

Effect of feeding sweet-potato condensed distillers solubles on intake and urinary excretion of minerals in Japanese Black steers

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1 Title: The Effect of Feeding Sweet-potato Condensed Distillers Soluble on
2 Intake and Urinary Excretion of Minerals in Japanese Black Steers

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11 Running Head: SWEET POTATO DISTILLERS RESIDUE AND URINE

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1 **ABSTRACT**

2 Four Japanese Black steers (16 months of age) were assigned to a 4 × 4 Latin
3 square design to investigate the effect of graded levels of sweet-potato
4 condensed distillers soluble (SCDS) in their diets on intake and urinary
5 excretion of minerals. The four diets consisted of 0%, 10%, 20% and 30% (dry
6 matter (DM) basis) SCDS, with SCDS replacing commercial concentrate (CC).
7 Intake of K, Cl, S, P and Mg increased linearly with increasing SCDS content.
8 Urinary pH increased linearly with increasing dietary SCDS content. SCDS
9 feeding increased urinary K concentrations (linear and quadratic effects).
10 Urinary concentrations of Cl increased linearly with increasing SCDS content.
11 In contrast, urinary concentrations of Mg decreased with increasing SCDS
12 content. Feeding of SCDS did not apparently affect urinary NH₃, P, Na or Ca
13 concentration. These results suggest that high SCDS feeding is not a risk for
14 crystallization of minerals leading to the formation of magnesium-phosphate
15 type calculi: although SCDS contains large amounts of P and Mg, high SCDS
16 feeding decreased the Mg concentration and did not affect the P concentration
17 in urine. Additionally, high SCDS feeding had no apparent effects on plasma
18 concentrations of Na, K, Cl, Ca or inorganic P.

19

20 ***Key words:*** Japanese Black cattle, mineral, sweet-potato condensed distillers
21 soluble, urine

22

1 INTRODUCTION

2 A recent increase of shochu (Japanese traditional hard liquor) production
3 has resulted in large quantities of shochu by-products. Sweet-potato
4 condensed distiller soluble (SCDS) is one of these by-products having high
5 nutritive value, namely, a high content of total digestible nutrients (TDN) and
6 crude protein (CP). Thus, SCDS is considered useful as a cattle feed (Kamiya
7 *et al.* 2010; Suzuki *et al.* 2010, 2011). SCDS contains a high amount of
8 potassium (K). Additionally, the concentrations of magnesium (Mg) and
9 phosphorus (P) are relatively high in SCDS, close to their levels in wheat bran.
10 A high-K diet was reported to increase urinary K excretion, urinary pH (Kume
11 *et al.* 2011) and urine volume (Suzuki *et al.* 2010) in ruminants. High dietary
12 levels of cations such as K induce metabolic alkalosis in cows, which reduces
13 the ability of the cows to maintain plasma Mg and calcium (Ca) (Goff & Horst
14 1997). Therefore, feeding beef steers large amount of SCDS could possibly
15 affects theirs mineral metabolism.

16 In beef steers, urolithiasis has long been an important problem. Many
17 factors have been implicated in its incidence, such as vitamins, minerals,
18 water intake, infections and hormonal balance (National Agriculture and
19 Food Research Organization, NARO 2008). Dietary mineral imbalances are
20 particularly well known to induce urolithiasis. Uroliths are frequently seen
21 in beef steers when urinary pH is high and urinary P and Mg concentrations
22 increase (National Agriculture and Food Research Organization, NARO 2008).

23 Our preliminary study (Kamiya *et al.* 2011) indicated that feeding of
24 fermented TMR containing SCDS when compared with commercial
25 concentrate (CC) has some effects on the urinary excretion of minerals such

1 as K and Mg. However, the results of our preliminary study were not
2 sufficient to clarify the direct effects of SCDS feeding on urinary mineral
3 excretion because SCDS was one of the ingredients in TMR. Further, the dose
4 response to dietary SCDS level was not clarified in the previous report.

5 The effects of 4 levels of dietary SCDS on feed dry matter intake,
6 digestibility and nitrogen metabolism in Japanese Black steers were reported
7 by Kamiya *et al.* (2013). In the present report, we examined the effects of
8 dietary SCDS on mineral intake, urinary excretion and plasma
9 concentrations of minerals of Japanese Black steers used by the Kamiya *et al.*
10 (2013).

11

12 **MATERIALS AND METHODS**

13 **Animals and procedure**

14 The experiment was conducted as previously described (Kamiya *et al.* 2013).
15 Briefly, four Japanese Black steers (16 months of age) were randomly
16 assigned to a 4 × 4 Latin square design. Each experimental period consisted
17 of 14 d, which included 9 d of adaptation to the diets and 5 d of the sample
18 collection period. Experimental steers were fed daily experimental
19 concentrate (CC replaced with SCDS (0%, 10%, 20% and 30% as DM basis))
20 on an *ad libitum* basis, together with 1.5 kg/day of rice straw as the upper
21 limit. Calcium carbonate (120 g/day) was added to experimental concentrate
22 so that the Ca-to-phosphorus (P) ratio in the diet would be no less than 1:1.
23 The chemical compositions of experimental diets were described in a previous
24 study (Kamiya *et al.* 2013). The steers were offered the experimental diet at
25 09.00 hours, once in a day. Mineral blocks and water were available

1 throughout the study. Feed refusals were collected and weighed daily in the
2 experimental periods. Mineral blocks were weighed at the beginning and end
3 of the experiment period. Urine was collected as spontaneous samples into a
4 plastic bag hung under the abdomen on the third and fifth day of the collection
5 period. Urine pH value was measured by a pH meter (Piccolo+ Hanna
6 Instruments Japan, Chiba, Japan), immediately after urination and urine
7 was frozen at $-20\text{ }^{\circ}\text{C}$ until analysis. Blood samples taken from the jugular
8 vein were collected in heparinized tubes before feeding on the final day of the
9 experimental period.

10 The management of steers was conducted as previously described (Kamiya
11 *et al.* 2013).

12

13 **Sample analysis**

14 For analysis of sodium (Na), K, sulfur (S), P, Ca, and Mg in diets and urine,
15 dietary samples and urine samples were digested in nitric–perchloric acid.
16 The concentrations of Na, K, Ca and Mg were determined by atomic
17 absorption spectrophotometry (SOLAAR M6; Nippon Jarrell-Ash Co., Ltd.,
18 Kyoto, Japan). The S content was determined by ICP-MS (SPS4000; Hitachi
19 high-Tech Science Co., Tokyo, Japan). The P content was determined using
20 the colorimetric method of Gomori (1942). For analysis of chlorine (Cl), diets
21 and urine were dry ashed at $550\text{ }^{\circ}\text{C}$. The Cl concentrations were determined
22 using the titration methods of Mohr (1856). The urinary total ammonia
23 concentration was measured using a commercial kit (F-kit Ammonia; Roche
24 Diagnostics, Basel, Switzerland). Urinary creatinine excretion are closely
25 correlated with body weight (BW) and the excretion rates of urinary

1 creatinine is considered to be constant (Jones *et al.* 1990; Chen *et al.* 1992,
2 Asai *et al.* 2005); therefore the urinary creatinine concentration has been used
3 as an indicator in estimating urine volume and assessing the balance of
4 nutrients in beef cattle digestion (Devant *et al.* 2000; Padilla *et al.* 2007;
5 Ceconi *et al.* 2015). Urinary creatinine concentration was measured using a
6 commercial kit (Labo Assay Creatinine; Wako Pure Chemical Industries, Ltd,
7 Osaka, Japan). The urinary excretion of minerals and ammonia were
8 expressed as the ratio to urinary creatinine (O'Kelley & Fontenot 1973; Roch
9 *et al.* 2003). The concentrations of plasma Na, K, Cl, inorganic P (Pi), Ca and
10 Mg were determined by an analyzer (DRI-CHEM 7070; Fujifilm, Tokyo,
11 Japan) using DRI-CHEM slides (Fujifilm). Mineral contents of the
12 experimental diets are shown in Table 1. The dietary mineral intake was
13 calculated from determined mineral contents and feed intake described in the
14 previous report (Kamiya *et al.* 2013). The dietary cation-anion difference
15 (DCAD) was calculated from determined mineral contents as $(\text{Na}+\text{K})-(\text{Cl}+\text{S})$
16 (Ender *et al.* 1971). To evaluate the likelihood of urolithiasis, the solubility of
17 struvite crystals was determined on the basis of struvite activity products
18 (SAP; $[\text{Mg}^{2+}] \times [\text{NH}_4^+] \times [\text{PO}_4^{3-}]$) according to Buffington *et al.* (1990). Urinary
19 NH_4^+ and PO_4^{3-} concentrations were estimated from urinary pH and total
20 concentrations of ammonia and inorganic P (Shimizu *et al.* 2006). For
21 convenience, the SAP is expressed as pSAP, the negative logarithm of SAP.

22

23 **Statistical analysis**

24 All data were analyzed according to the 4×4 Latin square design using the
25 mixed procedure of SAS (2004), including diet and period as the fixed effects

1 and steers as the random effect in the model. Orthogonal polynomial
2 contrasts were used to determine linear, quadratic and cubic responses to
3 dietary level of SCDS in diet and the significance among treatments was
4 tested by the PDIFF option (SAS 2004).

5

6 **RESULTS**

7 The DCAD in experimental concentrate increased with increasing dietary
8 SCDS content because of the high cation-anion difference in SCDS (Table 1).
9 The feed intake was previously described in detail (Kamiya *et al.* 2013). The
10 experimental concentrate intake showed high values in 10% and 20% SCDS
11 groups (0%:6.57 kg/day, 10%:7.88 kg/day, 20%:7.52 kg/day, 30%:7.23 kg/day).
12 The SCDS content of the experimental concentrate did not significantly affect
13 the steer's intake of rice straw (0%:1.06 kg/day, 10%:0.97 kg/day, 20%:0.95
14 kg/day, 30%:1.29 kg/day) or mineral blocks (0%:8.8 g/day, 10%:11.5 g/day,
15 20%:11.0 g/day, 30%:12.5 g/day). Increasing dietary SCDS from 0% to 30%
16 resulted in linear increases in K, Cl, S, P and Mg intake ($P<0.01$). There were
17 no effects of SCDS feeding on Na and Ca intake (Table 2).

18 The effects of the SCDS feeding level on urinary mineral excretions are
19 shown in Table 3. Urine pH ($P<0.05$) increased linearly with increasing
20 dietary SCDS level. The urinary creatinine concentrations ($P<0.01$) decreased
21 linearly with increasing dietary SCDS level. The urinary K concentration
22 showed linear and quadratic increases ($P<0.05$) with SCDS feeding. Urinary
23 estimated K excretions increased linearly ($P<0.01$) with increasing dietary
24 SCDS level. The urinary Cl concentration ($P<0.05$) and estimated excretion
25 ($P<0.01$) increased linearly with increasing dietary SCDS level. The urinary

1 Mg concentration decreased linearly with increasing dietary SCDS level
2 ($P<0.05$) while the SCDS level had no apparent effects on the estimated Mg
3 excretion in urine. The SCDS level had no apparent effects on urinary NH_3 ,
4 Na, P and Ca concentrations of experimental steers. The SCDS level had no
5 apparent effects on the pSAP of experimental steers.

6 The effects of SCDS feeding on plasma mineral concentrations are shown
7 in Table 4. There were no effects of SCDS feeding on concentrations of plasma
8 Na, K, Cl, inorganic P or Ca. The plasma Mg concentration showed quadratic
9 increase ($P<0.05$) with SCDS feeding; i.e., the plasma Mg concentration was
10 higher in the steers fed 10 and 20% SCDS than in the others.

11

12 **DISCUSSION**

13 The present study was conducted to examine the effects of 4 levels of SCDS
14 feeding on intake, urinary excretion and plasma concentrations of minerals
15 in Japanese Black steers. The SCDS feeding significantly increased urinary
16 pH, although feeding of TMR containing SCDS did not affect urinary pH in
17 our previous report (Kamiya *et al.* 2011). Kume *et al.* (2011) reported that
18 there were positive correlations between urine pH and urinary K
19 concentration or K intake in dairy cows. On the other hand, SCDS also
20 contained higher Cl compared to CC. Chloride such as NH_4Cl is often added
21 to diets as a urine acidifier. Chlorine is almost completely absorbed in the gut
22 and excess Cl is excreted into urine (NRC 2001). The amount of both absorbed
23 Cl and Cl excretion into urine were increased in cows and sheep fed diets
24 containing chloride (Takagi & Block 1991; Schonewille *et al.* 1999;
25 Charbonneau *et al.* 2009). It is well known that urinary electrolytes and acid-

1 base status directly affect urine pH. Tucker *et al.* (1988) indicated that the
2 changes in DCAD were responsible for the alterations in acid-base physiology
3 of cows. The DCAD has been known to be highly associated with urinary pH
4 in ruminants (Sanchez *et al.* 1994; Charbonneau *et al.* 2006; Hersom *et al.*
5 2009). In the present experiment, DCAD calculated from mineral intake was
6 shown to be increased with increasing dietary SCDS. Although the
7 concentration of Cl and S were higher in the SCDS than in the CC, DCAD
8 was high in SCDS because of the large amount of K in SCDS. Thus we suggest
9 that urinary pH is increased with increasing dietary SCDS through
10 increasing DCAD.

11 The urinary creatinine concentration was decreased with increasing
12 dietary SCDS level. Since daily creatinine production and consequently
13 urinary creatinine excretion are constant to the individual (Albin & Clanton
14 1966; Asai *et al.* 2005), urine volume could be estimated by dividing the daily
15 urinary excretion of creatinine by the creatinine concentration in the urine of
16 the spot samples. Therefore, urine volume was thought to be increased with
17 increasing dietary SCDS level. Several reports on cows and sheep have
18 indicated that high dietary K results in higher urine volume (Yano *et al.* 1977;
19 Bannink *et al.* 1999; Suzuki *et al.* 2010; Ohtani *et al.* 2010). Intake of K was
20 increased with increasing dietary SCDS in the present experiment because
21 SCDS contained a large amount of K. High K intake would contribute to the
22 increase of urine volume in this experiment. High protein in diet or high urea
23 concentrations of plasma also increase urine volume in ruminants (Wholt *et*
24 *al.* 1976; Ohtani *et al.* 2014). Kamiya *et al.* (2013) has shown that plasma urea
25 nitrogen concentration was higher in steers fed a high-SCDS diet, which

1 would have partially affected the urine volume in this experiment.

2 Although Mg intake was increased with increasing SCDS in diet and the
3 highest level of dietary SCDS increased Mg intake by 40%, the urinary Mg
4 excretion was not significantly affected by the graded levels of dietary SCDS.
5 Feeding a high level of K has been found to depress apparent Mg absorption
6 in ruminants (Greene *et al.* 1983; Fontenot *et al.* 1989). The high K in SCDS
7 in the present experiment probably depressed Mg absorption and thus
8 urinary Mg excretion was not increased in steer fed SCDS containing a large
9 amount of K and Mg. Further, the high K intake increased urine volume of
10 steers fed SCDS, which dilutes the Mg concentration in the urine. As a result,
11 the urine Mg concentration was decreased in steers fed high SCDS. Kamiya
12 *et al.* (2011) also reported that SCDS feeding decreased urinary Mg
13 concentration, though SCDS was one of the ingredients in TMR in that report.

14 The intake of P was increased with dietary SCDS level but the
15 concentration of plasma inorganic P was not affected by the dietary treatment,
16 which indicated that P homeostasis was maintained even in steers given the
17 highest level of SCDS. Urinary excretion and concentration of P was not
18 affected by the dietary treatment. Phosphorus metabolism is regulated by its
19 absorption, urinary and endogenous excretion, and bone metabolism. The
20 regulation of P absorption and/or endogenous excretion may contribute to its
21 homeostasis in steers given SCDS because urinary excretion of P is not
22 affected by the dietary treatment.

23 In the mineral nutrition of beef steers, urolithiasis has long been an
24 important problem. Calculi of the magnesium-phosphate type are commonly
25 found in ruminant urolithiasis (Lindley *et al.* 1953; Robbins *et al.* 1965). The

1 calculi have been reported to consist of magnesium and phosphate (Munakata
2 *et al.* 1974) or magnesium, ammonium and phosphate (Osborne *et al.* 1985;
3 Tsuchiya & Sato 1988). The urolith material consisting of magnesium,
4 ammonium and phosphate is referred to as struvite.

5 When the urinary concentrations of Mg and P are at a high level combined
6 with high urinary pH, they tend to crystallize and form calculi. Some
7 researchers (Packett & Hauschild 1964; Bushuman *et al.* 1965) reported that
8 urinary P concentration was high when the calculi were found in the bladders
9 of ruminants. To evaluate the effects of SCDS feeding on urolithiasis
10 throughout the fattening period, it is necessary to discuss the changes of
11 mineral concentrations and pH in urine. In addition, the crystallization of
12 struvite in feline urine was evaluated using the index, struvite activity
13 product (SAP, $[Mg^{2+}] \times [NH_4^+] \times [PO_4^{3-}]$) according to Buffington *et al.* (1990).
14 Shimizu *et al.* (2006) tried to investigate the pSAP value and struvite
15 crystallization of cats, suckling calves and dry cows, and indicated that pSAP
16 would reflect struvite crystal formation in urine.

17 In the present study, although urinary pH was high in the steers fed SCDS,
18 the urinary P concentration was not affected by dietary SCDS and the urinary
19 Mg concentration was decreased with SCDS consumption increased.
20 Furthermore, the present experiment indicated that dietary SCDS did not
21 affect the pSAP value of urine. Therefore, these results suggest that SCDS
22 feeding is not a risk factor for urolithiasis of magnesium-phosphate type
23 calculi in beef steers.

24 The dietary SCDS level did not affect the plasma concentrations of Na, K,
25 Cl, Ca or inorganic P. Plasma Mg concentration was increased in the steers

1 given 10% and 20% SCDS but interestingly, not so in steers fed 30% SCDS.
2 Plasma Mg concentrations are affected by both Mg absorption in the intestine
3 and urinary excretions. However, the highest SCDS intake did not result in
4 the highest Mg of plasma concentration or urinary excretion. It is well known
5 that feeding a high level of K depress apparent Mg absorption in ruminants
6 (Greene *et al.* 1983; Fontenot *et al.* 1989). It was suggested that the high K
7 concentration of SCDS affected Mg absorption and plasma Mg concentration.
8 It is still necessary to clarify the effect of feeding SCDS on the plasma Mg
9 concentration.

10 Although the intakes of K and Cl were increased with dietary SCDS level,
11 plasma concentrations of these minerals were not affected by the dietary
12 treatment, which can be explained by the increase in urinary excretion of
13 these minerals. The kidney is the major organ controlling K and Cl
14 metabolism because the absorptions of these minerals are not regulated and
15 these minerals in the diet are almost completely absorbed (NRC 2001). The
16 steers fed diets high in SCDS can adapt to the high intakes of K and Cl by
17 increasing urinary excretion of these minerals.

18 In summary, SCDS feeding increased K, Cl, S, P and Mg intake of steers.
19 SCDS feeding elevated urinary pH and urinary K and Cl concentrations and
20 decreased the urinary Mg concentration. SCDS feeding did not affect the
21 urinary P concentration. Our findings suggest that high SCDS feeding should
22 not influence the risk for crystallization of urinary minerals despite the fact
23 that SCDS contains large amounts of P and Mg. However, it is still necessary
24 to clarify the effect of feeding SCDS throughout fattening period on the
25 formation of uroliths of beef steers.

1

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11 カンショ焼酎粕濃縮液の給与が肥育牛のミネラル摂取量および尿中への
12 ミネラル排泄量に及ぼす影響

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17 配合飼料へのカンショ焼酎粕濃縮液の混合割合の異なる4種類の濃厚飼料(乾
18 物ベースでの混合割合0%, 10%, 20%, 30%)を黒毛和種肥育牛4頭(試験
19 開始時16ヶ月齢)に給与し, 1期2週間の4×4ラテン方格法による飼養試験
20 を行い, ミネラル摂取量および尿中へのミネラル排泄を比較検討した. 配合飼
21 料のミネラル含量は, Kが5.6 g/kg, Pが5.0 g/kg, Mgが1.8 g/kgであつ
22 た. カンショ焼酎粕濃縮液のミネラル含量は乾物あたりでKが63.3 g/kg, P
23 が9.4 g/kg, Mgが3.9 g/kgであった. カンショ焼酎粕濃縮液の混合割合の増
24 加に伴い, K, Cl, S, PおよびMg摂取量が増加した. カンショ焼酎粕濃縮液
25 の給与割合の増加に伴い, 尿pHが上昇した. カンショ焼酎粕濃縮液の給与割

1 合の増加に伴い，尿中 K および Cl 濃度は増加したが，尿中 Mg 濃度は低下し
2 た．カンショ焼酎粕濃縮液の給与は，尿中 NH₃，Na，P および Ca 濃度には影
3 響を及ぼさなかった．カンショ焼酎粕濃縮液給与は，血漿中 Na，K，Cl，Ca
4 および Pi 濃度に影響を及ぼさなかった．さらに，カンショ焼酎粕濃縮液の給
5 与は，リン酸マグネシウム塩結晶の生成要因に大きな影響を及ぼさないと推測
6 された．

Table 1 The mineral contents of commercial concentrate, sweet-potato condensed distillers solubles (SCDS), rice straw, mineral block and experimental concentrate

	Commercial concentrate	SCDS	Rice straw	Mineral block	Experimental concentrate†			
					0%	10%	20%	30%
Na (g/kgDM)	0.5	0.8	0.3	315.1	0.5	0.5	0.6	0.6
K (g/kgDM)	5.6	63.3	19.9	0.0	5.6	10.6	15.6	21.0
Cl (g/kgDM)	4.7	14.9	3.1	533.3	4.6	5.5	6.4	7.4
S (g/kgDM)	1.5	3.2	0.8	2.3	1.5	1.7	1.8	2.0
P (g/kgDM)	5.0	9.4	2.1	16.4	5.0	5.4	5.7	6.1
Ca (g/kgDM)	2.9	0.2	0.7	31.4	7.5	7.0	6.5	6.4
Mg (g/kgDM)	1.8	3.9	1.0	0.9	1.8	2.0	2.2	2.4
DCAD (mEq/100gDM)††	-5.7	103.3	38.3	-146.8	-5.9	3.5	13.1	23.2

†Experimental concentrate; 0%:98.7% commercial concentrate (CC) and 1.3% calcium carbonate on a dry matter basis, 10%:90.1% CC, 8.7% SCDS and 1.2% calcium carbonate on a dry matter basis, 20%: 81.4% CC, 17.4% SCDS and 1.2% calcium carbonate on a dry matter basis, 30%:72.1% CC and 26.7% SCDS and 1.2% calcium carbonate on a dry matter basis

Na: sodium, K: potassium, Cl: chlorine, S: sulfur, P: phosphorus, Ca: calcium, Mg: magnesium

††: DCAD: Dietary cation anion difference (mEq/100gDM) =(Na+K)-(Cl+S)

Table 2 The effect of feeding sweet-potato condensed distillers solubles (SCDS) on mineral intake of experimental steers

	Diet (SCDS)				SE	P values		
	0%	10%	20%	30%		Linear	Quadratic	Cubic
Na (g/day)	6.4	8.2	8.0	8.6	1.0	NS	NS	NS
K (g/day)	57.6	102.5	136.4	177.4	9.1	**	NS	NS
Cl (g/day)	38.3	52.6	57.0	64.0	3.4	**	NS	NS
S (g/day)	10.8	13.9	14.4	15.3	0.8	**	NS	NS
P (g/day)	35.0	44.4	45.3	47.3	2.5	**	NS	NS
Ca (g/day)	50.1	56.4	50.1	47.3	2.7	NS	NS	NS
Mg (g/day)	12.9	16.7	17.3	18.4	1.0	**	NS	NS

Na: sodium, K: potassium, Cl: chlorine, S: sulfur, P: phosphorus, Ca: calcium, Mg: magnesium

***P*<0.01, NS: not significant.

Table 3 The effect of feeding sweet-potato distillers solubles (SCDS) on urinary creatinine, mineral excretion and pSAP of experimental steers

	Diet (SCDS)					P values		
	0%	10%	20%	30%	SE	Linear	Quadratic	Cubic
Urinary pH	7.92	8.11	8.06	8.17	0.07	*	NS	NS
Urinary concentrations								
Creatinine (mg/dl)	200.2	135.2	99.1	95.5	31.4	*	NS	NS
NH ₃ (mg/l)	137.4	156.6	93.3	167.0	59.6	NS	NS	NS
Na (mg/l)	126.3	531.0	793.6	542.3	298.3	NS	NS	NS
K (mg/l)	6736.1	10945.0	10147.8	10563.0	1705.0	*	*	NS
Cl (mg/l)	2213.8	3916.1	4024.1	4104.5	596.3	*	NS	NS
P (mg/l)	191.6	173.1	189.2	145.6	55.2	NS	NS	NS
Ca (mg/l)	8.9	7.9	8.6	8.9	2.4	NS	NS	NS
Mg (mg/l)	646.6	561.8	423.4	382.3	121.5	*	NS	NS
Urinary estimated excretion (Ratios of urinary NH ₃ and minerals to urinary creatinine, mg:mg)								
NH ₃	0.12	0.12	0.12	0.28	0.07	NS	NS	NS
Na	0.10	0.41	0.93	0.89	0.41	NS	NS	NS
K	4.3	8.4	10.3	13.9	1.5	**	NS	NS
Cl	1.6	3.3	4.3	4.8	0.6	**	NS	NS
P	0.13	0.16	0.22	0.20	0.07	NS	NS	NS
Ca	0.005	0.006	0.010	0.015	0.004	NS	NS	NS
Mg	0.34	0.44	0.43	0.40	0.04	NS	NS	NS
pSAP [†]	9.5	9.4	9.5	9.5	0.2	NS	NS	NS

NH₃: ammonium, Na: sodium, K: potassium, Cl: chlorine, P: phosphorus, Ca: calcium, Mg: magnesium

*: $P < 0.05$, **: $P < 0.01$, NS: not significant.

†: the negative logarithm of SAP (SAP: $[Mg^{2+}] \times [NH_4^+] \times [PO_4^{3-}]$) according to Buffington et al. (1990)

Table 4 The effect of feeding sweet potato distillers solubles (SCDS) on plasma metabolites

	Diet (SCDS)				SE	P values		
	0%	10%	20%	30%		Linear	Quadratic	Cubic
Na (mEq/l)	139.8	138.8	138.3	141.0	1.0	NS	NS	NS
K (mEq/l)	3.8	4.0	3.9	3.9	0.1	NS	NS	NS
Cl (mEq/l)	90.5	90.8	89.5	91.3	0.9	NS	NS	NS
Pi (mg/dl)	8.3	8.6	8.6	8.4	0.3	NS	NS	NS
Ca (mg/dl)	11.1	11.1	10.8	11.0	0.2	NS	NS	NS
Mg (mg/dl)	2.4	2.7	2.7	2.5	0.1	NS	*	NS

*: $P < 0.05$, NS: not significant.

Na: sodium, K: potassium, Cl: chlorine, Pi: inorganic phosphorus, Ca: calcium, Mg: magnesium