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Effects of Prepartum Dietary Carbohydrate Source on Metabolism and Performance of Primiparous Holstein Cows during the Periparturient Period

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ABSTRACT : Forty-six Holstein heifers were used in a completely randomized design and assigned to 1 of 2 treatments to evaluate the effects of 2 diets varying in ruminal fermentable carbohydrate sources, namely ground corn (GC) and rolled wheat (RW), on metabolism and performance of primiparous cows in the periparturient period. The heifers were fed diets as a total mixed ration (TMR) with similar energy and crude protein content including i) 18.57% GC, or ii) 18.57% RW from -24.13±7.73 d relative to expected calving until calving. After calving, all animals received the same lactation diet until 28 d. Animals were group fed from the beginning of the study to -7 d relative to expected calving, fed individually from d -7 to 7 days in milk (DIM), and again group fed to 28 DIM. The *pre-partum* diets affected ($p<0.05$) dry matter intake (DMI), energy intake, energy balance (EB) and urinary pH during the last week *pre-partum*. There was no effect of *pre-partum* carbohydrate source on overall plasma concentration of glucose, nonesterified fatty acid (NEFA), β-hydroxybutyrate (BHBA), albumin, triglyceride (TG), cholesterol, aspartate aminotransferase (AST), insulin, and cortisol during the periparturient period. Cows fed the RW diet during the *pre-partum* period had greater calcium for the first week ($p<0.05$) and during 28 d ($p = 0.08$) of lactation compared with heifers fed the GC diet. Primiparous cows fed the RW diet produced greater milk protein content and yield ($p<0.05$). Primiparous cows fed the RW diet had lower milk urea nitrogen (MUN) and somatic cell count (SCC) than cows fed the GC diet ($p<0.05$). The results of this study show that feeding *pre-partum* diets with a rapidly fermentable source of starch but low energy content can improve animal metabolism and performance and smooth the transition of primiparous Holstein cows from gestation to lactation. (**Key Words :** Periparturient Period, Rapidly Fermentable Carbohydrates, Primiparous Cows)

INTRODUCTION

The periparturient period of dairy cows typically is defined as 3 wk before to 3 wk after parturition (Grummer, 1995). It is characterized by changes in the endocrine, metabolic, and immunological status from pregnancy to lactation. Requirements for glucose and metabolizable energy increase two- to threefold during the periparturient period (Drackley et al., 2001). In addition, the requirement for calcium increases approximately fourfold on the day of parturition (Horst et al., 1997). During this period, particularly the last week of gestation, dry matter intake (DMI) dramatically declines (20-40%) and slowly increases after parturition (Hayirli and Grummer, 2004). Metabolic disorders and health problems are common during this time and can easily erase the entire profit potential for an individual cow in lactation.

Post-partum diets contain high levels of fermentable carbohydrate and low level of fiber to maximize energy intake. These diets increase the risk of ruminal acidosis. This problem may be exacerbated in primiparous cows because they have not previously had long-term exposure to a highly fermentable lactation diet.

Most investigators have focused on increasing the energy content of the *pre-partum* diet by varying the non-fiber carbohydrate (NFC) content (Dan et al., 1999; Rabelo et al., 2003; Smith et al., 2005, 2008) and reported no advantage of high energy level with different NFC sources on *post-partum* metabolism and performance. However, some studies (Minor et al., 1998; Rabelo et al., 2003) reported improved outcomes when higher NFC diets were fed relative to a paired lower NFC control diet. Wheat grain

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Table 1. Ingredient composition (% of DM) of diets

Ingredient	*Pre-partum* diets		Lactation diet
	Corn	Wheat	
Alfalfa hay	64.60	64.60	40.00
Ground corn	18.57		14.00
Rolled wheat		18.57	
Rolled barley			14.00
Soybean meal, 46% CP	11.29	9.32	17.55
Cottonseed	1.45	3.46	5.64
Beet pulp	2.62	2.62	2.10
Fish meal	0.52	0.52	1.10
Meat meal			2.10
Ca- salt of fatty acid			1.80
Calcium carbonate	0.35	0.35	0.60
Sodium bicarbonate			1.10
Magnesium oxide			0.16
Sodium chloride			0.22
Vitamin and mineral[1]	0.60	0.60	0.32

[1] Contained: vitamin A, 800,000 IU; vitamin D, 230,000 IU; vitamin E,12,000 IU; Ca, 196 g; P, 96 g; Mg, 71 g ;Fe, 3 g; Cu, 0.3 g; Mn, 2 g; Zn, 3 g; Co, 0.1 g; I, 0.1 g; and Se, 0.1 g per kg of DM.

Table 2. Nutrient composition (DM basis) of diets

Item	*Pre-partum* diet		Lactation diet
	Corn	Wheat	
NEl (Mcal/kg)	1.50	1.50	1.68
CP (%)	16.50	16.50	19.60
RDP (%)	11.18	11.13	12.16
NDF (%)	34.39	35.00	30.30
NFC (%)	38.00	37.50	38.50
EE (%)	3.83	3.90	5.50
Ca (%)	0.90	0.90	1.00
P (%)	0.32	0.33	0.40
Mg (%)	0.22	0.23	0.38
K (%)	1.75	1.70	1.70
S (%)	0.27	0.27	0.27
Na (%)	0.34	0.40	0.46
Zn (mg/kg)	43.00	45.00	52.20
Cu (mg/kg)	12.20	12.30	12.10
Mn (mg/kg)	32.60	35.80	27.20
Vit. A (IU/kg)	5,000	5,000	5,000
Vit. D (IU/kg)	1,500	1,500	1,500
Vit. E (IU/kg)	75	75	38

contains 77% of dry matter as starch and a rate of digestion of 40%/h in the rumen compared to corn which contains 72% starch and has 15%/h rate of digestion (Huntington, 1997; Fox et al., 2003); cation-anion balance in wheat grain is also low (NRC, 2001). Wheat grain is seldom fed to dairy cows because of the concern that it contributes to the development of sub-acute rumen acidosis. However, the amount of starch commonly fed to the *pre-partum* cow is not high. Feeding anionic salts decreases dry matter intake and increases liver triglyceride in heifers (Moore et al., 2000). There is limited information in this area and further knowledge is needed to develop nutritional strategies that simultaneously offer a smooth rumen adaptation to high starch diets, stimulate DMI, maintain calcium homeostasis, and thereby reduce the risk of *post-partum* abnormalities. The objectives of this study was to determine the effects of feeding diets with different sources of carbohydrate on DMI, plasma metabolites, hormones, and lactation performance of primiparous cows during the periparturient period.

MATERIALS AND METHODS

Forty-six Holstein heifers were used in a completely randomized design and assigned to 1 of 2 treatments to evaluate the effects of 2 diets varying in ruminal fermentable carbohydrate sources (ground corn and rolled wheat) on metabolism and performance of primiparous cows in the periparturient period. The heifers were fed the dietary treatments from -24.13±7.73 d relative to expected calving until calving. After calving, all animals received the same lactation diet until 28 d. Ingredients and nutrient composition of the diets fed during *pre-partum* and *post-partum* periods are provided in Table 1 and 2. The experimental diets were formulated using the Cornell-Penn-Miner system (CPM Dairy, version 3.0.6) and prepared as a TMR with forage to concentrate ratio of 65:35 *pre-partum* and 40:60 *post-partum*. Heifers were group fed *ad libitum* (10% orts) from -24.13±7.73 to -7 d relative to expected calving. At that time, animals were moved to individual pens or tie stalls and fed *ad libitum* individually until 7 d *post-partum*. Again, after d 7 cows were group fed *ad libitum* until 28 days in milk (DIM). Diets were offered in equal proportions twice daily at 1100 and 1800 h *pre-partum* and three time daily at 0700, 1500, and 2300 h *post-partum*. Cows always had free access to fresh water. Cows were milked 3 times daily at 0700, 1500, and 2300 h in a milking parlor.

All feeds were analyzed for dry matter, crude protein, ether extract, and ash according to AOAC (2000) methods, NDF and ADF (Van Soest et al., 1991), neutral detergent insoluble CP (NDICP) and acid detergent insoluble CP (ADICP) by analyzing NDF and ADF residuals for Kejeldahl nitrogen (Licitra et al., 1996). Feed ingredients were not changed until the end of the experiment. The amount of TMR offered and refused was measured daily. Samples of diets and orts were obtained daily and a portion of each sample was oven dried at 105°C for 24 h to determine dry matter content. The remainder of each diet and orts sample was stored at -20°C, and then composited after four weeks and analyzed. Each animal was required to have at least 5 d of *pre-partum* intake data and at least 10 d

of *pre-partum* data to remain in the study. Body weight (BW) was measured at -28, +1, and +21 d relative to parturition. Body condition score (BCS) was assigned on a 1 to 5 scale (Wildman et al., 1982) for each cow weekly and within 12 h of calving by three skilled individuals independently throughout the study.

Energy balance (EB) was calculated for each cow according to NRC (2001). All equations used units of megacalories per kilogram. Net energy intake (NEI) was determined by multiplying the weekly DMI by the mean net energy for lactation (NEl) value of the diet. The equation used to calculate *pre-partum* EB was $EB_{Prepartum}$ = NEI-($NE_{Maintenance}$+$NE_{Pregnancy}$). The equation used to calculate *post-partum* EB was $EB_{Postpartum}$ = NEI-($NE_{Maintenance}$+$NE_{Lactation}$).

Milk yields were recorded at each milking until 28 DIM. Individual milk samples were collected weekly from 3 consecutive milkings, composited in proportion to milk yield, and preserved with potassium dichromate. The composited milk samples were analyzed for fat, protein, lactose, total solids, solids not fat, MUN, and SCC (Milko Scan 4000, FOSS Electric, Denmark).

Urinary pH was measured immediately after sampling at -1 week relative to expected calving.

Blood (10 ml) was sampled into heparinized evacuated tubes from the coccygeal vein or artery at 1000-1100 h weekly, and at -1, 0, and +1 d relative to calving. Samples were immediately placed on ice, and within 1 h were centrifuged at 3,000×g for 15 min. Plasma was harvested and aliquots were stored at -20°C until further analysis. Enzymatic assays were conducted to determine concentrations of nonesterified fatty acid (NEFA) and β-hydroxybutyrate (BHBA) using commercial kits (Randox, Cat. NO. RB1007 and FA115 respectively). Glucose, cholesterol, triglyceride (TG), aspartate aminotransferase (AST), urea, and calcium were measured using commercial kits (Pars Azmon, Tehran, Iran). Insulin and cortisol (-7 to +7 d around calving samples) were determined by radioimmunoassay kit (INSIK-5, P2796 and Gamma Coat cortisol, CA 1529E, Diasorin).

Data were separately analyzed using the PROC MIXED procedure of SAS (version 8.1; SAS Institute Inc., Cary, NC, 2000) as a completely randomized design for *pre-partum* and *post-partum* periods. The following base model was used for data measured over time as repeated measures.

$$Y_{ijk} = \mu+T_i+W_j+TW_{ij}+C_k(T_i)+\varepsilon_{ijk}$$

where Y_{ijk} is the dependent variable, μ is the overall mean, T_i is the effect of treatment i, W_j is the effect of time j, TW_{ij} is the interaction between time j and treatment i, $C_k(T_i)$ is the effect of cow k, nested in the treatment and ε_{ijk} is the residual error.

Data which did not have repeated measurements over time were analyzed as the following base model:

$$Y_i = \mu+T_i+C_k(T_i)+\varepsilon_{ik}$$

where Y_i is the dependent variable, μ is the overall mean, T_i is the effect of treatment i, $C_k(T_i)$ is the effect of cow k, nested in the treatment and ε_{ik} is the residual error.

Different variance - covariance error structures were tested as: compound symmetric, unstructured and autoregressive order 1. The error structure that resulted in the smallest Akaike's information criterion was selected. Measurements obtained before administration of treatments were used as covariates for statistical analyses of corresponding performance parameters (BW, BCS, and days on treatments) and metabolic responses (BW, BCS, and days on treatment and blood metabolites).The covariates were removed from the model one at a time, starting with the least significant. Statistical differences were considered significant when $p<0.05$ and trends are discussed when $p<0.1$. Least square means and standard error of the means and p-values are reported.

RESULTS AND DISCUSSION

Data of DMI, energy intake, EB, BCS, BW and urinary pH parameters are presented in Table 3. Dry matter intake, net energy intake and EB were lower ($p<0.05$) for heifers which consumed the RW than the GC diet at -7 to -1 day to calving (10.6 vs. 11.21 kg/d, 16.22 vs. 17.37 Mcal/d and 2.76 vs. 3.87 Mcal/d, respectively). During the first week of lactation, dry matter intake and changes of DMI, NEl intake, EB, and BCS were not significantly different. However, heifers fed the RW diet in the *pre-partum* period consumed about 0.5 kg more DMI than GC groups *post-partum* ($p = 0.10$). Body condition score at -28 to -1 day to calving was not significantly different between heifers fed the RW or GC diets. Furthermore, heifers fed the RW diet during this period tended to gain 0.09 units more body condition than heifers fed the GC diet ($p = 0.07$). The primiparous cows fed the RW diet had less BCS change until 28 DIM ($p = 0.05$).

After calving, primiparous cows fed the RW diet had higher DMI and then less BCS change. This implied that these cows released less fat from body tissue, although BCS as a visual measure of external fat accretion provides little information on internal fat stores (Nikkhah et al., 2008). Regulation of DMI during the periparturient period is complex and largely not understood (Ingvartsen and Andersen, 2000; Hayirli and Grummer, 2004). It has been proposed that increasing the starch content of a close-up diet promotes relatively greater ruminal production of propionate which reduces body fat mobilization. In addition, increasing starch content in the *pre-partum* diet adapts the

Table 3. Periparturient dry matter intake, energy balance, energy intake, BCS, BW, and urinary pH of primiparous cows

Item	Diet		SEM	p-value
	Corn	Wheat		
Pre-partum				
-7 to -1				
DMI (kg/d)	11.21	10.60	0.26	0.03
DMI (% of BW)	1.75	1.66	0.04	0.04
DMI change[1] (kg/d)	-2.92	-2.70	0.55	0.69
NEl intake (Mcal/d)	17.37	16.22	0.90	0.01
EB (Mcal/d)	3.87	2.76	0.90	0.03
BCS	3.24	3.10	0.04	0.08
Urinary pH	7.14	6.90	0.10	0.03
-28 to -1				
BCS	3.22	3.19	0.05	0.58
BCS change[2]	0.01	0.10	0.06	0.07
Initial BW (kg)	647.08	649.56	14.50	0.86
BW change[3] (kg)	-74.76	-70.15	4.70	0.005
Post-partum				
1-7 d				
DMI (kg/d)	13.08	13.56	0.27	0.10
DMI (% of BW)	2.30	2.38	0.05	0.10
DMI change[4] (kg/d)	6.10	6.15	0.40	0.90
NEl intake (Mcal/d)	21.98	22.78	0.45	0.19
EB (Mcal/d)	-5.76	-5.91	1.50	0.94
BCS	3.20	3.14	0.06	0.39
1-28 d				
BCS*	3.01	3.03	0.05	0.76
BCS change[5]	-0.36	-0.18	0.08	0.05
BW (1 DIM, kg)	573.85	578.46	4.1	0.004
BW change[6] (kg)	-33.97	-38.68	6.50	0.18

* Time effect $p<0.01$.
[1] Change = -7 d minus -1 d. [2] Change = Initial BCS minus BCS at calving. [3] BW changes = Initial BW minus BW at 1 DIM.
[4] 7 DIM value minus 1 DIM. [5] 28 DIM value minus calving day value. [6] 21 DIM value minus 1 DIM.

ruminal tissues and the rumen microbial population to the type of diet that will be fed after calving (Goff and Horst, 1997), and promotes the development of ruminal papillae for adequate absorption of VFA production during ruminal fermentation (Dirksen et al., 1985). However, this strategy is not likely to be a large factor in transition success of cows fed a more typical diet (Andesen et al., 1999; Smith et al., 2005, 2008; Penner et al., 2007). In some studies (Minor et al., 1998; Rabelo et al., 2003) feeding a high NFC diet compared to a low NFC diet, resulted in higher *pre-partum* DMI. Dann et al. (1999) reported that increasing the fermentability of NFC *pre-partum* (cracked corn replaced with steam flaked corn) tended to increase *pre-partum* DMI, but replacing sucrose with ground shelled corn in the *pre-partum* diet did not affect *pre-partum* performance (Ordway et al., 2002). Effects of ruminally available carbohydrate on DMI vary considerably and depend on the total amount of carbohydrate fermented in the rumen, source of grain and processing method, level of intake and forage source in the basal diet. Wheat and corn grains contain 77% and 72% of DM as starch with a rate of degradation 40% and 15%/h, respectively (Huntington, 1997; Fox et al., 2003). Ruminal degradability of starch for ground corn is 44.6% compared to rolled wheat which is 88.3% (Huntington, 1997). Although, the fermentative capacity of the rumen and nutritive value of feeds has not been adequately characterized through the dry period to lactation, it seems likely that the RW diet promotes more propionate production compared with the GC diet.

Peri-partum blood metabolites and metabolic hormones are presented in Table 4 and 5. In the periparturient period, there were no differences between diets in plasma glucose, NEFA, urea, TG, cholesterol, AST, and insulin concentrations. Primiparous cows fed the RW diet had greater plasma calcium at the first week of lactation ($p<0.05$) and *post-partum* until 28 DIM ($p = 0.08$)

Table 4. Periparturient blood metabolites and metabolic hormones of primiparous cows

Item	*Pre-partum*					*Post-partum*				
	Diet		SEM	p-value		Diet		SEM	p-value	
	Corn	Wheat		Diet	Time	Corn	Wheat		Diet	Time
Glucose (mg/dl)	54.56	58.88	3.13	0.18	0.63	46.68	49.87	2.69	0.25	0.003
NEFA (mmol/L)	0.22	0.23	0.02	0.71	0.02	0.47	0.39	0.04	0.11	0.001
BHBA (mmol/L)						0.30	0.32	0.04	0.69	0.003
Urea (mg/dl)	12.67	12.27	0.36	0.43	0.001					
TG (mg/dl)	20.91	19.51	2.03	0.49	0.06	17.79	18.97	1.83	0.52	0.07
Cholesterol (mg/dl)	66.75	74.25	4.30	0.15	0.01	104.97	105.75	4.41	0.86	0.001
Calcium (mg/dl)	9.09	9.38	0.33	0.39	0.003	8.67	9.10	0.28	0.08	0.001
AST (IU/L)	49.90	48.39	2.70	0.56	0.001	49.89	47.50	2.99	0.43	0.03
Insulin (pg/ml)	480.75	498.89	12.31	0.33	0.02	322.48	312.13	12.50	0.56	0.001
Cortisol (ng/ml)	10.78	13.66	1.03	0.07	0.001	13.64	16.04	1.10	0.14	0.001

compared with cows fed the GC diet. Heifers fed the RW diet tended ($p = 0.07$) to have greater plasma cortisol concentration during the last week of gestation.

These results are similar to other studies (Dann et al., 1999; Penner et al., 2007; Smith et al., 2008). There was no effect of *pre-partum* carbohydrate source on overall plasma concentration of glucose, NEFA, BHBA, albumin, triglyceride (TG), cholesterol, AST, insulin, and cortisol during week 1 and at 28 d of lactation. Heifers fed the RW diet compared with GC had a numerical increase in glucose concentration in the periparturient period. In general, glucose concentrations do not vary greatly due to nutritional changes of diet. Greater concentration of glucose in the present study likely resulted from high fermentability of starch in the RW diet. Rukkwamsuk et al. (1999) reported that high energy diets increased concentrations of plasma glucose in the last week of gestation. Glucose concentrations at calving are mainly mediated by cortisol and glucagon (Drackley et al., 2001). Our previous study (Amanlou et al., 2008) supports the results of the present study in which plasma glucose increased in the last week prior to calving and immediately after calving in response to feeding ground wheat during the *pre-partum* period.

Penner et al. (2007) reported that feeding additional concentrate to primiparous cows *pre-partum* did not improve energy balance or reduce adipose tissue mobilization around parturition. Holteniuse et al. (2003) reported that the magnitude of increase in NEFA concentration after calving was inversely related to DMI before calving. In the present study, although heifers fed the RW diet had lower DMI *pre-partum*, plasma NEFA did not different between treatments. In the *post-partum* period, these cows had numerically higher DMI and lower NEFA concentration. These results are further supported by the fact that changes in BCS were less for cows fed the RW diet than for those fed GC. In the present study, the dietary effect on plasma NEFA was lower in the first week of lactation compared to 28 DIM, likely due to changes in endocrine status (Drackley et al., 2001). The treatment effect on plasma BHBA was also not different in the *post-partum* period.

In general, plasma cholesterol and TG are not very good indicators of the rate of adipose tissue lipolysis and release of fatty acids. Plasma cholesterol may be used as an indirect index of liver function in peripartrient cows. Cholesterol in ruminants is largely in high density lipoproteins and therefore has very little relationship with VLDL export or body fat mobilization. Concentration of TG in blood arises

Table 5. Blood metabolites and metabolic hormones of primiparous cows (1-7 DIM)

Item	Diet		SEM	p-value
	Corn	Wheat		
Glucose (mg/dl)	43.52	48.24	2.10	0.12
NEFA (mmol/L)	0.59	0.49	0.06	0.26
BHBA (mmol/L)	0.34	0.41	0.05	0.33
TG (mg/dl)	15.22	22.50	2.50	0.07
Cholesterol (mg/dl)	101.50	101.00	3.30	0.91
Calcium (mg/dl)	8.17	9.09	0.28	0.04
AST (IU/L)	54.57	54.86	4.50	0.96
Insulin (pg/ml)	343.10	337.20	13.50	0.76
Cortisol (ng/ml)	13.64	16.04	1.10	0.14

both from dietary fatty acids absorbed and packaged into lipoproteins in the intestine as well as from production of VLDL in the liver. In addition, the concentration of TG in ruminants is very low and difficult to measure accurately (Dr Drackley, personal communication). In cows with fatty liver, plasma TG concentration sharply decreases after calving. Changes in liver metabolism of cows with fatty liver affect plasma TG concentration (Rukkwamsuk et al., 1999). Low plasma TG after calving implies low secretion and production of VLDL.

Increased serum levels of AST are weakly associated with increased total liver lipid. AST is not exclusively a liver enzyme but is also present in muscle, kidney and small intestine, and any increase may reflect injury to other tissues. In severe fatty liver, AST levels usually increase and levels of AST correlate with liver TG. However, this correlation is weak with the exception of severe cases of fatty liver. An AST value of more than 100 IU/L implies fatty liver (Gerloff and Herdet, 1999).

Plasma insulin, in agreement with other studies (van Knegsel et al., 2007; Smith et al., 2008), did not differ between treatments. In the present study, plasma insulin decreased and plasma cortisol increased near to parturition. Hypoinsulinemia in the dairy cow during early lactation is part of an adaptation process from gestation to lactation. Low plasma insulin concentration reduces glucose uptake by non-mammary extra-hepatic tissue and makes glucose available for uptake by the mammary gland which is not responsive to insulin (Bauman, 2000). Wathes et al. (2007) reported that in primiparous cows insulin might be less important in controlling the relative partitioning of nutrients between body tissues and milk synthesis, possibly because of prevailing higher IGF-1 concentration. In addition, due to lower milk production, primiparous cows have a higher plasma glucose concentration in the periparturient period (Wathes et al., 2007).

Calcium plays crucial roles in smooth muscle contraction and immune cell activation. Periparturient hypocalcaemia predisposes the cow to different disorders (Goff and Horst, 1997; Moore et al., 2000). Recently, Kimura et al. (2006) suggested that decreased calcium stores may depress the cell Ca^{2+} release in response to immune activation signals. So any strategies that prevent or reduce hypocalcaemia around calving may improve immunity and reduce the incidence of metabolic disorders. Reduced urine pH by feeding RW suggested a reduction in extracellular alkalinity. More acidic circulating fluids can fortify parathyroid-mediated bone resorption. Also, a reduction in extracellular alkalinity may potentially stimulate 1,25-dihydroxy vitamin D3 synthesis in the small intestine and result in reduced hypocalcaemia near calving (Horst et al., 1997), as observed in the present study.

Milk production and composition during the first week of lactation did not differ between diets (not shown), but primiparous cows fed the RW diet during the close-up period had higher milk production (1.6 kg/d) at this time (Table 6). Also, milk production and composition for the first 28 d of lactation were not different between treatments, but were greater for the RW diet compared with the GC diet. Primiparous cows fed the RW diet produced greater milk protein content (3.33 vs. 3.07%) and protein yield (1.07 vs. 0.98 kg/d) and had lower fat:protein ratio ($p<0.01$)

Table 6. Milk production and composition of primiparous cows (1-28 DIM)

Item	Diet		SEM	p-value		
	Corn	Wheat		Diet	Time	T×D
Milk (kg/d)	31.16	32.83	1.32	0.21	<0.01	0.66
$FCM_{3.5}$[1] (kg/d)	35.68	37.19	1.62	0.38	<0.01	0.10
ECM[2] (kg/d)	34.60	36.35	1.05	0.27	<0.01	0.08
Fat (%)	4.38	4.32	0.16	0.74	0.017	0.13
Fat (kg/d)	1.37	1.41	0.07	0.56	<0.01	0.06
Protein (%)	3.07	3.33	0.10	0.02	<0.01	0.34
Protein (kg/d)	0.98	1.07	0.04	0.04	<0.01	0.48
F:P ratio	1.43	1.31	0.04	0.01	0.03	0.43
Lactose (%)	4.08	4.05	0.07	0.75	0.07	0.64
Lactose (kg/d)	1.29	1.31	0.04	0.69	<0.01	0.24
Total solid (%)	12.21	12.38	0.24	0.48	<0.01	0.15
Total solid (kg/d)	3.88	3.99	0.14	0.45	<0.01	0.18
SNF (%)	7.85	8.04	0.10	0.08	<0.01	0.41
SNF (kg/d)	2.49	2.59	0.07	0.20	<0.01	0.47
MUN (mg/dl)	15.96	14.17	0.48	0.008	0.05	0.03
SCC[3]	3.12	2.43	0.21	0.03	0.15	0.84

[1] $FCM_{3.5} = (0.432 \times MY)+(16.23 \times FY_{(kg)})$. [2] ECM = Energy-corrected milk: $((0.327 \times Milk_{(kg)})+(12.95 \times Fat_{(kg)})+(7.2 \times Protein_{(kg)})$.
[3] $SCC = ([\log_{10}(SCC/1{,}000)+2]/\log_{10}(2))+3$.

compared to cows fed the GC diet. Milk production and components increased with time *post-partum* ($p<0.01$). Milk urea nitrogen was slightly lower (14.17 vs. 15.96 mg/dl) for cows fed the RW diet ($p<0.01$). In the present study, milk production was not affected by *pre-partum* treatment, and these results are consistent with the results obtained in other studies (Minor et al., 1998; Dann et al., 1999; Smith et al., 2005; Amanlou et al., 2008). The effect of changing ruminal starch degradation on milk production varies depending on the source of NFC. Dann et al. (1999) increased carbohydrate fermentability by including steam flaked corn in the close-up diet, and reported that cows produced more milk when fed steam flaked corn during the *pre-partum* period. Smith et al. (2005) reported that *pre-partum* carbohydrate source did not affect *post-partum* milk yield, milk component yields, and most milk component percentages. However, cows fed the high NFC diet during the *pre-partum* period tended to have a higher percentage of total solids in milk. Feeding sufficient ruminally-available NFC during the *pre-partum* period helps the rumen environment to adapt more rapidly to a high concentrate lactation diet (Dirksen et al., 1985). Shirley and Park (2003) reported that microbial adaptation for the lactation diet was more important compared to increasing energy value in the close-up diet. In some studies, enhanced energy density in the *pre-partum* diet only improved *pre-partum* metabolism and performance (Smith et al., 2005, 2008). In the present study, a rapidly ruminal fermentable starch source was included in the *pre-partum* diet with low energy density. Low energy diets in the *pre-partum* period are more beneficial relative to high energy density diets (Dann et al., 2006), but these diets do not adapt the rumen environment to a lactation diet.

The different milk protein and MUN data suggest that feeding the RW diet, which possessed a higher starch degradation rate than the GC diet, increased microbial protein synthesis and its flow to the small intestine, increased urea recycling to the gut, increased liver synthesis of glucose and mammary uptake of glucose and amino acids (Huntington, 1997). This increase in supply to and uptake of nutrients by the mammary gland probably results in the increased milk production and components observed when ruminal carbohydrate availability is increased in the diet. The sufficiently high milk fat yield may also suggest that *post-partum* rumen fermentation is not compromised. These data would also suggest that the amount of forage NDF in the diets was sufficient to maintain normal rumen fermentation.

CONCLUSIONS

Feeding a low energy density diet containing a rapidly rumen-fermentable carbohydrate source in the *pre-partum* period may be advantageous. Primiparous cows fed the RW diet during the *pre-partum* period had lower DMI and lower energy intake and balance. After calving, these cows had higher DMI and energy intake. Effect of *pre-partum* carbohydrate source on overall periparturient concentration of blood metabolites and hormones, with the exception of blood calcium, was not different. However, energy status was improved after parturition. Rapidly rumen-fermentable carbohydrate in the *pre-partum* diet improved milk yield and components. Cows fed the RW diet had higher milk protein content and yield, and lower MUN. Thus, inclusion of rapidly fermentable carbohydrate in a *pre-partum* diet with medium to low energy content may improve metabolic transition from gestation to lactation and productivity in primiparous cows.

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