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Effect of a Corn Straw or Mixed Forage Diet on Endocrine, Metabolism and Lactation Performance in Periparturient Cows

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Abstract: The objective of this study was to evaluate the effect of a corn straw or mixed forage diet on endocrine, metabolism and lactation performance in periparturient Holstein cows. Twelve multiparous, periparturient Holstein cows were randomly assigned to two groups and fed a corn straw or mixed forage diet, respectively. The CS diet included 33.8% corn straw and the F:C ratio [Dry Matter (DM)] was 60:40. The MF diet included 3.7% Chinese wildrye, 28.4% alfalfa hay and 26.5% corn silage, the F:C ratio (DM) was 40:60. All cows were fed from weeks 3-8 and Body Weight (BW), Body Condition Score (BCS) and Dry Matter Intake (DMI) were recorded. Milk protein, fat, lactose and Somatic Cell Count (SCC) were determined twice weekly. Metabolite and hormone analyses of blood were made weekly. Results showed that dietary treatments had no detectable effects on BW, BCS, DMI and blood hormones measured. From the 6 weeks of lactation, cows fed MF diet produced more milk ($p<0.05$) and tended to produce more milk fat ($p = 0.07$) and protein ($p = 0.10$) compared with cows fed CS diet. The proportions of milk fat, protein and lactose (%) did not differ between the two dietary treatments ($p>0.05$). In addition, the milk SCC in the CS group was significantly higher ($p = 0.02$) than the MF group. Cows fed MF diet experienced more severe Negative Energy Balance (NEB) and had higher concentrations of β-Hydroxy Butyric Acid (BHBA) and Non-Esterified Fatty Acid (NEFA) than cows fed CS diet. Collectively, these results suggest that cows fed MF diet improve lactation performance of periparturient cows but this dietary treatment may have an adverse effect on NEB of periparturient cows.

Key words: Forage type, endocrine, metabolite, lactation performance, periparturient cows

INTRODUCTION

The transition period (3 weeks before to 3 weeks after calving) is characterised by endocrine and metabolic changes to accommodate parturition and lactation (Drackley, 1999; Grummer, 1995). The decrease in Dry Matter Intake (DMI) before parturition, combined with gradually increasing energy demands in early lactation, mean that dairy cows have some degree of Negative Energy Balance (NEB) around calving (Herdt, 2000). The NEB associated with parturition leads to extensive mobilisation of body fat stores causing marked elevations in blood Non-Esterified Fatty Acid (NEFA) and β-Hydroxy Butyric Acid (BHBA) concentrations (Dann *et al*., 2006; Goff, 2006). Plasma concentrations of both insulin and IGF-1 generally decline postcalving and this decline is associated with a more severe NEB (Gong *et al*., 2002). Excessive elevation of serum NEFA or BHBA concentrations has been linked to reduced milk yield and decreased reproductive performance (Chapinal *et al*., 2012; Duffield *et al*., 2009; Ospina *et al*., 2010). The nutritional management strategy of transition cows is essential to make sure that the cow's genetic potential is fully developed. Numerous studies have focused on adjusting the levels of dietary energy or protein to influence the extent of the postpartum NEB as well as the circulating concentrations of specific blood metabolites and hormones. Further manipulation of the diet is possible by altering the forage source and amount offered to dairy cows. A wide variety of forage can improve the composition of diets and thus influence feed intake and nutrient digestion and affect milk production, milk composition and the health of dairy cows (Abrahamse *et al*., 2008; Kliem *et al*., 2008; Sterk *et al*., 2011). In China, corn straws are widely used as main roughage sources for most dairy farms but a major constraint of corn straw for livestock production is poor nutrient quality. Therefore, farmers tend to increase the proportion of concentrate to meet the demand of dairy cows. However, in large-scale farms, alfalfa and corn

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silage are used as the main source of roughage for dairy cows which can provide highly nutritious forage in terms of protein, vitamins and minerals for ruminant animals.

Currently, data are limited that related to periparturient dietary forage patterns. Therefore, the objectives of the present study were to evaluate the effects of two different forage quality diets on endocrine, metabolic regulation and lactation performance in periparturient cows and explore a more suitable dietary type for periparturient cows.

MATERIALS AND METHODS

Animal management: Animal care and procedures were approved and conducted under established standards of the Institute of Animal Science, Chinese Academy of Agricultural Sciences, Beijing, China. Twelve multiparous, periparturient Holstein cows were enrolled in this study which were randomly assigned to CS or MF group. Dietary treatments were initiated at approximately 3 weeks before the expected calving dates and continued until 8 weeks after calving. Throughout the experimental period, cows were housed in a tie-stall barn and fed individually and water was available *ad libitum*. They were fed a TMR twice daily at 0700 and 1900 h.

The CS and MF diets were formulated according to China NY/t 34 guidelines (China NY/t34, 2004). Treatments were Corn Straw (CS): 33.8% of corn straw as the only roughage and 66.2% of concentrate, Mixed Forage (MF): 58.6% of mixed forage (3.7% Chinese wildrye + 28.4% alfalfa hay + 26.5% corn silage) and 41.4% of concentrate. Ingredient and nutrient composition of the diets are presented in Table 1. The CS and MF diets had forage to concentrate ratios of 40:60 and 60:40, respectively.

Table 1: Ingredients and chemical composition of Corn Straw (CS) and Mixed Forage (MF) diets

	DM (%)	
Items	Corn Straw (CS)	Mixed Forage (MF)
Ingredients		
Chinese wildrye	-	3.700
Corn straw	33.80	-
Alfalfa hay	-	28.40
Corn silage	-	26.50
Concentrate mixture[1]	66.20	41.40
Chemical composition		
DM (%)	56.29	53.31
NE_L (Mcal kg^{-1})	1.54	1.520
CP (DM %)	16.90	16.30
NDF (%)	56.73	57.06
ADF (DM %)	18.67	24.86
EE (%)	1.58	2.380
Ca (DM %)	0.96	0.800
P (DM %)	0.43	0.330

[1]Concentrate mixture was composed of corn, soybean meal, wheat bran, cottonseed, calcium hydrophosphate, limestone, NaCl, trace mineral and vitamin premix (vitamin A, D and E). [2]NE_L = Net Energy for Lactation, determined based on chemical composition and 24 h gas production of feeds (Menke and Steingass, 1988)

Sampling and analysis: Amount of daily feed offered and refused was recorded for individual cows. A daily DMI for individual cows was calculated by subtracting the orts from the feed offered. Samples of TMR and orts were collected twice a week and frozen at -20°C for DM analysis. The DM content of the feed ingredients was determined by drying in a forced-air oven at 65°C for 48 h. Dried composite samples were ground to pass a 1 mm screen using a lab mill (ZM200, Retsch, Haan, Germany) and analyzed for concentrations of Crude Protein (CP), Ether Extract (EE), calcium, phosphorus (AOAC, 1990), Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF) (Van Soest *et al*., 1991). Net Energy of lactation (NE_L) was determined based on chemical composition and 24 h gas production of TMR (Hohenheim Gas Method) (China NY/t34, 2004, Menke and Steingass, 1988). Samples were further dried at 105°C for 6 h to determine absolute DM and all chemical analyses were expressed on DM basis.

Weekly Body Weight (BW) and Body Condition Score (BCS) were measured for each cow. A BCS was assigned independently by four individuals once a week and the median score was used for each cow (Wildman *et al*., 1982).

After parturition, cows were milked twice daily at 400 and 1600 h using a robotic sampling system (Westfalia Surge 9JGD-YG-32, GEA Farm Technologies, Bonen, Germany) and milk yields were recorded. Milk samples (50 mL) were mixed in a ratio of 3:2 by volume for morning and afternoon milk and preserved with bronopos-B2 (Sigma) and then analysed for fat, lactose, protein and Somatic Cell Count (SCC) by near mid-infrared procedures using a MilkoScan Minor machine (MilkoScan 4000, Foss Electric, Hillerod, Denmark).

Samples of blood (9 mL) were collected weekly from each cow from the coccygeal vein or artery using VACUETTE® serum separation tubes containing a clot activator (GreinerBio-One-suns Co., Ltd. Beijing, China). Samples were collected before feeding (0600 h). All blood samples were immediately placed on ice and centrifuged at 3,000 g for 25 min at 4°C within 1 h of collection, divided into aliquots and stored at -20°C until analysis. Serum samples were assayed for glucose, NEFA and BHBA concentrations using the following commercial kits: glucose GOD-PAP assay kit (Prodia Diagnostics, Botzingen, Germany), Clinimate NEFA kit (SEKISUI Medical Co., Ltd. Toyko, Japan) and BHBA reagent set (Shanghai JingYuan Co., Ltd. Shanghai, China). Serum concentrations of Prolactin (PRL), GH and Insulin (INS) were measured using an iodine [^{125}I] radioimmunoassay kit (Tianjin Nine Tripods Medical&Bioengineering Co., Ltd. Tianjin, China). Serum concentrations of

IGF-1 were etermined using a double-antibody IGF-1 radioimmunoassay kit (Tianjin Nine Tripods Medical&Bioengineering Co., Ltd. Tianjin, China). The inter and intra-assay coefficients of variation were: 11.5 and 5.4% for PRL, 9.3 and 5.8% for GH, 12.2 and 7.6% for INS and 15 and 5% for IGF-1, respectively.

Calculation of energy balance: Energy balance was calculated both pre and postpartum for each multiparous cow according to Janovick and Drackley (2010). Intake of NE_L was calculated by multiplying the daily DMI by NE_L density in the diet determined using the monthly composites of individual feed ingredients as described earlier. Maintenance NE_L (Mcal) was calculated as $BW^{0.75}\times 0.080$. Pregnancy requirements for NE_L (Mcal) were calculated as $[(0.00318\times\text{day of gestation}-0.0352)\times(\text{calf birth weight}/45)]/0.218$. Requirements of NE_L for milk production were calculated as $(0.0929\times\text{fat }\%) + (0.0547\times\text{protein }\%) + (0.0395\times\text{lactose }\%)$.

Statistical analysis: Data were analyzed using MIXED Models of SAS (Version 9.0, SAS Institute Inc., Cary, NC) with repeated observations. Fixed effects included treatment, time (week or DIM) and treatment x time interaction. Cow was considered as random variable. Data from BW, BCS, DMI and energy balance were split into prepartum and postpartum periods and analysed separately. SCC data were converted into Somatic Cell Score (SCS) $[SCS = \log_2(SCC/100{,}000) + 3]$ to eliminate the effect of lactation day and period of sampling on SCS (Shook, 1982). Differences were considered to be significant at $p\leq 0.05$ whereas tendencies were discussed at $p>0.05$ but $p\leq 0.10$.

RESULTS

DMI, BW and BCS: As shown in Table 2, there was no significant difference in DMI between the two dietary treatments during the whole experiment (p> 0.05). Pre and postpartum BW, BCS and the changes in transition cows were also not affected by dietary treatments.

Milk yield and composition: Milk production data are presented in Fig. 1a and Table 3. From 6 weeks of lactation, cows in the MF group produced more milk (p<0.05) than those in CS group. Cows fed MF diet tended to produce more milk fat (p = 0.07) and protein (p = 0.10) compared with cows fed CS diet. Milk lactose yields (kg/day) as well as proportions of milk fat, protein and lactose (%) did not differ between the two dietary treatments (p>0.05). In addition, the milk SCC in the CS group was significantly higher (p = 0.02) than the MF group.

Table 2: DMI and changes in BW, BCS for peripartum Holstein cows fed two different diets

	Trt[1]			
Item[2]	CS	MF	SEM	p-value
DMI (kg day^{-1})				
Prepartum	8.80	8.10	0.88	0.57
Postpartum	11.70	12.50	1.01	0.62
BW (kg)				
Prepartum	583.00	594.00	25.30	0.76
Postpartum	474.00	468.00	24.70	0.86
Initial BW	576.00	589.00	26.20	0.73
Prepartum change[3]	14.80	8.20	3.04	0.16
Postpartum change[4]	-120.00	-129.80	12.75	0.60
BCS (5-point scale)				
Prepartum	3.65	3.58	0.05	0.41
Postpartum	2.93	2.91	0.10	0.86
Initial BCS	3.70	3.63	0.05	0.35
Prepartum change[3]	-0.10	-0.08	0.06	0.84
Postpartum change[4]	-0.85	-0.79	0.12	0.75

[1]CS = Corn Straw; MF = Chinese wildrye + Corn silage + Alfalfa hay; Trt = CS, MF. [2]Prepartum means were averaged over 3 weeks before calving; Postpartum means were averaged over 3 weeks of lactation. [3]For both BW and BCS, changes were calculated from weeks 3 relative to parturition. [4]For both BW and BCS, changes were calculated from week 1 of lactation through week 8 of lactation for all cows

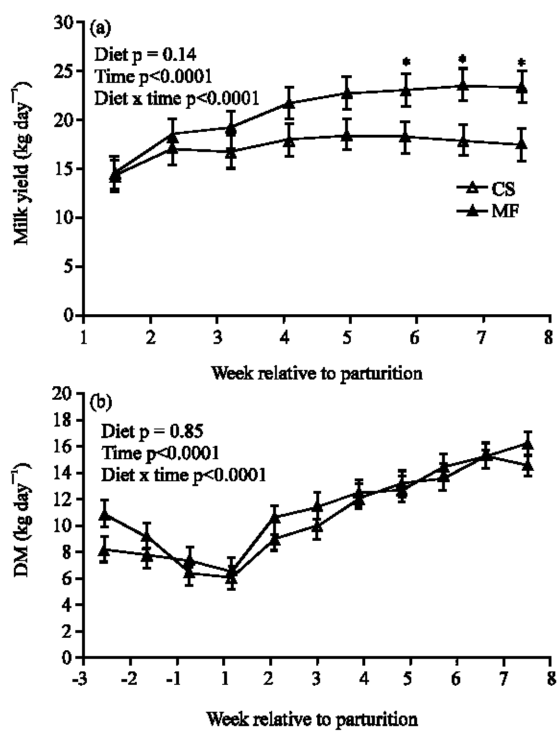

Fig. 1: a) Milk yield and b) DMI of cows fed a corn straw diet (CS; n = 6) or mixed forage diet (MF; n = 6). Data are presented as least squares means±SEM. *p≤0.05

Blood metabolites: Blood metabolites changes are presented in Fig. 2a-c. A large spike in blood glucose concentration occurred at parturition for both treatments

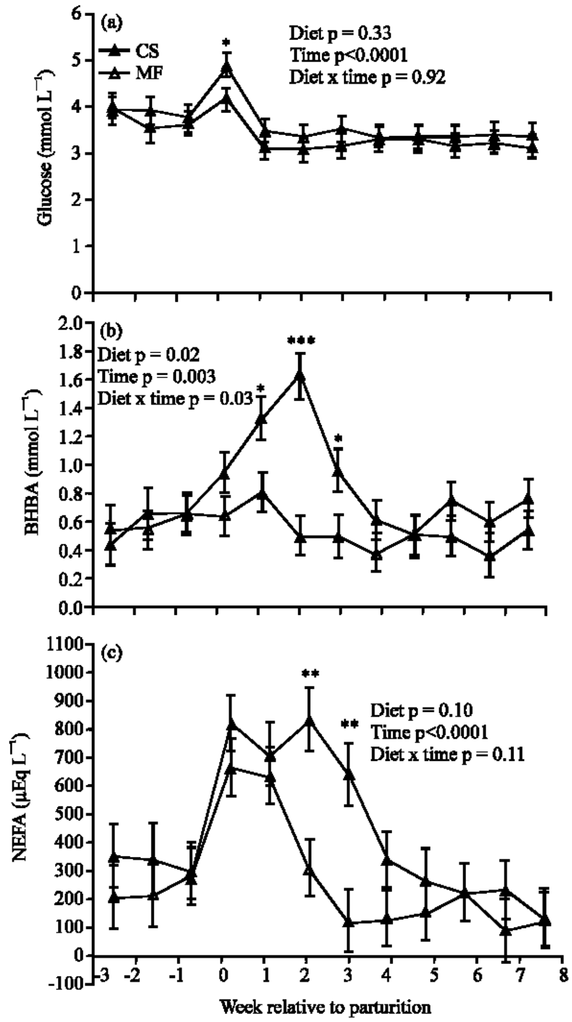

Fig. 2: Serum concentrations of a) Glucose, b) BHBA and c) NEFA in cows fed a corn straw diet (CS; n = 6) or mixed forage diet (MF; n = 6). *p<0.05; **p<0.01; ***p<0.001. Data are presented as least squares means±SEM

which were greater in cows fed CS diet (4.91 mmol L^{-1}) than those fed MF diet (4.16 mmol L^{-1}) (Fig. 2a; p = 0.04). Mean concentration of serum BHBA in MF cows peaked in week 2 after calving and significantly higher for MF treatment relative to CS treatment (1.64 vs. 0.51 mmol L^{-1}; p<0.0001). Mean concentration of serum NEFA in MF cows were also significantly higher than CS cows in week 2 (832.3 vs. 309.0 μEq L^{-1}; p = 0.001) and week 3 after calving (637.8 vs. 121.8 μEq L^{-1}; p = 0.002). There were no treatment effects on any of the hormones measured (Table 4).

Metabolic regulation: As shown in Fig. 3, cows were in a positive energy balance until the immediate precalving period, entering a period of NEB at day 17 and 8 for MF and CS cows, respectively. Days to reach NEB nadir averaged 7 days postpartum and were not affected by dietary treatments. At 4, 5 and 7 weeks postpartum, cows

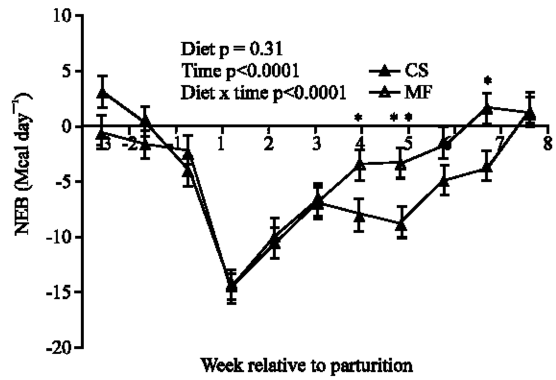

Fig. 3: Calculated energy balance by week relative to parturition for cows fed a corn straw diet (CS; n = 6) or mixed forage diet (MF; n = 6). Data are presented as least squares means±SEM. *p≤0.05

Table 3: Milk production and composition (over an average of 8 weeks) for Holstein cows fed two different diets

	Trt[1]			
Items	CS	MF	SEM	p-value
Milk yield (kg day^{-1})	17.25	20.84	1.59	0.14
Milk composition				
Fat				
%	4.68	5.33	0.28	0.13
kg day^{-1}	0.81	1.08	0.09	0.07
Protein				
%	3.48	3.43	0.18	0.84
kg day^{-1}	0.59	0.69	0.04	0.10
Lactose				
%	4.61	4.58	0.06	0.74
kg day^{-1}	0.80	0.96	0.08	0.16
Somatic cell score[2]	-5.25	-6.88	0.25	0.02

[1]CS = Corn Straw; MF = Chinese wildrye + Corn silage + Alfalfa Hay; Trt = CS, MF. [2]Somatic cell score = $\log_2$ (SCC/100000) + 3, SCC = Somatic Cell Counts

Table 4: Serum concentrations of GH, PRL, INS and IGF-1 in cows fed a corn straw or mixed forage diet

	Trt[1]			p-value		
Items	CS	MF	SEM	Trt	Time[2]	Trt x Time
GH (ng mL^{-1})						
Prepartum	0.37	0.37	0.15	0.99	0.04	0.21
Postpartum	0.43	0.45	0.11	0.91	0.42	0.45
PRL (ng mL^{-1})						
Prepartum	3.35	2.62	0.54	0.39	0.26	0.64
Postpartum	3.37	3.12	1.03	0.94	0.53	0.89
Insulin (μIU mL^{-1})						
Prepartum	9.35	9.64	1.93	0.56	0.70	0.93
Postpartum	8.32	6.68	0.88	0.24	0.82	0.51
IGF-1 (ng mL^{-1})						
Prepartum	73.32	93.45	15.80	0.40	0.52	0.47
Postpartum	50.49	70.21	9.27	0.23	0.62	0.39[1]

CS = Corn Straw; MF = Chinese wildrye + Corn silage + Alfalfa hay; Trt = CS, MF; [2]Time = -3, -2, -1, 1, 2, 3, 4, 5, 6, 7 and 8 weeks fed MF diet experienced a more serious NEB relative to cows fed CS diet ($p<0.05$). Cows entered a period of energy balance for CS and MF treatments at 6 and 8 weeks postpartum, respectively.

DISCUSSION

Milk yield and composition: Increasing the proportion of concentrate in the diet is often associated with a decrease in ruminal pH (Yang and Beauchemin, 2007, 2009) which can lead to subacute ruminal acidosis. A low ruminal pH leads to a decrease in digestive effectiveness which in turn, leads to a drop in DMI, milk yield, milk fat content and many other disorders (Plaizier *et al*., 2008). Over 8 weeks of lactation in the study although DMI did not differ between two dietary treatments, the milk yield of the CS treatment displayed to decline from 5 weeks of lactation which may be due to the higher proportion of concentrate in the diet. Meanwhile, milk Somatic Cell Count (SCC) is not only a measure of herd udder health performance, it is also a standard for milk quality. Increased SCC early in the first lactation has been associated with decreased milk yield throughout the entire first lactation (Archer *et al*., 2013). The higher milk SCC in this study for CS treatment may imply an incidence of intramammary infection, not surprisingly which negatively affected milk production.

Blood hormones and metabolic regulation: Hormones and metabolites analyzed in this study followed similar patterns postpartum to those reported in earlier studies (Doepel *et al*., 2002; Gong *et al*., 2002). The decline in glucose concentrations can be attributed to increased demand and uptake of glucose by the mammary gland for lactose synthesis (Leroy *et al*., 2008) whereas declining insulin levels postpartum have been attributed to nutrient prioritization, specifically to balance glucose supply to tissues of the body during early lactation (Bauman, 2000). The high concentrations of NEFA during first 3 weeks postpartum are the result of drastic increases in lipolysis due to increased diversion of nutrients to the mammary glands as NEFA acts as an alternative energy source (Leroy *et al*., 2008).

Gradual increasement of milk yield in the MF cows leaded to a more severe NEB in them. Results are consistent with earlier studies that reported high milk yield is also associated with NEB in the immediate postpartum period (Butler, 2000; Doepel *et al*., 2002). Furthermore, researchers observed a relationship of elevated serum NEFA and BHBA concentrations around parturition with high milk production in early lactation. This result is reverse to that reported by Chapinal *et al*. (2012) who found high serum concentrations of NEFA and BHBA around parturition were associated with early lactation milk loss. This result might be explained in part by no significant differences in postpartum DMI between two dietary treatments and cows fed MF diet had to rely on excessive mobilization of body fat to meet lactation. A moderate degree of fat mobilization in early lactation may be critical to obtain high milk yields. Nevertheless, excessive magnitude or rate of mobilization of fat reserves will cause suboptimal metabolic performance and is likely an indicator of a reduced adaptive response to NEB. It can be expected that reproductive performance of cows fed MF diet will be impaired.

Although, the transition period has been the focus of intensive research over the last 20 years, practical management strategies to minimize health problems while still promoting high milk production have remained controversial (Drackley and Dann, 2008). More research is required to focus on minimizing the extent and duration of postpartal NEB to minimize the mobilization of NEFA around calving for MF treatment.

CONCLUSION

These results showed that mixed forages with a lower proportion of concentrate can improve lactation performance of periparturient cows. However, a high milk yield was often negatively correlated to postpartum Negative Energy Balance (NEB). The MF cows experienced a more severe NEB and elevated postcalving NEFA and BHBA concentrations which indicated be unfavorable for subsequent performance and health of dairy cows. Exploring other nutrition programs for maintenance of milk yield and better energy balance after calving were the focus in the future.

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