Effects of Higher Dietary Cation with or without Protected Fat and Niacin on the Milk Yield and Thermoregulatory Ability in Holsteins During Summer Heat Stress

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여름철 고온스트레스 기간에 고 양이온 사료와 반추위 보호지방과 나이아신의 추가공급시 착유우의 유생산 및 체온조절에 미치는 영향

김현섭 · 이왕식 · 이현준 · 기광석 · 백광수 · 안병석 · 아주말 칸

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요　　약

본 실험은 여름철 착유우의 체온조절 능력, 산유량 및 유성분에 미치는 양이온－음이온 균형 (dietary cation-anion difference : DCAD)과 반추위 보호지방이나 나이아신의 첨가 효과를 구명하기 위하여 수행하였다. 30두의 비유중기 홀스타인 착유우 (DIM 134 ± 12.4, 산유량 23.4 ± 2.3 kg/d)를 세개의 군으로 구분하여 배치하였다 (처리당 10두). 시험축은 후리스톨 우사에서 사육되었고, 우사에는 41 cm 직경의 송풍팬이 부착되어 풍속 4 m/s로 송풍되도록 하였다. 시험축은 7월부터 8월까지 2개월동안 3가지의 시험사료를 섭취할 수 있도록 하였으며, 시험사료는 양이온－음이온 균형이 ＋15와 ＋30인 사료에 보호지방 첨가, 나머지 사료는 반추위 보호지방이나 보호지방과 나이아신을 보충하였다. 시험기간 중 7월에는 최대 온도가 28.5℃로 시험축이 약간의 고온스트레스를 받는 정도로 유지되었으나, 시험이 진행되어 8월에는 특징적인 심한 고온스트레스를 보였고, 최대온도가 32.4℃에 도달하였으며, THI는 74.0이었다. 건물, 조단백질, 가소화양분총량 섭취량은 양이온－음이온 균형 수준과 반추위 보호 지방이나 나이아신에 의하여 영향을 받지 않았으나, 산유량은 반추위 보호지방과 나이아신을 첨가한 사료를 섭취한 착유우에서 무첨가구에 비하여 높았다($P<0.05$). 반추위 보호지방이나 반추위 보호지방과 나이아신을 동시에 첨가한 처리간에는 산유량의 차이는 없었다. 그리고 유지방과 직장온도도 양이온－음이온 균형 수준과 반추위 보호지방이나 나이아신 첨가에 의한 차이는 나타나지 않았다. 그러나 호흡률은 반추위 보호지방이나 반추위 보호지방과 나이아신을 동시에 첨가한 처리에서 낮게 나타났다 ($P<0.05$). 본 연구의 결과는 높은 수준의 양이온－음이온 균형 (＋30)과 반추위 보호지방과 나이아신을 첨가하는 경우에 여름철인 7월과 8월 고온기에 홀스타인 착유우의 고온스트레스를 줄이고, 호흡율을 감소시키며, 산유량을 증가시킬 수 있음을 나타내었다.

(**Key words** : 양이온－음이온 균형(DCAD), 고온스트레스, THI, 산유량, 유지방, 젖소)

Ⅰ. INTRODUCTION

Heat stress is one of the major factors that decrease milk production and fertility of dairy animals during summer. Thermal environment and the metabolic heat production are two sources of heat which can negatively affect milk production of dairy cows (Linn, 1997). For normal behavior,

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physiological metabolism and milk yield, it is essential that the body temperature of cows should be maintained within narrow limits. At moderate environmental temperature (5.5－25℃), physiological demands for cooling or warming the body temperature are minimal and an optimal performance usually occurs (Thatcher *et al*, 1974). However, when environmental temperature exceeds the range mentioned above, thermoregulatory activities increased and feed intake is reduced, leading to a reduction in milk yield (Schneider *et al*, 1984).

Dairy cows tend to reduce their feed intake by 8－12% or more under heat stress (Roman-Ponce, 1977). As dairy cows reduce their feed intake under heat stress, more nutrients needed to be condensed into a smaller volume of feed to maintain the nutrient supply for normal milk yield. Optional methods to increase nutrient density in a diet include feeding high quality forage, feeding more grain, and supplementing fats (Leighton and Rupel, 1960; Knapp and Gramner, 1991; Chan *et al*., 1993; Huber *et al*., 1993). Minerals, especially Na and K, easily depleted in cows under a high environmental temperature (Jenkinson and Mabon, 1973). Higher rate of respiration and perspiration can cause an excessive loss of water, thereby reducing mineral levels in the body. Increasing the K and Na contents in the ration to compensate for both increased losses and decreased intake may improve the performance of heat stressed cows (Jenkinson and Mabon, 1973).

Fat is a cold nutrient because its hydrolysis yields less heat in the animal body thus its feeding can mitigate some of the negative effects of high environmental temperature on animal productivity. However, a depression in milk protein content often occurs when fat is supplemented in the diet of dairy cows (Horner *et al*., 1986). Some studies have reported a reduction in the depression of milk protein percentage when supplemental niacin was fed (Cervantes *et al*., 1996). However, the response to niacin might have been independent of the response to supplemental fat, because similar increases in milk protein content occurred in cows fed niacin without supplemental fat. Several studies have indicated increased milk production when either supplemental fat (Horner *et al*., 1986 and Kim *et al*., 1993) or niacin (Cervantes *et al*., 1996) fed to lactating Holsteins.

Thus, the present study was conducted to evaluate the effect of dietary cation-anion difference (DCAD) with or without supplemental fat and niacin as a mean of improving thermoregulatory response and milk yield of Holsteins during summer.

Ⅱ. MATERIALS & METHODS

1. Animals and treatments

This study was carried out at National Livestock Research Institute, Seonghwan, Korea. Thirty mid-lactating Holstein cows (134 ± 12.4 DIM and 23.4 ± 2.3 kg/d of milk yield) were divided into three groups (10 animals/group). Cows were housed in a free-stall barn and were provided with forced-air ventilation (wind velocity = 4 m/s) using 41 cm diameter fans. Cows were assigned to one of three treatment diets for the period of 2 months from July to August. All the diets were iso-nitrogenous and were formulated according to the recommendations of NRC (2001). Diet one was formulated to contain low DCAD (+15 DCAD) while the remaining two diets were higher in DCAD (+30 DCAD). One higher DCAD diet was formulated to contain by-pass fat and the second higher DCAD diet contained the niacin along with by-pass fat (Table 1). Cows were fed TMR *ad libitum* twice a day (09 : 30 and 15 : 00). Feed offered was adjusted daily to ensure approximately 5% orts.

Table 1. Ingredient and nutrient composition of experimental diet

Item	Low DCAD	High DCAD[1]	High DCAD[2]
○ Ingredient(kg, FM)			
－Corn silage	7	7	7
－Tall fescue straw	8	7	7
－Whole cottonseed	1	1	1
· Concentrate	8.5	8.0	7.9
· Whole soybean	－	0.57	0.57
· Protected fat	－	0.23	0.23
· $NaHCO_3$	－	0.12	0.12
· $KHCO_3$	－	0.11	0.11
· MgO	－	0.04	0.04
· Niacin	－	－	0.01
○ Nutrient composition (%)			
－CP	13.6	14.5	14.5
－TDN	67.4	72.1	72.1
－Ca	0.52	0.52	0.52
－P	0.33	0.33	0.33
－Na	0.19	0.38	0.38
－K	1.45	1.72	1.72
－Mg	0.25	0.27	0.27
－Cl	0.48	0.48	0.48
－S	0.27	0.27	0.27
○ Cation-anion balance (meg/100g)	+15	+30	+30

[1] Diet was formulated to contain by-pass fat.

[2] Diet contained the niacin along with by-pass fat.

2. Sampling and analyses

Orts were measured before feeding once a day. Feed and orts were sampled for chemical composition analysis by the procedures of AOAC (1995). The DCAD was calculated using the percentage of mineral in the diet DM, adjusted for atomic weight and charge. To calculate the DCAD as mEq/100g DM, the following equation was used:

$$DCAD = [(\%Na/0.023) + (\%K/0.039)] - [(\%Cl/0.0355) + (\%\ S/0.016)]$$

Rectal temperatures were recorded using a thermometer. Respiratory rates were recorded by visual observation and were expressed as the number of breaths per minute. Rectal temperature and respiratory rate were measured daily at 15:00. Maximum and minimum air temperature and relative humidity were recorded using a thermometer and a Relative Humidity probe (Hobber Co., USA), located 1 m high from the floor in the central part of the free stall. Temperature humidity index (THI) was calculated according to the method of West (1999) using following equation.

$$THI = td - (0.55 - 0.55\ RH) \times (td - 58)$$

Where td = dry bulb temperature (°F, where °F = (°F + 9/5) + 32), and RH = relative humidity expressed as a decimal.

Milk yield were recorded at each milking (05 : 30 and 17 : 00). Monthly milk samples were analyzed for fat (Lactoscope FTIR - 200, Delta instrument, Denmark). Both 4% FCM was calculated using the following equations.

$$4\ \%\ FCM = (0.4 \times MP) + (15 \times FY)$$

where, MP = milk production and FY = fat yield

3. Statistical analysis

Data on various parameters were analyzed using the general linear models procedure of SAS (1999). In case of any significance means were compared by Duncan's Multiple Range Test (Steel and Torrie, 1980).

Ⅲ. RESULTS

The average ambient temperature and relative humidity during the experimental period are shown in Table 2. Distribution of temperaturehumidity index (THI) by days during the experimental

Table 2. Environmental temperature, humidity and temperature-humidity index (THI) during the experimental period

Period	Air temperature			Humidity	THI		
	Max	Min	Mean		Max	Min	Mean
July	30.3	22.1	25.7	73.4	82.3	69.7	75.3
August	30.9	22,.4	26.1	74.0	83.4	70.2	76.0

Table 3. Distribution of temperature-humidity index (THI) by days in the Seunghwan region

Period	THI					
	Max. temp.(℃)			Mean temp.(℃)		
	less than 72	73−78	79−90	less than 72	73−78	79−90
	……… days ………					
July	—	1	30	—	14	17
August	—	5	26	5	16	10

Table 4. Average nutrients intake by Holsteins fed different experimental diets

Item	Low DCAD	High DCAD[1)]	High DCAD[2)]
○ Nutrient intake			
— DM (kg/d)	17.03 ± 1.2	17.78 ± 2.3	17.79 ± 1.9
— CP (kg/d)	2.32 ± 0.8	2.47 ± 0.6	2.47 ± 0.4
— TDN (kg/d)	11.96 ± 1.3	12.6 ± 1.8	12.6 ± 1.7
— Ca (g/d)	88.0 ± 12.1	88.8 ± 10.2	88.8 ± 9.85
— P (g/d)	56.43 ± 7.7	56.73 ± 6.8	56.73 ± 7.2
— Na (%)	0.19 ± 0.1	0.38 ± 0.2	0.38 ± 0.4
— K (%)	1.42 ± 0.23	1.62 ± 0.16	1.62 ± 0.14
— Mg (%)	0.19 ± 0.03	0.27 ± 0.02	0.27 ± 0.05
— Cl (%)	0.48 ± 0.04	0.48 ± 0.06	0.48 ± 0.05
— S (%)	0.27 ± 0.07	0.27 ± 0.06	0.27 ± 0.04
○ Cation-anion balance (meg/100g)	+14.2 ± 2.4	+27.5 ± 3.6	+27.5 ± 4.2
○ Niacin (g/kg)	—	—	0.35 ± 0.01

[1)] Diet was formulated to contain by-pass fat.
[2)] Diet contained the niacin along with by-pass fat.

period is given in Table 3. The maximum ambient temperature during July was 28.5 ℃ which could be seen as a the period of mild heat stress. As summer progressed, August was characterized as a severe heat stress condition with maximum ambient temperature (32.4℃) and THI (74.0). Dry matter, crude protein, and total digestible nutrients intake was not affected by the DCAD level and supplementation of ruminally protected fat or niacin (Table 4).

Table 5. Milk yield and its composition by Holstein cows fed different experimental diets

Item	Low DCAD	High DCAD[1]	High DCAD[2]
○ Milk yield (kg)			
– Inital (A)	20.4 ± 1.2	18.6 ± 1.6	19.7 ± 1.4
– Final (B)	18.4 ± 0.9	18.4 ± 0.6	20.5 ± 0.8
– Difference (B-A)	−2.0 ± 0.7^{a}	−0.2 ± 0.68^{ab}	+ 0.8 ± 0.54^{b}
○ Fat (%)			
– Initial (A)	3.7 ± 0.2	3.7 ±0.2	3.7 ± 0.3
– Final (B)	3.7 ± 0.3	3.9 ± 0.3	3.9 ± 0.2
– Difference (B−A)	–	+ 0.2	+ 0.2
○ 4% FCM			
– Initial (A)	19.5 ± 1.3	17.8 ± 1.5	18.8 ± 1.1
– Final (B)	17.6 ± 0.7	18.1 ± 0.4	20.2 ± 1.2
– Difference (B−A)	−1.9 ± 0.8^{a}	+ 0.3 ± 0.64^{ab}	+ 1.4 ± 0.56^{b}

[a,b] Means within the same row with different superscripts are significantly different ($P<0.05$).
[1] Diet was formulated to contain by-pass fat.
[2] Diet contained the niacin along with by-pass fat.

Table 6. Rectal temperature and respiration rate of cows fed different experimental diets

Item	Low DCAD	High DCAD[1]	High DCAD[2]
Rectal temperature (°C)	38.9 ± 1.2	38.6 ± 1.6	38.3 ± 2.1
Respiration rate (breaths/minute)	87 ± 1.4^{a}	76 ± 1.6^{b}	74 ± 1.3^{b}

[a,b] Means within the same row with different superscripts are significantly different ($P<0.05$).
[1] Diet was formulated to contain by-pass fat.
[2] Diet contained the niacin along with by-pass fat.

Milk production was higher in cows fed diets supplemented with fat and niacin than that fed un-supplemented diet (Table 5). No difference in milk yield was observed in cows fed diets supplemented with fat or niacin plus fat. Similar trend was noticed for 4% FCM yield. Milk fat was not affected by the DCAD level and supplementation of ruminally protected fat or niacin (Table 5). Body condition scores (BCS) of cows were also not influenced by the DCAD level and supplementation of fat and niacin. The DACD level and supplementation of both niacin and fat did not affect the rectal temperature of the cows. However, respiration rates were decreased in cows fed diets supplemented with either fat or fat and niacin compared to those fed un supplemented diets (Table 6).

Ⅳ. DISCUSSION

In agreement with present results Johnson *et al.* (1963) reported previously that THI greater than 72 can decrease milk yield of lactating Holstein cows. This phenomenon was observed specifically during august in the present study when THI was increased well above to 72. Much of the effect of high environmental temperature on milk yield occurred because of reduced DM intake. The NRC (1981) predicted that DM intake for a 600 kg cow producing 27 kg/d of milk could decline from 18.2 kg/d at 20℃ to 16.7 kg/d at 35℃, and metabolic energy (ME) requirement for maintenance can increase by 20%. At 40℃, the ME requirement for maintenance increases by 32% and DMI falls to about 56% of that in cows at thermo-neutral conditions. The effect of a high environmental temperature on the performance of the cows apparently mediated through their body temperature. Each 0.56℃ increase in body temperature above 38.6℃ could decrease 1.8 kg/d of milk yield and 1.4 kg/d of TDN intake (Johnson *et al*., 1963). Fat supplementation during hot weather does not consistently affect DMI (Skaar *et al*., 1989) but can improve milk production. Diets with supplemental fat during hot weather improved 4% FCM yield (Knapp and Grummer, 1991). Increase of the energy density can possibly reduce the intake because less volume of feed can satisfy the energy needs of the animal. Lack of difference in DM intake by Holsteins fed diets supplemented with fat and niacin and those fed un-supplemented diets in the present study is attributable to variation in energy density and protein to energy ratio of the diets.

Higher milk yield in cows fed diets supplemented with fat and niacin compared with those fed un-supplemented diets may be due to higher energy intake and cooling effect of fat. Higher energy intake due to added dietary fat can spare more energy for milk synthesis. Further, lipolysis of fat in the body of animal generally yields less heat of nutrient metabolism and more metabolic water. Thus the higher milk yield with supplementation of fat could be attributed to the lower heat increment of fat and higher energy intake by the cows. Further, niacin supplementation in the diets of high yielding dairy cows can cause a reduction of blood plasma NEFA and ketone concentrations, increase in microbial protein synthesis and protozoal numbers in the rumen thus resulted in higher milk and protein yield (Erickson *et al*., 1990). Previously other workers (Hassan and Roussel, 1975; Danfaer *et al*., 1980; Jones, 1999) reported similar results when they supplemented animal, vegetable or ruminally protected fat and niacin in dairy diets.

Low respiration rate in lactating Holsteins fed higher DCAD diet supplemented with fat and niacin can be attributed to the low cooling effects of fat through higher yield of metabolic water and less heat increment (Schneider *et al*., 1986; West *et al*., 1987; Jones, 1999).

Nicotinic acid has vasodilatory function that might have helped the heat stress cows in the present study to dissipate heat from core to skin sites and generate a temperature gradient favoring heat loss from skin to environment. Previous works (Muller *et al*, 1986; De Costanzo *et al*, 1997) conducted during hot weather conditions showed similar results when cows were fed diets supplemented with 6 g/d of nicotinic acid. Thus cooling effect of supplemented fat along with vasodilatory functions of niacin has probably resulted in reduced respiration rate and increased milk yield in lactating cows in the present study.

Ⅴ. CONCLUSIONS

The results of the present study indicated that higher DCAD (+30) and supplementation of fat along with niacin can somehow mitigate the negative effects of heat stress on milk yield and physiology of lactating Holsteins during July and August in Korea. In the present study reduced respiration rate and increased milk yield in lactating cows may be attributed to the cooling effect of supplemented fat along with vasodilatory functions of niacin.

Ⅵ. ABSTRACT

The objective of this study was to evaluate the effects of dietary cation-anion difference (DCAD) with or without ruminally protected fat and niacin on the thermoregulatory ability, milk yield and milk composition of lactating dairy cows during summer in Korea. Thirty mid-lactating Holstein cows (134 ± 12.4 DIM and 23.4 ± 2.3 kg/d of milk yield) were divided into three groups (10 animals/group). Cows were housed in a free-stall barn and were provided with forced-air ventilation (wind velocity = 4 m/s) using 41 cm diameter fans. Diet one was formulated to contain low DCAD (+15 DCAD) while the remaining two diets were higher in DCAD (+30 DCAD). One higher DCAD diet was formulated to contain by-pass fat and the second higher DCAD diet contained the niacin along with by-pass fat. The maximum ambient temperature during July was 28.5℃ which could be seen as a period of mild heat stress. As summer progressed, August was characterized as a severe heat stress condition with maximum ambient temperature (32.4℃) and THI (74.0). Dry matter, crude protein and total digestible nutrients intake was not affected by the DCAD level and supplementation of ruminally protected fat or niacin. Milk production was higher in cows fed diets supplemented with fat and niacin than those fed un-supplemented diet. No difference in milk yield was observed in cows fed diets supplemented with fat or niacin plus fat. Milk fat and rectal temperature were not affected by the DCAD level and supplementation of ruminally protected fat or niacin. However, respiration rate was decreased in cows fed diets supplemented with either fat or fat and niacin compared to those fed. The results of the present study indicated that higher DCAD (+30) and supplementation of fat along with niacin can somehow mitigate the negative effects of heat stress on milk yield and physiology of lactating Holsteins during July and August in Korea. In present study reduced respiration rate and increased milk yield in lactating cows may be attributed to the cooling effect of supplemented fat along with vasodilatory functions of niacin.

(Key Words : DCAD, Heat stress, THI, milk yield, Milk fat, Holstein)

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(접수일자 : 2006. 6. 26. / 채택일자 : 2006. 8. 18.)