation (Bauman & Currie, 1980). Kolver and Muller (1998) reported that 61% of the difference in milk production between high yielding cows offered fresh pasture or a total mixed ration (TMR) was attributable to differences in DMI. Supplying additional energy in a concentrated form, during this period, results in higher DMI and, depending on the energy type, can potentially modify the milk fat and protein ratio (Bargo *et al.*, 2002; Kennedy *et al.*, 2003; Robaina *et al.*, 1998; Roche *et al.*, 2006). Different forms of energy, such as starch, fibre, or sugar, can elicit different effects on milk composition through changes in ruminal volatile fatty acid (VFA) profiles (Bauman *et al.*, 1971; Beckman & Weiss, 2005) and subsequent regulatory effects associated with the metabolism of different substrates (Griinari *et al.*, 1997; Van Soest, 1994). Specifically, altering the propionate:acetate ratio by increasing starch or sugar levels in the diet can decrease milk fat yields and increase milk protein yields (Broderick, 2003). The current study investigated the effect of supplementing different carbohydrate types including starch, fibre, or sugar, on milk yield and composition. The hypothesis that glucogenic substrates such as starch and sugar, will increase milk protein, and fibre will increase milk fat was tested.

MATERIALS AND METHODS

Experimental work was conducted at the DairyNZ Lye Farm, Hamilton, New Zealand (37 47' S, 175 19' E) during July and August 2010. Prior approval for animal use was obtained from the Ruakura Animal Ethics Committee, Hamilton, New Zealand.

Experimental design, treatments and animals

Sixty-eight dairy cows (Friesian (n = 42), Friesian×Jersey (n = 26); Multiparous (n = 55), Primiparous (n = 13)) aged 4.5 ± 0.2 years (standard deviation) with a mean live weight of 549 ± 29 kg and a mean body condition score (BCS) BCS (1-10 scale where 1 = Emaciated and 10 = Obese; Roche *et al.*, 2004) of 4.5 ± 0.3 that were due to calve over a 21-day period, were randomly assigned to one of four treatments at parturition with 17 cows per treatment. Treatments consisted of a pasture only control (P) and pasture with starch (St)-, fibre (Fb)- or sugar (Sg)-based supplements. Maize grain was used as the starch source, broll (wheat middlings) the fibre source and molasses the sugar source. Supplements were formulated using the Cornell Net Carbohydrate and Protein System (CNCPS) v6.1 (Tylutki *et al.*, 2008; Van Amburgh *et al.*, 2010) and fed at an isoenergetic rate to supply sufficient metabolisable energy (ME) and metabolisable protein (MP) to support a target of 30 kg of milk production, assuming the cows would consume 13 kg of pasture dry matter (DM)/day; 11 MJME/kg DM). Supplements were offered in pellet form (St 4.1 kg DM/day; Fb 5.5 kg DM/day) except the Sg treatment which was liquid and fed at 1.2 kg/day to prevent adverse health effects. The assumptions used when formulating the diets containing supplements were that cows in early lactation at approximately 40 days in milk (DIM), of similar live weight, offered between 30 and 40 kg DM/ day of ryegrass-based pasture (measured to ground level) would consume approximately 15kg DM/d (Dalley *et al.*, 1999) and would substitute approximately 0.3 kg of pasture DM/kg of concentrate DM fed (Bargo *et al.*, 2003). Supplements were introduced gradually over a 3-day period and offered in two equal portions at the evening and morning milking. The Sg treatment was provided orally in a diluted bolus (3:1 molasses:water) after each milking. Dietary treatments, composition and intakes are presented in Table 1. Treatment began immediately after parturition and continued for eight weeks. Data presented in this manuscript are mean values from the last three weeks of the study from 8 August to 28 August 2010.

TABLE 1: Estimated dry matter intake and chemical composition of treatment diets, pasture (P), or pasture with a starch (St)-, fibre (Fb)- or sugar (Sg)-based supplement.

Measurement	Treatment diet			
	P	St	Fb	Sg
Dry matter intake (kg/d)	14.9	17.6	18.1	16.1
Diet composition (kg DM/d)				
Pasture[1]	14.9	13.7	13.5	14.9
Maize grain		3.5		
Broll		0.4	4.4	
Molasses				1.2
Fat			0.2	
Urea			0.1	
Chemical composition (% DM)[2]				
Crude protein	28.1	24.1	25.5	26.5
Neutral detergent fibre	39.5	34.0	38.7	36.6
Acid detergent fibre	22.0	18.5	19.7	20.4
Starch	0.3	13.2	5.9	0.3
Sugar	12.8	10.7	10.8	17.0
Fat	4.9	4.7	5.6	4.7
Ash	10.1	8.4	8.6	10.2
Metabolisable energy (MJ /day)[2]	164.5	201.3	197.9	179.9
Metabolisable protein (g /day)[2]	2,119	2,369	2,516	2,214

[1]Estimated by difference and based on the assumptions: cows in early lactation (~40 days in milk), of similar live weight, offered between 30 and 40 kg DM/day of ryegrass-based pasture (measured to ground level) would consume approximately 15kg DM/day (Dalley *et al.*, 1999) and would substitute approximately 0.3 kg of pasture DM/kg of concentrate DM fed (Bargo *et al.*, 2003).

[2]Calculated using the Cornell Net Carbohydrate and Protein System v6.1.

Grazing management

Cows were rotationally grazed as one group on 37 hectares permanently subdivided into one hectare paddocks. Each paddock was further subdivided into morning and evening grazing areas using a temporary electric fence. This established grazing conditions that encouraged pasture to be harvested to a post-grazing residual mass of 1,500-1,600 kg DM/ha. Pasture allowance was 29 ± 5 kg DM/cow/dayfor the last three weeks of the study. Pre- and post-grazing compressed sward heights for that period were 22.9 ± 2.3 and 10.6 ± 1.2 cm, respectively, and pre- and post-grazing pasture mass was 3,243 ± 261 and 1,681 ± 233 kg DM/ha, respectively. Measurements were made using a Rising Plate Meter with an electronic counter (Farmworks, Palmerston North, New Zealand).

Pasture measurements

Representative samples of pasture from paddocks due to be grazed were collected daily by plucking pasture to grazing height. The pasture offered consisted of 90.2 ± 2.8% perennial ryegrass (*Lolium perenne*) leaf, 2.5 ± 1.4% perennial ryegrass stem, 1.5 ± 2.2% white clover (*Trifolium repens*), 0.6 ± 0.7% weeds, and 5.2 ± 1.8% dead material on a DM basis. Samples were bulked on a weekly basis for the duration of the experiment, and duplicate samples were dried for 48 hours at either 100°C, for dry matter analysis, or 60°C for analysis of nutrient composition. Samples dried at 60°C were subsequently ground to pass through a 2.0 mm sieve (Christy Lab Mill, Suffolk, UK) and analysed by wet chemistry (DairyOne, Ithaca, New York, USA).

Animal measurements

Mean pasture DMI across all treatment groups was calculated as the product of the difference between the pre- and post-grazing pasture mass and area grazed daily and divided by the total number of cows to estimate average DMI per cow per day (Roche et al., 1996).

Supplement offered and refused was measured at each milking. Individual group pasture intakes were estimated by adjusting the mean pasture intake across all groups by substitution rates described by Bargo et al. (2003). Briefly, cows <50 DIM, producing <30 kg milk, and supplemented with 2-5 kg concentrate DM/day substituted between 0.14 and 0.46 kg pasture DM/kg concentrate supplement. The mean of these data was used (0.3 kg pasture DM/ kg concentrate DM) and total pasture consumption was re-distributed across the four treatments based on measured concentrate consumption (Table 1). Individual milk yields were recorded daily (GEA, Oelde, Germany). Fat, true protein (TP), casein and lactose concentrations in milk were determined by a Milkoscan FT120 (Foss Electric, Hillerød, Denmark) on individual evening and morning aliquot samples collected on two days each week for the duration of the experiment.

Statistical analysis

Data are expressed as means of the last three weeks of the study and were analysed using a restricted maximum likelihood model (REML) in GenStat 13.2 (VSN International, 2010). The model included the fixed effects of calving group (three groups to account for stage of lactation), age (primiparous and multiparous), week, treatment and the interaction of calving group and week. Cow was included as a random effect. Differences were considered significant at P <0.05.

RESULTS AND DISCUSSION

Significant treatment effects were found for the yields of milk, crude and true protein, casein and lactose (P <0.01) but no differences in fat yield (Table 2). Although fat yields were not statistically different, the Fb treatment production was numerically higher. Differences in milk yield between the St and Fb treatments and the control can be attributed to greater energy intake which is predicted by the CNCPS to be the first limiting nutrient for milk production (Table 1). However, milk yield was similar between the P control and Sg treatment despite the provision of an additional 15 MJ/ME/day. Cows fed Sg also had the lowest true protein concentration (3.11%) which is contrary to the hypothesis and what may have been expected based on previous work that increased dietary sugar content (Miller *et al.*, 2001; Moorby *et al.*, 2006). In the current study, the dosage of 1.2 kg molasses per day may have caused rumen pH to drop to the point where fibre fermentation was disrupted (Huhtanen & Khalili, 1991). In addition, molasses, which is largely sucrose, would have followed the liquid passage rate, predicted by the CNCPS in this situation to be 11 % per hour. Sugar fermentation in mixed rumen bacteria varies between 40 and 60 % per hour (Van Amburgh *et al.*, 2010) meaning 15% to 22% would have escaped fermentation if calculated mechanistically from digestion (K_d) and passage (K_p) rates (Fox *et al.*, 2004) using the relationship, $K_d/(K_d + K_p)$. Ruminants do not secrete invertase (sucrase) in the lower tract, hence the sucrose that escaped the rumen could not have been absorbed in the small intestine leaving fermentation in the caecum or large intestine as the only possible fate (Van Soest, 1994). These factors may be responsible for disparity between energy intake, and milk yields between the Sg treatment and Control. The difficulty in accurately measuring pasture intake and substitution rates also needs to be considered when interpreting these results. The assumptions used provide a basis for comparing treatments in the current study. However, care should be taken if extrapolating the responses reported here to different

TABLE 2: Milk and milk component yields, and milk composition from cows fed treatment diets of either pasture or pasture with a starch (St)-, fibre (Fb)- or sugar (Sg)-based supplement. Bolding of P value indicates significance (P <0.05).

Measurement	Treatment diet				Standard error of difference	P value
	P	St	Fb	Sg		
Milk and components (kg/d)						
Milk yield	23.14	27.70	26.21	23.56	1.34	**0.002**
Fat yield	1.03	1.07	1.16	1.06	0.06	0.220
Crude protein yield	0.80	1.01	0.94	0.79	0.04	**<0.001**
True protein yield	0.74	0.95	0.87	0.73	0.04	**<0.001**
Casein yield	0.63	0.80	0.74	0.62	0.03	**<0.001**
Lactose yield	1.13	1.38	1.28	1.14	0.06	**<0.001**
Milk composition (%)						
Fat	4.44	3.88	4.41	4.57	0.21	**0.008**
Crude protein	3.45	3.65	3.59	3.36	0.08	**0.001**
True protein	3.20	3.43	3.34	3.11	0.08	**<0.001**
Casein	2.72	2.89	2.84	2.64	0.07	**0.002**
Lactose	4.89	4.99	4.92	4.85	0.04	**0.004**

circumstances (Bargo *et al.*, 2003).

The increase in milk protein evident in cows fed St is consistent with the hypothesis and previous work that increased dietary starch content (Broderick, 2003; Kennedy *et al.*, 2003; Rius *et al.*, 2010; Roche *et al.*, 2006). On pasture, such responses are often considered to result from greater microbial protein yields providing additional amino acids to the small intestine (Miller *et al.*, 2001; Moorby *et al.*, 2006). However, the CNCPS predicts all treatments in the current study to contain 30% more MP than required, making this explanation unlikely (Table 1). When considering the ratio of milk true protein:MP supply (Tables 2 and 1, respectively), the St treatment gives 0.40 compared to 0.35, 0.33 and 0.35 for the Fb and Sg treatments and P Control, respectively suggesting an increase in the efficiency of MP use. Starch supplementation in high forage diets stimulates propionate production, which is used primarily for glucose synthesis in the liver (Bauman *et al.*, 1971). Both glucose and propionate promote insulin secretion, and insulin has been implicated as an important regulator of milk protein synthesis (Griinari *et al.*, 1997; Rius *et al.*, 2010). Therefore, it is likely changes in milk protein production are due to differences in endocrine control rather than substrate supply. Comparatively, fat yield did not follow the increase in lactose secretion, but was maintained and not depressed. Cows fed Fb had similar milk fat concentrations to the P Control at the higher milk yield which is probably due to higher concentrations of both fat and fat precursors in the diet (Table 1). Limitations imposed by the diet have been previously reported to alter the priorities of nutrient use in lactating cows which mitigate stress and enable physiological stability (Bauman & Currie, 1980; Kolver & Muller, 1998). Cows fed St were not supplied with additional fat precursors and, therefore, homeorhetic control mechanisms (ST-IGF axis) probably prevented the mobilisation of additional body fat to support higher fat yields as milk volume increased (Bauman & Currie, 1980). Therefore, fat concentration was diluted by higher concentrations of protein and lactose. Further work to understand the mechanisms involved would assist decision making when considering supplements in early lactation.

CONCLUSION

Early lactation cows offered energetically similar supplements differing in carbohydrate type responded differently in milk and milk component yields. Compared with an unsupplemented pasture diet, starch-based supplements increased milk and milk protein yield, but did not affect fat yield, whereas fibre based supplements primarily increased milk and milk fat yield. Bolus doses of sugar (molasses) did not affect milk or milk component yields in this study.

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