NUTRITION, FEEDING, AND CALVES

Effect of Restricted Feed Intake of Dams and Heat Stress on Mineral Status of Newborn Calves

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ABSTRACT

To clarify the effects of restricted feed intake, heat stress, and parity on the mineral status of cows and heifers around parturition and on the mineral status of their calves during 1 wk of age, data were collected from 66 Holstein cows and heifers and their calves. In Experiment 1, 36 heifers and mature cows that calved during hot or cool weather were fed to meet requirements for total digestible nutrients (TDN), protein, and minerals. In Experiment 2, 15 mature cows that calved during hot or cool weather were fed to meet maintenance requirements for TDN plus requirements for TDN for the last 2 mo of gestation, and 15 heifers were fed to meet TDN requirements. Heat stress increased rectal temperatures of newborn calves. Blood hematocrit and hemoglobin of heifers around parturition were higher than those of mature cows, but blood hematocrit and hemoglobin of calves born from heifers were lower. The restricted feed intake of dams decreased blood hematocrit and hemoglobin as well as plasma Fe of calves in hot and cool weather. Plasma Ca, inorganic P, and alkaline phosphatase as well as colostral Ca, P, Mg, and Zn of heifers were higher than those of mature cows, but plasma Mg of heifers was lower. Plasma Mg of calves and their dams was lower in hot weather than in cool weather, and restricted feed intake accelerated the reduction in plasma Mg of calves and their dams during hot weather. Plasma Na of calves and their dams was higher in hot weather than in cool weather. Heat stress increased plasma K of heifers and their calves. Heat stress increased Ca concentration in meconium of calves born from cows, and the restricted feed intake increased P concentrations in meconium. These results suggest that the maintenance of optimum erythropoiesis and mineral status in heat-stressed periparturient cows and heifers and their calves must be met by dietary energy and minerals that are fed at maintenance concentrations plus excess requirements necessary during the gestation period.

(**Key words**: feed intake, hot weather, mineral status, newborn calves)

Abbreviation key: **Hb** = hemoglobin, **Hct** = hematocrit, $\mathbf{P_i}$ = inorganic P.

INTRODUCTION

The mineral status of newborn calves varies according to a number of factors. Many farmers may reduce the overall costs of raising heifers by reducing calf mortality. Anemia in newborn calves as well as calf mortality at birth is observed more often for multiple calves than for single calves, for calves born from primiparous cows than for calves born from multiparous cows, and for bull calves than for female calves (12, 13, 14). Kume and Tanabe (12) reported that calves born from primiparous cows developed low blood hematocrit (**Hct**) and hemoglobin (**Hb**) at d 1 of age because placental Fe transfer from primiparous cows might have been too low due to the high demand for Fe for growth in heifers.

The transition period from nonlactation to lactation imposes enormous stress on dairy cows and may impair DMI, milk production, and herd health (8). Plasma Ca, inorganic P ($\mathbf{P_i}$), and Zn concentrations of dairy cows decreased around parturition because of the transfer of large amounts of these minerals to colostrum, and older cows were at a greater risk of developing milk fever (7, 10, 20, 25). High environmental temperature is a primary factor that adversely affects the productivity of dairy cows. Heat stress in summer reduces feed intake and milk production of dairy cows and alters mineral needs in ruminants (4, 6, 11, 16). Collier et al. (6) indicated that heat stress in late gestation reduced fetal growth and altered the endocrine status of dams. However, the relationships among heat stress, reduced feed intake of dams, and the optimal mineral status of

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newborn calves are unclear, although heat stress may exaggerate the prepartum decline in DMI of cows (8).

The present experiments were conducted to clarify the effect of restricted feed intake of dams and heat stress on the mineral status of newborn calves born from mature cows and heifers and to clarify the effect of heat stress on mineral status of newborn calves during 1 wk of age that were born from heifers and mature cows.

MATERIALS AND METHODS

Experiment 1

Data from 36 Holstein cows and heifers and their calves were collected at the National Institute of Animal Industry (Tsukuba, Japan) in hot and cool weather from June 1994 to March 1995. Eight primiparous or multiparous mature cows and 11 heifers that calved from June 26 to August 28 were termed the hot group, and 7 primiparous or multiparous mature cows and 10 heifers that calved from November 23 to March 19 were termed the cool group.

Dams were managed in individual tie stalls and a paddock during dry period. From approximately 3 wk before the expected calving date, dams were fed 3 to 4 kg/d of concentrate and appropriate amounts of silage from Italian ryegrass (Table 1) in individual tie stalls to meet recommendations (3) for TDN, protein, and minerals. Calves were separated from the dams at parturition and housed in individual pens. Each calf received approximately 1 kg of colostrum at parturition and, thereafter, 2.5 kg of colostrum at 0900 and 1600 h daily from the fresh colostrum of the dam.

Experiment 2

Sixteen primiparous or multiparous Holstein cows and 16 heifers that calved from June 1995 to March 1996 at National Institute of Animal Industry and their calves were used. Because 1 cow gave birth to twins and 1 calf born from a heifer died at parturition, data from 15 cows, 15 heifers, and their calves were collected in this study. Seven cows and 8 heifers that calved from June 6 to September 13 were termed the hot group, and 8 cows and 7 heifers that calved from October 22 to March 20 were termed the cool group (22, 23, 24).

Cows and heifers were fed in individual tie stalls to meet maintenance requirements plus requirements for TDN for the last 2 mo of gestation (3). Cows and heifers in the hot group were fed at 0830 and 1530 h in equal amounts for 4 wk before the expected calving date, and cows and heifers in the cool group were fed in equal amounts at the same times for 12 wk before the expected calving date. The gestation length was assumed to be 280 d. The diet consisted of 70% silage from Italian ryegrass and 30% concentrate (DM basis) (Table 1). Nutrient contents of the feed met recommendations (3) for protein and minerals for pregnant cows. Feed intake was measured from 4 wk prepartum until parturition. Heifers were fed 3 to 4 kg/d of concentrate and appropriate amounts of silage from Italian ryegrass in individual tie stalls to meet recommendations (3) for TDN, protein, and minerals before parturition, but feed intake was not measured.

Calves were separated from their dams at parturition and were housed in individual pens. Each calf received approximately 1 kg of colostrum at parturition and, thereafter, 2.5 kg of colostrum at 0900 and 1600 h daily from the fresh colostrum of the dam for 1 wk postpartum.

Sampling Methods

In Experiment 1, blood samples were obtained from dams at 0830 h at 2 wk, 1 wk, and 2 d before the expected calving date; at parturition; and 1 and 6 d after parturition. At parturition, blood samples were taken within 12 h after birth. Blood samples were collected from calves at 0830 h on d 1 of age. The mean time of the first blood sampling of calves was 22 h after parturition, and calves received colostrum one or two times before the first blood sampling. Blood was collected via jugular puncture into heparinized vacuum tubes. Colostrum samples of dams were collected at parturition. Rectal temperatures of dams were measured using a thermometer and were recorded daily at 0900 and 1600 h from 2 wk before the expected calving date until parturition. The mean rectal temperatures from 10 to 4 d before parturition were available for the data.

In Experiment 2, blood from cows and heifers was sampled via jugular vein puncture into heparinized vacuum tubes prior to feeding at 0830 h at 3, 2, and 1 wk before and 2 d before the expected calving date; at parturition; and 1 and 6 d after parturition (22, 23, 24). Blood samples from calves were collected at parturition and at 0830 h on 1 and 6 d of age. At parturition, blood samples were taken within 12 h after birth. Colostrum samples from dams were collected at parturition. Meconium samples from calves were taken within 12 h after birth. At parturition and at 0830 h on 1 and 6 d of age, rectal temperatures of calves were measured using a clinical thermometer.

Blood Hct and Hb (11), plasma macrominerals (11) and trace minerals (13), and colostrum composition (11) were determined as previously described.

TABLE 1. Chemical composition of the concentrate and silage from Italian ryegrass fed during hot and cool weather in Experiments 1 and 2.

	Experiment 1				Experiment 2			
	Hot		Cool		Hot		Cool	
	Concentrate	Silage	Concentrate	Silage	Concentrate	Silage	Concentrate	Silage
DM, %	86.2	39.2	87.3	45.8	86.9	40.9	88.1	41.6
	(% of DM)							
CP	16.3	9.8	16.9	10.2	16.7	12.6	16.6	13.0
ADF	6.4	36.1	9.2	37.8	9.3	40.0	10.0	39.0
NDF	16.5	54.8	17.5	56.6	16.0	63.4	17.1	62.9
Ca	0.74	0.46	0.87	0.48	0.81	0.49	0.82	0.45
P	0.57	0.29	0.59	0.28	0.62	0.28	0.61	0.34
Mg	0.27	0.23	0.29	0.23	0.29	0.22	0.30	0.32
	(ppm)							
Fe	125	551	171	548	250	1819	156	1038
Zn	74	20	84	19	82	30	84	27

Plasma or serum alkaline phosphatase was determined according to the method of Bessey et al. (5). Meconium samples were dried, ground in a stainless steel mill, and determined as previously described (11) after digestion in nitric and perchloric acids.

Daily temperatures and relative humidities were recorded at the Division of Agrometeorology, National Institute of Agro-Environmental Sciences (Tsukuba, Japan), which was located approximately 1 km from the experimental barn. Daily temperatures and relative humidities were measured using a platinum resistance thermometer and dewcel dew point hygrometer, respectively.

Experimental Design and Analysis

Data from plasma samples of dams in Experiment 1 and from cows and heifers and their calves in Experiment 2 were analyzed by least squares ANOVA using the general linear models procedure of SAS (17). The model was as follows:

$$Y_{ijklm} = \mu + P_i + W_j + C_{(ij)k} + T_l + PW_{ij} + PT_{il} + WT_{jl} + PWT_{ijl} + E_{ijklm}$$

where

μ = overall mean,
P_i = effect of parity (or diet),
W_j = effect of weather,
$C_{(ij)k}$ = random variable caused by cow nested in parity (or diet) and weather,
T_l = effect of sampling day,
PW_{ij}, PT_{il}, WT_{jl}, and PWT_{ijl} = interactions, and
e_{ijklm} = residuals.

The general linear models procedure of SAS (17) was used to analyze the effects of parity and weather on colostrum composition and rectal temperatures of dams or blood composition of calves in Experiment 1. Data from cows and heifers and their calves in Experiment 2 were analyzed as previously described (24). An ANOVA was performed, and the differences were tested by least significant difference (17). Significance was declared at $P < 0.05$ unless otherwise noted.

RESULTS AND DISCUSSION

Animal Health in Hot Weather

The summers in Japan in 1994 and 1995 were very hot and humid, and approximately 4600 dairy cows from 2.02 million head in 1994 died from heat stress. The upper critical temperature for dry, pregnant cows is defined as 25°C, and a relative humidity >80% indirectly affects the upper critical temperatures (6, 15).

In the present experiments, mean temperatures and relative humidities in July and August 1994 and in August 1995 were >26°C and 80%, respectively (Table 2). As a result, 2 heifers in the hot weather died after collapsing from heat stress within 2 d after parturition, and another heifer was slaughtered because of vaginal prolapse within 1 wk postpartum in 1994, although appropriate therapy was carried out for these heifers. In the cool weather, 1 heifer died just after parturition because of dystocia. Also, newborn calves born from heifers died at parturition because of dystocia in the hot (n = 3) and cool (n = 2) weather in 1994. In 1995, 1 cow fed to meet main-

TABLE 2. Monthly temperatures and relative humidities during hot and cool weather in Experiments 1 and 2.

	Hot				Cool					
Experiment	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
1 (1994–1995)										
Maximum temperature, °C	25.3	31.2	33.2			16.2	11.7	9.1	9.4	12.3
Mean temperature, °C	20.6	26.3	27.5			10.3	5.5	3.1	3.8	6.9
Minimum temperature, °C	16.8	22.7	23.3			5.2	0.1	–2.1	–1.6	1.8
Mean relative humidity, %	81.8	85.5	83.1			80.6	69.8	59.0	61.2	75.0
2 (1995–1996)										
Maximum temperature, °C	22.5	28.7	32.9	26.4	22.1	15.8	10.9	9.2	8.6	12.2
Mean temperature, °C	18.8	24.5	27.2	21.6	17.1	9.1	4.0	3.3	2.8	7.0
Minimum temperature, °C	16.1	21.4	23.2	17.8	12.8	2.7	–2.1	–2.4	–2.3	2.2
Mean relative humidity, %	89.0	89.4	82.9	81.2	81.5	69.5	59.2	61.7	65.0	66.2

tenance requirements in the hot weather had severe dystocia and was slaughtered at 2 wk postpartum; 1 calf born from a heifer died at parturition. No metabolic disorders were detected around parturition for the other cows or heifers in 1994 and 1995 in either hot or cool weather.

In Experiment 1, the gestation length and BW of mature cows and heifers were not significantly different between the hot and cool groups, although the BW of heifers at parturition was lower ($P < 0.01$) than that of mature cows (Table 3). Rectal temperatures of heifers at 1600 h ($P < 0.001$) and those of mature cows in the hot group were significantly higher than the rectal temperatures recorded for cows and heifers in the cool group, but rectal temperatures at 0900 h were not significantly different. The mean rectal tem-

TABLE 3. Least squares means of blood hematocrit (Hct), hemoglobin (Hb), and plasma Fe of heifers and mature cows that calved during hot and cool weather and those of their calves (Experiment 1).

	Heifer		Mature cow			Effect		
	Hot	Cool	Hot	Cool	SE	Parity (P)	Weather (W)	P × W
						P		
Dams								
No.	11	10	8	7				
Age, mo	28.1	29.0	59.5	61.5	1.4	***	NS[1]	NS
Gestation length, d	282	279	281	283	1	NS	NS	NS
BW,[2] kg	496	488	602	597	10	***	NS	NS
Rectal temperature,[3] °C								
At 0900 h	39.2	39.2	39.1	39.0	1.3	NS	NS	NS
At 1600 h	39.9	39.5	39.8	39.4	1.4	NS	***	NS
Blood Hct,[4] %	32.6	33.5	31.7	30.4	0.1	***	NS	***
Blood Hb,[4] g/dl	11.6	11.6	11.3	10.7	0.1	***	*	***
Plasma Fe,[4] ppm	1.15	1.31	1.71	1.56	0.02	***	NS	***
Colostrum yield,[2] kg	1.9	1.8	2.4	2.1	0.1	NS	NS	NS
Colostrum composition[2]								
Protein, %	14.2	14.2	12.6	14.9	0.6	NS	NS	NS
Fe, ppm	2.7	1.9	1.4	2.5	0.2	NS	NS	**
Calves								
no.	8	8	8	7				
BW, kg	42.1	41.9	42.3	45.6	0.8	NS	NS	NS
Blood Hct,[5] %	30.8	32.8	39.7	40.2	1.3	**	NS	NS
Blood Hb,[5] g/dl	9.2	9.5	12.0	12.0	0.4	**	NS	NS
Plasma Fe,[5] ppm	1.03	1.51	1.11	1.30	0.09	NS	NS	NS

[1]$P > 0.05$.

[2]At parturition.

[3]Means from 4 to 10 d before parturition.

[4]From 2 wk prepartum to 6 d postpartum.

[5]At d 1 of age.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

peratures at 0900 and 1600 h for 3 heifers in the hot group that died because of the weather conditions were 39.4 and 40.3°C, respectively.

In Experiment 2, heat stress increased ($P < 0.01$) rectal temperatures of newborn calves born from cows and heifers (Tables 4 and 5), but the restricted feed intake of dams had no effect on the health status and rectal temperatures of calves. Heat stress increased the rectal temperatures of periparturient cows, and the restricted feed intake during hot weather accelerated the increase in rectal temperatures (22, 23, 24).

Fe Status of Newborn Calves in Hot Weather

In Experiment 1, blood Hct ($P < 0.01$) and Hb ($P < 0.01$) of calves born from heifers were lower at d 1 of age than were those of calves born from mature cows; however, no significant differences in blood Hct and Hb were detected between the hot and cool groups (Table 3). Plasma Fe of calves at d 1 of age and colostral Fe at parturition were not significantly different between parities or between the hot and cool groups. These results agree with the data in our previous reports (12, 14). Blood Hct ($P < 0.001$) and Hb ($P < 0.001$) of heifers around parturition were higher than those of mature cows, but plasma Fe ($P < 0.001$) of heifers was lower. Blood Hb of mature cows in the hot group was significantly higher than that of mature cows in the cool group; no significant differences in blood Hct and plasma Fe were detected between the hot and cool groups.

In Experiment 2, blood Hct and Hb of cows fed to meet maintenance requirements were higher ($P <$

TABLE 4. Least squares means of blood hematocrit (Hct), hemoglobin (Hb), and plasma Fe of cows and heifers and their newborn calves. Cows and heifers were either fed to meet maintenance requirements (MR) or were fed to meet maintenance requirements plus requirements for TDN for the last 2 mo of gestation (MR + TDN) during hot and cool weather (Experiment 2).

	Hot		Cool			Effect		
	MR	MR + TDN	MR	MR + TDN	SE	Diet (D)	Weather (W)	D × W
							P	
no.	3	4	4	4				
Dams								
Age, mo	64.9	66.8	55.9	63.2	5.3	NS[1]	NS	NS
Gestation length, d	285	288	285	284	2	NS	NS	NS
BW,[2] kg	582	648	514	595	20	NS	NS	NS
DMI,[3] kg/d	6.1	8.6	6.0	8.8	0.1	***	NS	NS
Blood Hct,[4] %	31.6	29.3	26.7	29.0	0.1	NS	***	***
Blood Hb,[4] g/dl	10.8	9.8	9.1	10.1	0.1	NS	***	***
Plasma Fe,[4] ppm	1.70	1.74	1.47	2.14	0.04	***	NS	***
Colostrum[2]								
Yield, kg	1.8	2.0	1.6	1.7	0.2	NS	NS	NS
CP, %	18.1	16.1	16.0	16.6	0.6	NS	NS	NS
Fe, ppm	1.9	2.1	1.6	1.6	0.1	NS	NS	NS
Calves								
BW,[2] kg	51.5	51.9	43.8	44.7	1.6	NS	*	NS
Rectal temperature,[5] °C	39.2	39.4	38.5	38.3	0.1	NS	**	NS
Blood Hct,[5] %	36.8	38.8	37.4	39.8	0.4	*	NS	NS
Blood Hb,[5] g/dl	10.5	11.0	10.9	11.8	0.1	*	*	NS
Plasma Fe,[5] ppm	1.16	1.32	1.32	1.91	0.08	*	*	NS
Meconium[2]								
DM, %	37.2	30.0	35.5	34.9	1.2	NS	NS	NS
CP,[6] %	38.7	50.3	38.6	43.1	4.0	NS	NS	NS
Fe,[6] ppm	8.4	13.2	12.8	12.6	1.0	NS	NS	NS

[1]$P > 0.05$.

[2]At parturition.

[3]Means from 3 to 1 wk prepartum.

[4]Collected from 3 wk prepartum to 6 d postpartum.

[5]Collected at parturition and at 1 and 6 d of age.

[6]DM basis.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

0.001) than those of cows fed to meet maintenance requirements plus requirements for TDN for the last 2 mo of gestation during hot weather. The reverse relationships were observed during cool weather (Table 4). The restricted feed intake of cows and heifers significantly decreased blood Hct and Hb as well as plasma Fe of calves, and heat stress decreased blood Hb and plasma Fe of calves born from cows. However, heat stress increased blood Hct ($P < 0.01$) and Hb ($P < 0.01$) as well as plasma Fe ($P < 0.001$) of calves born from heifers, although blood Hct and Hb of heifers were not affected by heat stress (Table 5). Blood Hct ($P < 0.001$) and Hb ($P < 0.001$) and plasma Fe of calves decreased at d 6 of age. Colostral and meconium Fe were not significantly different because of weather or feed restriction.

Iron deficiency anemia of calves at birth adversely affects calf growth rate and health (9, 21). Anemia may also contribute to a high calf mortality at parturition, and normal development of erythropoiesis may be needed to prevent high mortality in anemic newborn calves (9, 12, 13, 14, 21). Kume and Tanabe (12) reported that calves born from heifers appeared to develop low Hct and Hb, but low placental transfer of Fe during gestation in calves born from heifers was not well characterized. In the present experiments, blood Hct and Hb in heifers were higher than those in mature cows, although, at d 1 of age, blood Hct and Hb of calves born from heifers were lower. Plasma Fe was lower in heifers than in mature cows, but concentrations were similar in calves born from heifers or mature cows. These results suggest that the erythropoiesis in heifers during gestation is active and that the shift in plasma or storage Fe to blood Hb is accelerated in heifers. Because low placental transfer of Fe during gestation in calves born from heifers may be due to the high Fe demand for growth, Fe supplementation for newborn calves born from heifers is needed to prevent low blood Hb in calves at birth.

Blood Hct and Hb of cows decreased during hot weather, and the depression in blood Hct and Hb was related to the reduction in cellular oxygen requirements to compensate for elevated environmental heat load (18). Restricted feed intake increased rectal temperatures as well as blood Hct and Hb of dams; the higher rectal temperatures of cows and heifers during hot weather may be partly due to the imbalance of erythropoiesis (22). Optimal dietary conditions for periparturient cows are also needed to maintain the normal erythropoiesis of newborn calves as well as periparturient cows because the restricted feed intake of dams reduced blood Hct and Hb of newborn calves. However, it is unclear whether heat stress adversely affected erythropoiesis of newborn calves in the present experiments. Further study is needed to clarify the Fe status of periparturient cows and heifers and their calves during hot weather.

Ca, P_i, Mg, Na, K, and Zn Metabolism in Hot Weather

In Experiment 1, plasma Ca ($P < 0.01$), P_i ($P < 0.001$), and alkaline phosphatase ($P < 0.001$) of heifers around parturition were higher than those of mature cows, but plasma Mg ($P < 0.01$) of heifers were lower (Table 6). Plasma Ca of heifers, plasma Mg ($P < 0.001$) of mature cows and heifers, and plasma alkaline phosphatase ($P < 0.001$) of mature cows around parturition in hot weather were significantly lower than those in cool weather; however, there were no significant differences in plasma P_i and Zn between the hot and cool groups. Plasma Ca, P_i, Mg, Zn, and alkaline phosphatase of calves at d 1 of age were not significantly different between the hot and cool groups or between parities. Colostral Ca ($P < 0.10$) and Mg ($P < 0.10$) tended to be lower in hot weather

TABLE 5. Least squares means of blood hematocrit (Hct), hemoglobin (Hb), and plasma Fe of heifers and their newborn calves during hot and cool weather (Experiment 2).

	Hot	Cool	SE	P
no.	8	7		
Heifers				
Age, mo	28.5	27.6	0.7	NS[1]
Gestation length, d	279	282	1	NS
BW,[2] kg	487	517	8	NS
Blood Hct,[3] %	32.9	33.3	0.1	NS
Blood Hb,[3] g/dl	11.1	11.2	0.1	NS
Plasma Fe,[3] ppm	1.20	1.11	0.03	NS
Colostrum[2]				
Yield, kg	1.4	1.4	0.2	NS
CP, %	13.4	16.3	0.8	NS
Fe, ppm	2.0	1.5	0.1	NS
Calves				
BW,[2] kg	39.5	38.7	1.0	NS
Rectal temperature,[4] °C	39.2	38.6	0.1	**
Blood Hct,[4] %	35.9	33.1	0.4	**
Blood Hb,[4] g/dl	10.5	9.6	0.1	**
Plasma Fe,[4] ppm	1.42	0.98	0.04	***
Meconium[2]				
DM, %	35.1	37.3	1.2	NS
CP, %	46.9	40.9	2.2	NS
Fe, ppm	9.6	10.4	0.7	NS

[1]$P > 0.05$.

[2]At parturition.

[3]Collected from 2 wk prepartum to 6 d postpartum.

[4]Collected at parturition and at 1 and 6 d of age.

**$P < 0.01$.

***$P < 0.001$.

than in cool weather. Colostral Ca ($P < 0.01$), P ($P < 0.001$), Mg ($P < 0.01$), and Zn of heifers were significantly higher than those of mature cows.

In Experiment 2, plasma Mg of calves as well as that of cows ($P < 0.001$) and heifers ($P < 0.001$) was lower in hot weather than in cool weather, and the restricted feed intake decreased plasma Mg of cows ($P < 0.001$) and their calves (Tables 7 and 8). Plasma Mg of calves significantly decreased at d 6 of age. Plasma Na ($P < 0.01$) of calves as well as cows ($P < 0.001$) and heifers ($P < 0.001$) was higher in hot weather than in cool weather. Heat stress increased plasma K of heifers ($P < 0.001$) and their calves ($P < 0.01$), but plasma K of calves born from cows were not affected by heat stress, although heat stress increased ($P < 0.001$) plasma K of cows. Heat stress increased plasma P_i of cows ($P < 0.01$) and heifers ($P < 0.001$), but plasma P_i of calves born from heifers was lower ($P < 0.01$) in hot weather. Restricted feed intake significantly increased plasma Ca of calves born from cows during hot weather, but restricted feed intake had no effect on plasma Ca of cows. Heat stress significantly decreased serum alkaline phosphatase of calves born from cows, but the plasma Zn of calves born from cows was not affected by heat stress or restricted feed intake.

Heat stress decreased P ($P < 0.01$) and Mg concentrations in the colostrum of cows, but Na concentration in colostrum was higher in hot weather (Table 7). Heat stress decreased Mg concentrations in the colostrum of heifers (Table 8). Heat stress significantly increased Ca concentration in the meconium of calves born from cows, and the restricted feed intake increased P concentrations in meconium. However, no significant differences on mineral concentrations in meconium of calves born from heifers were detected.

Calcium, P, Mg, and Zn are essential for bone formation in ruminants, and the mineral status of newborn calves depends not only on mineral intake from colostrum but also on mineral transfer from the placenta of the dam during gestation (12). Heat stress reduced the rate of blood flow to the uterus, mammary gland, and portal drained viscera (16). In the present experiments, heat stress decreased

TABLE 6. Least squares means of plasma mineral composition of heifers and mature cows that calved during hot and cool weather and those of their calves (Experiment 1).

	Heifer		Mature cow			Effect		
	Hot	Cool	Hot	Cool	SE	Parity (P)	Weather (W)	P × W
						P		
Dams, no.	11	10	8	7				
Plasma[1]								
Ca, mg/dl	10.0	10.4	9.7	10.0	0.1	***	**	NS[2]
P_i,[3] mg/dl	5.7	6.0	4.9	5.0	0.1	***	NS	NS
Mg, mg/dl	2.14	2.37	2.27	2.46	0.02	**	***	NS
Zn, ppm	0.68	0.76	0.76	0.76	0.01	NS	NS	NS
Alkaline phosphatase, IU	39.5	40.6	19.6	27.6	0.6	***	***	**
Colostrum composition[4]								
Ca, mg/dl	253	265	184	230	9	**	NS	NS
P, mg/dl	206	218	150	172	6	***	NS	NS
Mg, mg/dl	34.7	39.1	24.2	31.8	1.3	**	*	NS
Zn, ppm	27.2	25.4	19.4	17.6	1.6	*	NS	NS
Calves, no.	8	8	8	7				
Plasma[5]								
Ca, mg/dl	11.3	11.7	11.7	12.0	0.1	NS	NS	NS
P_i, mg/dl	7.4	9.0	8.5	8.5	0.2	NS	NS	NS
Mg, mg/dl	1.98	2.17	2.07	2.09	0.05	NS	NS	NS
Zn, ppm	1.07	1.01	1.21	0.98	0.08	NS	NS	NS
Alkaline phosphatase, IU	97	177	120	152	17	NS	NS	NS

[1]From 2 wk prepartum to 6 d postpartum.

[2]$P > 0.05$.

[3]Inorganic P.

[4]At parturition.

[5]At d 1 of age.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

plasma Mg of periparturient cows and their calves as well as colostral Mg, and restricted feed intake accelerated the reduction in plasma Mg of cows and their calves during hot weather. However, whether plasma Ca, P_i, and Zn of newborn calves were affected by heat stress and restricted feed intake was unclear, although heat stress tended to decrease colostral Ca and P. Thus, the improvement of malnutrition in periparturient cows and heifers is useful for the maintenance of Mg status in newborn calves during hot weather.

Horst et al. (10) reported that the intestine and bone of first lactation cows adapt rapidly to the Ca demands of lactation, but, for older cows, this adapta-

TABLE 7. Least squares means of plasma mineral composition of cows and heifers and their newborn calves. Cows and heifers were either fed to meet maintenance requirements (MR) or were fed to meet maintenance requirements plus requirements for TDN for the last 2 mo of gestation (MR + TDN) during hot and cool weather (Experiment 2).

	Hot		Cool			Effect		
	MR	MR + TDN	MR	MR + TDN	SE	Diet (D)	Weather (W)	D × W
							P	
no.	3	4	4	4				
Dams								
Plasma[1]								
Ca, mg/dl	9.8	9.6	9.7	9.6	0.1	NS[2]	NS	NS
P_i,[3] mg/dl	5.9	5.7	5.1	4.9	0.1	NS	**	NS
Mg, mg/dl	2.00	2.19	2.22	2.45	0.08	***	***	NS
Na, mg/dl	348	348	339	343	1	NS	***	NS
K, mg/dl	21.0	20.2	18.7	18.5	0.1	NS	***	NS
Zn, ppm	0.74	0.78	0.57	0.73	0.01	***	***	*
Serum[1]								
Alkaline phosphatase, IU	24.7	19.9	20.6	22.7	0.4	NS	NS	*
Colostrum[4]								
Ca, mg/100 g	191	168	210	256	12	NS	NS	NS
P, mg/100 g	171	151	203	228	8	NS	**	NS
Mg, mg/100 g	37.0	22.2	43.0	47.3	2.7	NS	*	NS
Na, mg/100 g	52.0	76.5	51.3	43.4	3.7	NS	*	NS
K, mg/100 g	135	145	163	173	7	NS	NS	NS
Zn, ppm	31.7	21.9	18.4	23.1	1.2	NS	*	*
Calves								
Plasma[5]								
Ca, mg/dl	12.0	11.0	11.7	11.6	0.1	**	NS	*
P_i, mg/dl	8.5	8.0	9.0	9.5	0.1	NS	**	NS
Mg, mg/dl	1.90	2.18	2.18	2.20	0.03	*	*	NS
Na, mg/dl	347	360	337	330	2	NS	**	NS
K, mg/dl	22.8	21.7	21.0	22.5	0.2	NS	NS	*
Zn, ppm	1.22	0.96	1.24	1.21	0.04	NS	NS	NS
Serum[5]								
Alkaline phosphatase, IU	86	133	229	165	17	NS	*	NS
Meconium[4,6]								
Ca, mg/100 g	258	262	356	382	22	NS	*	NS
P, mg/100 g	63	48	58	44	3	*	NS	NS
Mg, mg/100 g	2.4	4.6	3.5	4.2	0.5	NS	NS	NS
Na, mg/100 g	608	680	707	692	34	NS	NS	NS
K, mg/100 g	155	142	151	210	12	NS	NS	NS
Zn, ppm	166	124	184	175	11	NS	NS	NS

[1]Collected from 2 wk prepartum to 6 d postpartum.

[2]$P > 0.05$.

[3]Inorganic P.

[4]At parturition.

[5]Collected at parturition and at 1 and 6 d of age.

[6]DM basis.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

tion takes longer, and severe hypocalcemia usually occurs in their third or greater lactation cows. Tucker et al. (25) reported that calves born from heifers had higher plasma Ca than those born from mature cows, but plasma P was lower for calves born from heifers. Of the essential trace elements, Zn can effectively stimulate bone growth and mineralization, and alkaline phosphatase, an enzyme containing Zn, is present in large quantities in the growing bone (18). In the present experiments, low plasma Ca, P_i, and alkaline phosphatase as well as low colostral Ca, P, Mg, and Zn were observed in mature cows around parturition, although plasma Mg was higher. At parturition, heifers experienced a rapid increase in alkaline phosphatase, and plasma Ca and P_i in heifers were higher than those in mature cows. These results suggest that the increase in alkaline phosphatase at parturition in heifers may be partly due to the rapid adaptation of bone to meet Ca and P needs for lactation.

TABLE 8. Least squares means of plasma mineral composition of heifers and their newborn calves during hot and cool weather (Experiment 2).

	Hot	Cool	SE	*P*
no.	8	7		
Heifers				
Plasma[1]				
Ca, mg/dl	9.8	9.6	0.1	***
P_i,[2] mg/dl	5.6	4.9	0.1	***
Mg, mg/dl	1.95	2.20	0.02	***
Na, mg/dl	344	332	1	***
K, mg/dl	18.3	17.2	0.1	***
Zn, ppm	0.71	0.78	0.01	**
Serum[1]				
Alkaline phosphatase, IU	43.5	55.7	1.0	***
Colostrum[3]				
Ca, mg/100 g	193	228	12	NS[4]
P, mg/100 g	178	209	10	NS
Mg, mg/100 g	29.2	40.4	2.4	*
Na, mg/100 g	74.5	49.5	7.2	NS
K, mg/100 g	182	183	8	NS
Zn, ppm	20.5	22.4	0.7	NS
Calves				
Plasma[5]				
Ca, mg/dl	11.7	11.9	0.1	NS
P_i, mg/dl	8.9	9.4	0.2	NS
Mg, mg/dl	1.96	2.09	0.03	*
Na, mg/dl	358	328	2	***
K, mg/dl	21.4	19.9	0.2	**
Zn, ppm	1.05	1.17	0.04	NS
Serum[5]				
Alkaline phosphatase, IU	174	185	13	NS
Meconium[3,6]				
Ca, mg/100 g	261	264	20	NS
P, mg/100 g	48	53	4	NS
Mg, mg/100 g	4.4	3.3	0.4	NS
Na, mg/100 g	786	608	100	NS
K, mg/100 g	150	135	13	NS
Zn, ppm	153	168	11	NS

[1]Collected from 2 wk prepartum to 6 d postpartum.

[2]Inorganic P.

[3]At parturition.

[4]$P > 0.05$.

[5]Collected at parturition and at 1 and 6 d of age.

[6]DM basis.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

Heat-stressed dairy cows may exhibit increased Na and K requirements and decreased plasma Na and K because the loss of Na and K via the skin, saliva, or urine in dairy cows increases in a hot environment (2, 4, 6, 11, 15). Shalit et al. (19) have reported that Na and K balances of periparturient cows during summer decreased at the onset of lactation and that the lactation resulted in a significant reduction in plasma Na and K. However, heat stress increased plasma and colostral Na of periparturient cows as well as plasma Na of their calves and also increased plasma K of heifers and their calves. The reason for the increased plasma Na and K of periparturient cows and their calves during summer was unclear, but heat stress may alter the metabolism of Na and K in periparturient cows and their calves.

Plasma or serum mineral concentrations have been used as an indicator of the mineral status of ruminants (26). The storage of minerals in fetal tissue reflects fetal demands for growth and the ability of the dam to transfer minerals (1). Mineral excretion into meconium represents an endogenous loss in fetal mineral status at parturition. In the present experiments, Ca and P concentrations in the meconium were affected by heat stress or restricted feed intake. At d 6 of age, Mg and Fe concentrations in feces of calves increased drastically (unpublished data), although plasma Mg and Fe and blood Hb decreased as age postpartum increased. Thus, the mineral concentration in the meconium or feces may be an indicator of the mineral status of newborn calves, and the assessment of the relationship between mineral status and fecal mineral excretion by newborn calves is necessary.

CONCLUSIONS

The shift in plasma Fe to blood Hb is accelerated in heifers because of the high Fe demand of growth. Restricted feed intake of dams reduced blood Hct and Hb of newborn calves. Heat stress decreased plasma Mg of periparturient cows and heifers and their calves, and the restricted feed intake accelerated the reduction of plasma Mg of cows and heifers and their calves during hot weather. Low plasma Ca, P_i, and alkaline phosphatase, as well as low colostral Ca, P, Mg, and Zn, were observed in mature cows around parturition, although plasma Mg was higher. Thus, the maintenance of optimum erythropoiesis and mineral status in heat-stressed periparturient cows and heifers and their calves must be met by maintaining dietary requirements for energy and minerals at a level appropriate for the gestation period.

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