Asian-Aust. J. Anim. Sci.
Vol. 23, No. 12 : 1594 - 1600
December 2010

www.ajas.info

Effects of Dietary Addition of Bentonite on Manure Gas Emission, Health, Production, and Meat Characteristics of Hanwoo (*Bos taurus coreanae*) Steers

Sangmoo Lee[1], Youngil Kim and Wansup Kwak*
Department of Animal Science, College of Natural Sciences, Konkuk University,
Chung-Ju, Chung-Buk, 380-701, Korea

ABSTRACT : A study was conducted to determine the dietary effects of a clay mineral (sodium bentonite, NaB) on manure gas emission, health, production, and meat characteristics of Hanwoo steers. Two diets fed to steers included a control diet (concentrate mix and rice straw) and a treatment diet (control diet+1.0% clay mineral/concentrate mix). Dietary NaB addition considerably reduced concentrations of gases (H_2S, SO_2 and NH_3) in the manure of Hanwoo steers. Growing steers fed NaB had similar blood profiles with the exception of lower ($p<0.05$) concentrations of blood alkaline phosphatase and lactate dehydrogenase. Dietary NaB addition tended to increase ($p = 0.10$) live weight by 30 kg at slaughtering and did not affect carcass yield and quality traits. Dietary NaB addition increased concentrations of P ($p<0.01$), Mg ($p<0.01$), Na ($p<0.01$), Zn ($p<0.005$), K ($p = 0.08$), Fe ($p = 0.08$) and Cu ($p = 0.07$) in the *longissimus* muscle compared to the control but did not affect ($p>0.05$) fatty acid composition. The study demonstrated that the dietary addition of a clay mineral could be effective in improving mineral bioavailability to Hanwoo steers, which could be one of the reasons for their improved performance. (**Key Words :** Clay Mineral, Bentonite, Production, Meat Quality, Hanwoo)

INTRODUCTION

Annually more than 12,000 tons of clay mineral is used as an animal feed supplement in Korea. Clay mineral such as sodium bentonite (NaB) is an expanded lattice clay of the montmorillonite group of minerals (Bates and Jackson, 1980) with a high ion exchange capacity that binds a wide range of cations (Fenn and Leng, 1989). Because acid buffering capacity has been correlated with total cations and total ash (Jasaitis et al., 1987), mineral buffers such as clay minerals might be effective in alleviating acid stress in ruminants under intensive feeding and management programs. Incorporated into diets, bentonite has improved wool growth of sheep (Fenn and Leng, 1989), decreased ruminal ammonia concentrations, improved feed and bacterial protein flow to the small intestine of ruminants, and had little effect on mineral metabolism in bone, liver and kidney (Ivan et al., 1992). It has been reported that feeding clay minerals had positive effects on productivity and meat quality of swine (Kim et al., 2000) and beef cattle (Cho et al., 2001; Kang et al., 2002). Among clay minerals, its effect was highest in the order of Na-bentonite, illite and kaolinite (Kang et al., 2002). However, research is lacking on the effect of dietary NaB addition on manure gas emission and meat characteristics, especially meat chemical profiles of Hanwoo steers. We hypothesized that NaB addition may affect the gas emission and meat quality of Hanwoo steers.

Based on previous reports of the positive effects of clay minerals incorporated into diets of ruminants, a study was conducted to determine the effects of NaB on gas emissions, animal performance, meat quality and meat chemicals of Hanwoo steers.

MATERIALS AND METHODS

Animals and treatments

All animal care protocols were approved by the Konkuk University Institutional Animal Care and Use Committee. Thirty six Hanwoo (*Bos taurus coreanae*) steers at 9 months

* Corresponding Author: Wansup Kwak. Tel: +82-43-8403521, Fax: +82-43-8518675, E-mail: wsk@kku.ac.kr
[1] Department of Animal Science, Sangju Campus, Kyungpook National University, Sangju, Kyungbuk, 742-711, Republic of Korea.
Received January 5, 2010; Accepted May 11, 2010

of age (avg BW 232 kg) were allotted in groups of 4 steers to each of 9 pens. Six of the pens were located at Farm 1, and three of the pens at Farm 2 in Boeun County, Chungbuk Province, Korea. Steers were fed one of two rations: a control diet (concentrate mix and rice straw), and a modification of the control diet (treatment NaB) which consisted of the control diet+1.0% clay mineral/concentrate mix. Periods for growing, fattening and finishing were 6, 8, and 8 months, respectively. Diets were fed for 22 months until the animals were slaughtered.

The concentrate mix was fed in a restricted manner to achieve 0.8% levels of ADG during the growing period, and over 0.9 kg ADG during the fattening period. Animals had free access to rice straw at all times. The clay mineral was top-dressed at each feeding time. Feed was supplied twice daily at 07:00 h and 18:00 h. During the finishing period, the concentrate mix was fed *ad libitum* and rice straw was restricted at a level of approximately 10% of concentrate mix. The chemical composition of the corn-based concentrate mix according to the feeding periods and of the rice straw fed to the steers is presented in Table 2. Rice straw was fed in the form of large bales (400 to 500 kg). The clay mineral (sodium bentonite) used in the study was an extra-purified powder for animal use, which contained 75 to 85% Montmorillonite and was composed of 58% SiO_2, 20% Al_2O_3, 6% Fe_2O_3, 3.5% MgO, 2.5% CaO, 2% Na_2O, and 1% K_2O. Based on mineral elements, it contained 1.41% Ca, 0.04% P, 0.10% Mg, 1.78% K, 0.66% Na, 1,631 ppm Fe, 7.9 ppm Zn, 5.0 ppm Cu, and 212 ppm Mn. The pH was about 10, swelling volume was 9 ml/g, cation exchange capacity was 80 meq/100 g, and the specific surface area was 400 to 600 m^2/g.

Animals were observed for health status, and body weight was measured on a monthly basis throughout the study. Samples of concentrate mix and rice straw were collected every 2 wk for proximate analysis.

Table 1. Diets for growing, fattening and finishing periods for Hanwoo steers[1]

Item	Control	NaB
Growing period		
Concentrate mix (% live wt)	1.44	1.44
Rice straw	FA[3]	FA
Na-Bentonite[2] (% conc. mix)	0.0	1.0
Fattening period		
Concentrate mix (% live wt)	1.50	1.50
Rice straw	FA	FA
Na-Bentonite[2] (% conc. mix)	0.0	1.0
Finishing period		
Concentrate mix	FA	FA
Rice straw	10	10
Na-Bentonite[2] (% conc. mix)	0.0	1.0

[1] Dry matter basis.
[2] Na-bentonite (NaB) was top-dressed on concentrate (conc.) mix at each feeding time.
[3] FA means ‘free access’ to rice straw or concentrate mix all the time.

Sampling and chemical analysis

Feed samples taken from troughs prior to feeding were dried and ground to pass through a 1 mm screen using a Sample Mill (Cemotec, Tecator, Sweden). Dry matter was determined by drying samples at 105°C for 24 h to constant weight. Crude protein, EE, NDF, ADF, and ash were determined by the AOAC (2000) methods.

During the growing period of steers, health diagnosis was made and blood samples were taken from the jugular vein and an equal portion divided into bottles with or without anti-coagulant EDTA. Serum profiles including

Table 2. Chemical composition of concentrates mix and rice straw[1,2,3]

Item	Concentrates mix			Rice straw
	Growing	Fattening	Finishing	
	%			
Dry matter	88.0	88.0	85.8	86.8
Organic matter	92.3	91.5	93.2	89.8
Ether extract	3.6	3.1	3.0	0.7
Crude protein	15.7	14.1	14.0	3.7
Neutral detergent fiber	29.8	27.2	25.8	75.7
Acid detergent fiber	13.9	19.6	15.3	46.9
Crude ash	7.7	8.5	6.8	10.2
Minimum target TDN	80.7	80.7	81.8	-

[1] Dry matter basis. [2] Means of 3 observations.
[3] Ingredient composition (as-fed basis) of concentrates mix was as follows: corn grain 22.5%, wheat 18.0%, molasses 5.5%, wheat bran 21.0%, corn gluten meal 4.5%, rapeseed meal 7.0%, coconut meal 7.0%, palm meal 11.0%, NaCl 0.6%, limestone 2.0%, vitamin premix 0.1%, mineral premix 0.1% and other additives 0.7% for the growing period; corn grain 22.0%, wheat 18.0%, molasses 5.5%, tapioca 8.0%, wheat flour 3.0%, wheat bran 12.7%, rapeseed meal 4.4%, coconut meal 7.0%, palm meal 11.0%, mixed hays 5.0%, NaCl 0.6%, limestone 2.0%, vitamin premix 0.1%, mineral premix 0.1% and other additives 0.6% for the fattening period; corn grain 29.7%, wheat 18.0%, molasses 6.0%, tapioca 8.0%, wheat bran 4.0%, corn gluten meal 10.35%, distiller’s rice 1.0%, coconut meal 5.05%, palm meal 11.0%, mixed hays 4.0%, NaCl 0.6%, limestone 1.475%, vitamin premix 0.1%, mineral premix 0.1% and other additives 0.655% for the finishing period.

enzymes were analyzed using an Automatic Biochemical Analyzer (Hitachi 7170A, Hitachi Ltd., Tokyo, Japan) based on photometric and ion selective electrode methods, and whole blood profiles were analyzed with an Automatic Blood Analyzer (Coulter STKS, Beckman Coulter Co., Miami, FL, USA) based on impedence and VCS (volume, conductivity, light scattering) methods.

Gas emission from manure was measured during the fattening period of steers. Triplicate manure samples were taken randomly from each of the floors at Farm 1 where the steers were bedded on sawdust and at Farm 2 where no bedding was used. Samples were stored at -20°C. For analysis of gases, samples were placed in Tedlar Pyvinylfluoride bags, thawed at room temperature for 3 d, and analyzed for SO_2, NH_3 and H_2S with gas measurement kits (Gastec, Japan).

Steers were withdrawn from the experimental diets 24h before slaughter. Following a 48-h carcass chill, yield and quality grades were assigned to each carcass using Korean carcass grading standards specified in the attached list No. 4 of Korean Livestock Enforcement Regulation (KMAF, 2007). The 12^{th} to 13^{th} rib *longissimus* muscle was removed from each steer and frozen until later analysis.

For mineral analysis of the rib muscle, samples were analyzed for Ca, P, Mg, K, Na, Mn, Fe, Zn and Cu by inductively coupled argon plasma emission spectroscopy (ICP-OES 5300DV, Perkin Elmer, USA) as described by Braselton et al. (1997). For fatty acid analysis of the rib muscle, frozen samples were sent to a certificated, commercial laboratory (Scientific Lab Center Co, LTD). Fat was extracted according to the method of Folch et al. (1957). Fatty acids were methylated by the method of Morrison and Smith (1964) and analyzed using gas chromatography (6890N, Agilent, USA).

Statistical analysis

Data were analyzed using farms as a block in a randomized complete block design by the General Linear Model (SAS Institute, Inc., 1990). Gas emission data for each farm were analyzed by one-way analysis of variance. Comparison of means between control and NaB treatment was made using studentized-*t* test (SAS Institute, Inc., 1990). Significant differences were detected at p<0.05.

RESULTS AND DISCUSSION

Blood profiles of the growing steers

The blood profiles of the Hanwoo steers were analyzed

Table 3. Blood profiles of Hanwoo steers fed different diets[1]

Item	Control	NaB	SE
Triglyceride (mg/dl)	29.8	27.6	3.3
Cholesterol (mg/dl)	154.7	146.9	12.0
High density lipoprotein (mg/dl)	121.3	118	8.4
Low density lipoprotein (mg/dl)	29.9	26.3	4.5
Glucose (mg/dl)	69.8	67.5	2.9
Total protein (g/dl)	6.58	6.24	0.19
Electrolytes			
Calcium (Ca^+) (mg/dl)	9.43	9.38	0.23
Inorganic phosphorus (P^-) (mg/dl)	8.16	8.66	0.28
Potassium (K^+) (mmol/L)	5.40	5.24	0.16
Sodium (Na^+) (mmol/L)	145.8	144.4	0.8
Chlorine (Cl^-) (mmol/L)	103.7	102.5	0.9
Albumin (g/dl)	3.01	2.9	0.05
Globulin (g/dl)	3.58	3.34	0.17
Albumin/globulin	0.87	0.86	0.05
Uric acid (mg/dl)	1.22	1.15	0.06
Total bilirubin (mg/dl)	0.10	0.10	0.01
Alkaline phosphatase (IU/L)	539[a]	379[b]	62
Alanine aminotransferase (IU/L)	25.3	22.6	1.8
Aspartate aminotransferase (IU/L)	85.1	76.4	4.4
r-glutamyltransferase (IU/L)	21.9	20.6	2.3
Lactate dehydrogenase (IU/L)	1,285[a]	1,191[b]	34
Amylase (IU/L)	27.6	26.5	2.2
Urea-N (mg/dl)	10.7	11.2	0.8
Creatinine (mg/dl)	1.26	1.33	0.06
White blood cell counts (10^3/μl)	25.0	23.6	5.5
Red blood cell counts (10^6/μl)	7.27	7.10	0.29
Platelet counts (10^3/μl)	241	271	53

[a] Control differs from NaB treatment (p<0.05). [1] Means of 12 observations.

during the growing period and presented in Table 3. For blood nutrients, the dietary treatment showed no differences in blood concentrations of triglyceride, cholesterol, high density lipoprotein, low density lipoprotein, glucose and total protein. These results indicated that fat, energy and protein metabolism was not affected by NaB addition to a growing steer diet.

The blood electrolytes Ca, P, K, Na and Cl were not affected by dietary NaB treatment. Blood enzyme analyses showed little effect of the NaB treatment on liver and kidney; however, blood concentrations of alkaline phosphatase and lactate dehydrogenase, which are used as markers of tissue damage, were favorably decreased ($p<0.05$) by dietary NaB addition. However, the consistency of this phenomenon needs to be further investigated. Blood cell counts were not affected by the treatment. Generally, values for all blood constituents were within the normal range for healthy cattle (Wallach, 1974; Church and Pond, 1982). In a similar study, Cho et al. (2001) reported that feeding clay minerals to growing Hanwoo steers did not affect their red and white blood cell counts. Pulsipher et al. (1994) reported that feeding 42 g/d bentonite to lambs did not affect their blood nutrients, electrolytes, and enzymes. In another study, Ha et al. (1985) reported that feeding 2% bentonite to lambs did not affect concentrations of blood Ca, P, K, and Na. Generally the dietary addition of NaB had little effect on blood profiles of steers. None of the steers showed abnormal health problems throughout the experimental periods.

Gas emission from manure of fattening steers

Concentrations of gases emitted from manure on the floor were analyzed during the fattening period and the data are presented in Table 4. For Farm 1 floors bedded with sawdust, the dietary addition of NaB reduced ($p<0.05$) concentrations of H_2S by 100% and NH_3 by 24% compared to the control. For Farm 2 unbedded floors, dietary NaB addition reduced SO_2 concentrations ($p = 0.06$) by 31% and NH_3 concentrations ($p = 0.08$) by 56%. When data for Farm 1 and 2 were pooled, addition of dietary NaB reduced concentrations of H_2S by 100%, SO_2 by 27%, and NH_3 by 52%. The removal rate of gases was highest in the order of H_2S, NH_3 and SO_2. This phenomenon may be attributed to the swelling (Bates and Jackson, 1980), adsorbing (Harvey et al., 1991) and ion exchanging capacity (Fenn and Leng, 1989) of NaB resulting in binding these gaseous chemicals and reducing their release into the surrounding environment.

Based on appearance the floors of NaB-fed steers looked drier and this was more obvious for unbedded floors which had higher DM levels. These results suggest that dietary NaB addition with ventilation fans on the ceiling can help keep the floor dry even though bedding material is not used. Where bedding costs are high, this might be an economic benefit.

Body weight change of steers during the whole feeding periods

Body weight data for the Hanwoo steers were recorded for the growing, fattening and finishing periods, and are shown in Table 5. During the growing and fattening periods, steers were fed restricted amounts of concentrate mix, but had free access to rice straw. Daily voluntary rice straw intake measured during these periods decreased gradually from 1.0 to 0.83% of live weight during the growing period and from 0.80 to 0.35% of live weight during the fattening period.

Based on body weights measured each month, the

Table 4. Concentrations of gases emitted from manure bedded with sawdust for Farm 1 or unbedded for Farm 2

Item	Control	NaB	SE
Farm 1[1]			
H_2S (ppm)	1.00[a]	0.00[b]	0.21
SO_2 (ppm)	0.72	0.55	0.15
NH_3 (ppm)	7.75[a]	4.32[b]	1.16
DM (%)	26.8	29.4	2.8
Farm 2[1]			
H_2S (ppm)	0.12	0.00	0.12
SO_2 (ppm)	0.75	0.52	0.15
NH_3 (ppm)	11.06	4.88	4.19
DM (%)	28.4	33.7	3.4
Pooled (Farm 1+Farm 2)[2]			
H_2S (ppm)	0.56[a]	0[b]	0.22
SO_2 (ppm)	0.74	0.54	0.09
NH_3 (ppm)	9.40[a]	4.54[b]	1.96
DM (%)	27.4	31.5	2.2

[a] Control differs from NaB treatment ($p<0.05$).
[1] Means of 3 observations. [2] Means of 6 observations.

Table 5. Production characteristics of Hanwoo steers fed different diets during the growing, fattening, and finishing periods[1]

Item	Control	NaB	SE
	------------------------ kg	--------------------	
Growing period			
Initial weight	232	232	8
Final weight	380	384	12
Gain	148	152	8
Average daily gain	0.82	0.85	0.04
Fattening period			
Initial weight	423	432	10
Final weight	588	601	15
Gain	165	170	7
Average daily gain	0.91	0.93	0.03
Finishing period			
Initial weight	588	603	17
Final weight	697	727	28
Gain	109	124	8
Average daily gain	0.53	0.59	0.04

[a] Control differs from NaB treatment ($p<0.05$).
[1] Means of 12 observations.

concentrate mix was controlled to achieve a planned level of ADG during the growing (0.8 kg levels) and fattening (>0.9 kg) periods. Under these conditions, feeding 1.44% BW of concentrate mix resulted in an ADG of 0.82 to 0.85 kg during the growing period. When concentrate mix was fed at 1.50% of BW the ADG was 0.91 to 0.93 kg during the fattening period, irrespective of the dietary treatment.

The dietary treatment did not affect body weight gain of the steers during the growing and fattening periods. The effects of NaB on body weight gain are not shown during either the growing or fattening periods. The small differences attributed to the treatment could have been predicted by the restricted intake of concentrate mix throughout the feeding periods.

During the finishing period the ADG was 11.3% higher for the NaB-fed steers than the ADG for the control steers. The higher ADG was attributed to the higher daily intake of concentrate mix for group NaB (8.58 kg) than for the control steers (8.36 kg). Similar responses to clay minerals were observed in other studies. Feeding 5% clay mineral to growing Hanwoo steers for 6 months was reported to not affect feed intake, body weight gain and feed efficiency (Cho et al., 2001). When Hanwoo steers were fed 2% bentonite from 6 months up to 24 months of age, body weight gain was increased by 8 to 22% during the finishing period. In our study, the live slaughtering weight of the NaB-fed steers was 30 kg higher than that of the control steers (p = 0.10). A similar benefit on animal performance of incorporating a clay mineral into the diet of sheep was reported by Ivan et al. (1992) from incorporation of 0.5% bentonite, and this appeared to be associated with improved feed and bacterial protein flow to the small intestines. The improved feed intake and weight gain of finishing steers fed NaB in the present study can also be explained partly by its ruminal buffering capacity (Son et al., 1998) or relief of ruminal pH drop caused by the *ad libitum* feeding of concentrate mix during this period, followed by a better rumen environment for microbial fermentation.

Table 6. Meat characteristics of Hanwoo steers fed different diets[1]

Item	Control	NaB	SE
Cold carcass weight (kg)	403	420	13.4
Yield traits			
Backfat thickness (mm)	16.8	14.8	1.9
Longissimus muscle area (cm^2)	82.3	81.8	2.8
Yield index	61.9	62.7	1.3
Yield grade[2]	2.34	2.13	0.18
Quality traits			
Marbling score[3]	4.88	5.00	0.72
Meat color[4]	4.50	4.50	0.16
Fat color[5]	2.84[a]	3.00[b]	0.05
Texture[6]	1.31	1.38	0.16
Maturity[7]	2.19	2.19	0.15
Quality grade[8]	2.75	2.69	0.41

[a] Control differs from NaB treatment (p<0.05).
[1] Means of 12 observations.
[2] Scored: grade A = 1 (lean), B = 2, C = 3 (fat).
[3] Scored: grade 1 = poor, grade 9 = excellent.
[4] Scored: grade 1 = scarlet, grade 7 = dark red.
[5] Scored: grade 1 = white, grade 7 = yellow.
[6] Scored: grade 1 = good, grade 3 = bad.
[7] Scored: grade 1 = fully mature, grade 9 = least mature.
[8] Scored: grade 1^{++} = 1 (best), 1^{+} = 2, 1 = 3, 2 = 4, 3 = 5 (poorest).

Meat characteristics after slaughtering of steers

Yield and quality profiles : The effects of the dietary NaB addition on meat characteristics are presented in Table 6. The cold carcass weights of steers tended to increase (p = 0.14) with the addition of NaB to the animal diet. The carcass weights were 17 kg higher for treatment NaB than for the control. Carcass yield traits including *longissimus* muscle area, yield index and yield grade and quality traits including marbling score, meat color, texture, maturity and quality grade were not affected (p<0.05) by the dietary NaB addition. However, backfat thickness tended to decrease (p = 0.12) at least 2 mm for steers with clay mineral in their diet. Fat color was closer (p<0.05) to yellow; however, the differences were inconsistent and very small. This phenomenon appeared to be caused by the light yellowish color of NaB. For the meat quality grades the number of carcasses graded as 1^{++}, 1^{+}, 1, 2, and 3 grades were 2, 3, 4, 2, and 1, respectively, for the control steer group and 3, 3, 3, 3, and 0, respectively, for the NaB-added group. Overall, the dietary NaB addition had a beneficial effect on the carcass quality grades. In another study (Walz et al., 1998), feeding 0.75% clay mineral did not affect carcass weight, *longissimus* muscle area, backfat thickness, quality grade or yield grade of lambs. The differences in response to a clay mineral could be due to different feeding periods and contents. In our study, steers were fed a clay mineral at 1% level of concentrate mix for 22 months. When beef steers were supplemented with Zn, carcass weights were increased (Spears and Kegley, 2002). The better performance in response to NaB in the present study can be partly attributed to the improved bioavailability of Zn and other minerals as shown in Table 7. It is well known that dietary supplementation of zinc and other trace minerals positively affect ruminant performance (Spears, 1996).

Meat mineral profile : The effect of the dietary treatment on the meat mineral profiles of steers is presented in Table 7. The treatment affected (p<0.05) the mineral concentrations in the *longissimus* muscle. Compared with the control, dietary NaB treatment had increased concentrations of P (p<0.01), Mg (p<0.01), Na (p<0.01), Zn (p<0.005), K (p = 0.08), Fe (p = 0.08) and Cu (p = 0.07), but concentrations of Ca and Mn were not affected (p>0.05). The *longissimus* muscle of steers assigned to treatment NaB had 29.6% higher P, 35.1% higher Mg, 18.8% higher K,

Table 7. Mineral profiles (ppm) in the *longissimus* muscle of Hanwoo steers fed different diets[1]

Item	Control	NaB	SE
Ca	109	111	29
P	2,156 [a]	2,794 [b]	299
Mg	239 [a]	298 [b]	33
K	4,149	4,930	396
Na	584 [a]	761 [b]	76
Mn	0.13	0.10	0.04
Fe	25.5	29.3	2.9
Zn	37.8[a]	49.6[b]	4.4
Cu	1.7	3.2	0.9

[a] Control differs from NaB treatment (p<0.05).
[1] Means of 12 observations.

30.3% higher Na, 14.9% higher Fe, 31.2% higher Zn, and 88.2% higher Cu than the control group. Individual herd data showed little variation associated with the increasing rates of the specific minerals. The *longissimus* muscle of animals fed NaB had consistently higher concentrations of most minerals than the control animals. The mineral concentrations ranged between the values reported by Westing et al. (1985) and Williams et al. (1983). However, Cu levels in this study were rather low compared with those reported by Salles et al. (2008). This difference was attributed to the different analytical method. In a short term study with lambs, Walz et al. (1998) reported that a diet with 0.75% bentonite did not affect concentrations of Ca, Mg, K, Cu, Zn, Mn, and Fe in bone, liver and kidney.

The control diet in this study contained more K, Na, Fe and Mn and less Mg, Zn and Cu (data not presented) than the dietary requirement specified in KFSEC (2007) and NRC (2000). Consistent dietary incorporation of these deficient minerals and Na for NaB-supplemented steers resulted in a higher retention in the *longissimus* muscle. Cao et al. (2000) reported that Zn supplementation of ruminant diets that were deficient in Zn resulted in increased Zn content of the ruminant muscle.

The biological reasons for the improved effects of dietary clay mineral on mineral metabolism are not apparent. The improved bioavailability of mineral might be due to the high swelling capacity of clay minerals (Bates and Jackson, 1980), resulting in a slowing in the rate of digesta passage through the gastro-intestinal tract, or might be related to the high cation exchange capacity of the clay mineral (Fenn and Leng, 1989).

Meat fatty acid profile : The effect of the dietary treatment on the fatty acid composition of *longissimus* muscle is presented in Table 8. The fatty acid composition and saturated and unsaturated fatty acid ratios of *longissimus* muscle were not affected (p<0.05) by the dietary NaB addition. Other fatty acids were not affected by the dietary treatment. When the fatty acid profile of Hanwoo steers was compared to that of Angus, Choi et al.

Table 8. Fatty acid composition in the *longissimus* muscle fat of Hanwoo steers fed different diets[1]

Item	Control	NaB	SE
C10:0	0.03	0.05	0.01
C12:0	0.09	0.09	0.01
C14:0	3.46	3.83	0.21
C14:1	1.40	1.31	0.13
C15:0	0.27	0.29	0.03
C16:0	26.62	28.06	0.79
C16:1	5.24	5.50	0.21
C17:0	0.63	0.64	0.06
C18:0	16.09	15.82	0.81
C18:1	43.20	41.53	1.21
C18:2n6	2.00	1.92	0.10
C18:3n6	0.034	0.034	0.002
C18:3n3	0.133	0.126	0.006
C20:0	0.102	0.099	0.004
C20:1	0.369	0.354	0.039
C20:2	0.034	0.033	0.002
C20:3n6	0.108	0.100	0.006
C20:4n6	0.080	0.088	0.008
C22:0	0.010	0.010	0.001
C22:1	0.011	0.012	0.001
C22:2	0.012	0.013	0.001
C22:5n3	0.021	0.027	0.006
C23:0	0.058	0.052	0.004
C24:0	0.010	0.013	0.001
SFA	47.37	48.95	1.32
UFA	52.63	51.05	1.320
MUFA	50.22	48.71	1.310
PUFA	2.42	2.34	0.11

[a] Control differs from NaB treatment (p<0.05).
[1] Means of 12 observations.

(2008) reported that palmitic and stearic acid contents were similar, but oleic acid content was higher for Hanwoo steers. However, this study did not support the higher oleic acid levels reported by Choi et al. (2008).

IMPLICATIONS

The dietary addition of a clay mineral had a manure gas-reducing, pro-environmental effect for beef steers. The use of a clay mineral in the diet showed higher mineral bioavailability. These results suggest that the concentrate mix-rice straw feeding system formulated for this study might have been limiting in certain essential dietary minerals, whereas the commercial concentrate mix was supplemented with a mineral premix which had an adequate supply of all or most of the required dietary minerals.

ACKNOWLEDGMENTS

This study was funded by the Boeun County Agricultural Technology Center in Chung-Buk province. The authors are grateful to Mrs. Song, J. H. and Sim, K. Y.

for the use of their farms to conduct the study. Appreciation is also extended to Mrs. Ji, H. K., Lee, H. J., Hur, K. Y. and Cho, K. W. with the Boeun County Livestock Cooperative for their full research assistance and Mr. Yang, J. H. with the Boeun County Agriculture Technology Center for his support of the project.

REFERENCES

AOAC. 2000. Official methods of analysis. 17th ed. Association of Official Analytical Chemists, Washington, DC, USA.

Bates, R. L. and J. A. Jackson. 1980. Glossary of geology. American Geological Institute, Alexandria, VA, USA.

Braselton, W. E., K. J. Stuart, T. P. Mullaney and T. H. Herdt. 1997. Biopsy mineral analysis by inductively coupled plasma-atomic emission spectroscopy with ultrasonic nebulization. J. Vet. Diagn. Invest. 9:395-400.

Cao, J., P. R. Henry, R. Guo, R. A. Holwerda, J. P. Toth, R. C. Littell, R. D. Miles and C. B. Ammerman. 2000. Chemical characteristics and relative bioavailability of supplemental organic zinc sources for poultry and ruminants. J. Anim. Sci. 78:2039-2054.

Cho, W. M., B. H. Paek, S. W. Kang, J. S. Kim and Y. K. Kim. 2001. Effects of dietary supplements of clay minerals on the growth performance and immunity in growing Hanwoo steers. J. Anim. Sci. Technol. (Kor.) 43(2):203-210.

Choi, C. B., H. U. Shin, S. O. Lee, S. I. Kim, K. K. Jung, C. W. Choi, K. H. Back, D. K. Lunt and S. B. Smith. 2008. Comparison of cholesterol contents and fatty acid composition in *M. longissimus* of Hanwoo, Angus and Wagyu crossbred steers. J. Anim. Sci. Technol. (Kor.) 50(4):519-526.

Church, D. C. and W. G. Pond. 1982. Feedstuffs for animals. In: Basic Animal Nutrition and Feeding. John Wiley and Sons. NY. USA.

Fenn, P. D. and R. A. Leng. 1989. Wool growth and sulfur amino acid entry rate in sheep fed roughage based diets supplemented with bentonite and sulfur amino acids. Aust. J. Agric. Res. 40:889-896.

Folch, J., M. Lees and G. H. S. Stanley. 1957. Simple method for the isolation and purification of total lipids from animal tissues. J. Biol. Chem. 226:497-509.

Ha, J. K., R. J. Emerick and L. B. Embry. 1985. Effect of bentonite and limestone on the growth rate and plasma mineral concentrations of fattening lambs. Korean J. Anim. Sci. 27(1):24-28.

Harvey, R. B., L. F. Kubena, T. D. Phillips, D. E. Corrier, M. H. Elissalde and W. E. Huff. 1991. Diminution of aflatoxin toxicity to growing lambs by dietary supplementation with hydrated sodium calcium aluminosilicate. Am. J. Vet. Res. 52:152-156.

Ivan, M., M. de S. Dayrell, S. Mahadevan and M. Hidiroglou. 1992. Effects of bentonite on wool growth and nitrogen metabolism in fauna-free and faunated sheep. J. Anim. Sci. 70: 3194-3202.

Jasaitis, D. K., J. E. Wohlt and J. L. Evans. 1987. Influence of feed ion content on buffering capacity of ruminant feedstuffs *in vitro*. J. Dairy Sci. 70:1391-1403.

Kang, S. W., J. S. Kim, W. M. Cho, B. S. Ahn, K. S. Ki and Y. S. Son. 2002. Effect of domestic clay minerals on growth performance and carcass characteristics in growing-fattening Hanwoo steers. J. Anim. Sci. Technol. (Kor.) 44(3):327-340.

Kim, C. J., E. S. Lee, M. S. Song and J. K. Cho. 2000. Effects of illite supplementation on the meat quality of finishing pigs. Korean J. Food Sci. Anim. Res. 20(2):152-158.

Korean Feeding Standard Establishment Council. 2007. Korean feeding standard for Korean cattle (Hanwoo). National Livestock Research Institute, RDA, Ministry of Agriculture and Forestry, Korea.

Korean Ministry of Agriculture and Forest. 2007. Carcass grading standards. Livestock Regulation Practice, Appendix no. 4, KMAF, Korea.

Morrison, W. R. and L. M. Smith. 1964. Preparation of fatty acid methyl esters and dimethylacetals from lipids with boron fluoride-methanol. J. Lipid Res. 5:600-608.

National Research Council. 2000. Nutrient requirements of beef cattle. Update 2000, National Academy Press, Washington, DC, USA.

Pulsipher, G. D., M. L. Galyean, D. M. Hallford, G. S. Smith and D. E. Kiehl. 1994. Effects of graded levels of bentonite on serum clinical profiles, metabolic hormones, and serum swainsonine concentrations in lambs fed locoweed (*Oxytropis sericea*). J. Anim. Sci. 72:1561-1569.

Salles, M. S. V., M. A. Zanetti and F. A. Salles. 2008. Effect of monensin on mineral balance in growing ruminants reared under different environmental temperatures. Anim. Feed Sci. Technol. 141:233-245.

SAS Institute, Inc. 1990. SAS User's Guide: Version 6.08. 4th ed., SAS Institute Inc., Cary, North Carolina. USA.

Spears, J. W. and E. B. Kegley. 2002. Effect of zinc source (zinc oxide vs. zinc proteinate) and level on performance, carcass characteristics, and immune response of growing and finishing steers. J. Anim. Sci. 80:2747-2752.

Wallach, J. 1974. Interpretation of diagnostic tests (2nd Ed.). Little, Brown and Company, Boston, MA, USA.

Walz, L. S., T. W. White, J. M. Fernandez, L. R. Gemtry, D. C. Blouin, M. A. Froetschel, T. F. Brown, C. J. Lupton and A. M. Chapa. 1998. Effect of fish meal and sodium bentonite on daily gain, wool growth, carcass characteristics, and ruminal and blood characteristics of lambs fed concentrate diets. J. Anim. Sci. 76:2025-2031.

Westing, T. W., J. P. Fontenot, W. H. McClure, R. F. Kelly and K. E. Jr. Webb. 1985. Characterization of mineral element profiles in animal waste and tissues from cattle fed animal waste. I. Heifers fed broiler litter. J. Anim. Sci. 61(3):670-681.

Williams, J. E., D. G. Wagner, L. E. Walters, G. W. Horn, G. R. Waller, P. L Sims and J. J. Guenther. 1983. Effect of production systems on performance, body composition and lipid and mineral profiles of soft tissue in cattle. J. Anim. Sci. 57(4):1020-1028.