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Original Article (Full Paper)

Effects of Soybean Curd Residue Silage on the Growth Performance, Meat Quality, and Cecal Microbial Population in Finishing Pigs

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ABSTRACT Soybean curd residue silage (SCRS) was incorporated into the diet of 24 crossbred (Landrace × White × Duroc) finishing pigs at levels of 0 (control), 15, 30, and 60% for an experimental period of 60 days. The estimated total digestible nutrient intakes (TDN) did not differ among any treatments. The growth performance of pigs did not differ significantly between the control and the 30% or 60% SCRS groups, but growth decreased in the 15% SCRS group ($P < 0.05$). Pork derived from the pigs fed with 30% or 60% SCRS showed a higher fat content ($P < 0.05$) and relatively lower shear force values. SCRS feeding generally did not affect fatty acid composition of the pork, and consequently those melting points did not differ among the dietary groups. Feeding SCRS to pigs positively impacted cecal microbiology by reducing coliform, *Enterobacteriaceae*, and *Escherichia coli* numbers ($P < 0.05$). Thus, feeding of 30% and 60% SCRS may contribute considerably to pig safety and pork quality.

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Key words : cecal bacteria, finishing pig, meat quality, silage, soybean curd residue

Introduction

Approximately 700 thousand tons of soybean curd residue (SCR), wastes from tofu industries, are generated a year in Japan (Amaha *et al.* 1996). Since the act concerning the promotion of utilization of recyclable food waste, known as the food-recycle law, has become effective in 2000, recycling of SCR has been of increasing importance. Preparation of animal feeds with SCR is one of the possible ways for its utilization (Barroga *et al.* 2000; Tarachai and Yamauchi 2001).

Because raw SCR spoils quickly, it should be preserved with appropriate means. While drying process by heating is one of the solutions to the spoilage problem, thermal drying of SCR results in loss of its nutrients and huge energy costs. On the other hand, fermentation strategy would be another method that has nutritional and economical benefits (Martin 1996). Actually our colleague has developed a method for ensilage and preservation of SCR (Tsugeta and Tsugeta 2007). Soybean curd residue silage (SCRS) mixed with other dry feeds is successfully resistant to aerobic deterioration and some pathogenic microbe as *Clostridium* spp.

The contribution of SCRS to animal growth performance and product quality must be evaluated. Some researchers have reported that feeding of tofu cake silage to swine did not affect the pig growth, and increased the unsaturated fatty acid concentration in body fat (Niwa and Nakanishi 1995). Osawa *et al.* (2004) have reported that the meat from pigs fed fermented tofu cakes has higher amounts of inter-muscle fat and tends to be tastier compared with the meat from pigs fed conventional diets. In addition, animal safety aspects of feeding materials should be carefully considered, particularly in the context of food-borne disease concerns. To the best of our

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knowledge, the bio-safety of SCRS to swine has not been examined. Therefore, we investigated the effects of SCRS feeding on growth performance, meat quality, and cecal microbial populations in finishing pigs.

Materials and Methods

Preparation of Soybean Curd Residue Silage

The SCR used in this study was provided by a local tofu producer. The SCRS was prepared by mixing wheat bran, barley, lucerne, and the SCR with fermented tuberous taro as a starter culture (Tsugeta and Tsugeta 2007). The composition of the SCRS is shown in Table 1. This mixture was stuffed in a polyethylene bag, protected from the sun, and allowed to ferment for 1 month at room temperature. Random samples of SCRS were collected and subjected to chemical composition analysis of VFA, volatile basic nitrogen (VBN), and pH. The chemical composition, including concentrations of DM, crude protein, crude fat, ash, and nitrogen-free extracts (NFE), was determined according to the methods of the Fertilizer and Feed Inspection Services of Japan (1983). The concentrations of VFA such as acetic acid, lactic acid, and butyric acid were determined with a GC–14B gas–liquid chromatograph (Shimadzu Corporation, Kyoto, Japan) equipped with a flame-ionization detector using a glass column (160 × 0.3 cm) packed with polyethylene glycol 6000 according to a method of Kageyama *et al.* (1973). The VBN was analyzed with the steam-distillation method, which was followed by titration with 0.01 mol/L H_2SO_4. To determine the pH, the silage was suspended in degassed distilled water at 10% (w/v), and the pH was measured with a pH meter (HM–30S; DKK–TOA Corporation, Tokyo, Japan).

Animals and Diets

Twenty-four castrated pigs (Landrace × White × Duroc) were used to determine the effects of SCRS feeding on animal growth performance, meat quality, and characteristics of cecal microbes. The pigs were randomly assigned to 1 of 4 treatment groups, i.e., 0% (control), 15%, 30%, and 60% SCRS-fed groups, and each treatment group consisted of 2 pens (approximately 5.25 m^2 each) of 3 pigs. The average age of the pigs at the beginning of the experiment was 118 ± 1.8 days SD, and the average body weight was 67.8 ± 1.1 kg SD. The animals were given free access to experimental diets and to water *ad libitum* for approximately 60 days. Treatment and management of the animals were carried out according to the guidelines for the care and use of experimental animals of the Miyazaki Livestock Research Institute. The ingredients and chemical composition of the finishing diets used in this experiment are shown in Table 2. At the end of the designated experimental period, all pigs were slaughtered over 14 days at a local commercial slaughterhouse. The carcasses were assessed and graded according to the standard of the Japan Meat Grading Association (Japan Meat Grading Association 1988), and then the marbling score was visually determined as specified by the National Pork Board (National Pork Board 1999). After dressing of the carcasses, meat samples (approximately 200 g each) were collected from loin cuts. The meat samples were vacuum-packed and stored at –30˚C until further analysis.

Shear Force Measurement

Cubic cuts of meat (approximately 30 g) were enclosed in polyethylene bags and cooked in boiled water to an internal temperature of 70˚C. Then, the cuts were cooled for 30 min at room temperature (22˚C), and the cooked meats were weighed on an electronic scale. Cooking loss was calculated as the difference in sample weight before and after cooking. Then, the shear force of the meat cuts was measured with an Instron Universal Testing Machine (Instron Japan Company Ltd., Kawasaki, Japan) in which a Warner–Bratzler meat shear fixture was installed.

Measurement of Fat Content and Fatty Acid Composition

Lipid extraction from meat samples was carried out using the method described by Folch *et al.* (1957). The lipid content of the total extracted lipid was determined gravimetrically. Fatty acid methyl esters were prepared using HCl/methanol as described (Takenoyama *et al.* 1999), and the resulting methyl esters were analyzed on a GC–2010 gas chromatograph (Shimadzu Corporation) equipped with a flame-ionization detector using a capillary column (Supelcowax™ 10, 60 m × 0.32 mm i.d.; Supelco, Inc., Bellefonte, PA, USA). The operating conditions of the gas chromatograph were as follows: oven temperature was held at 195˚C for 8 min, increased to 220˚C at a rate of 2˚C/min, and then held at this temperature for 40 min. The temperature of the injector was 240˚C and of the detector was 250˚C. The carrier gas (helium) was maintained at a constant flow of 2.0 mL/min.

Melting Point Measurement of Subcutaneous Fat

Total fat that was prepared by heating the subcutaneous fat removed from the loin region to 80˚C was used to measure the melting point. The sliding point of the resulting fat was determined as the melting point by using the method of the Japan Oil Chemists' Society (2003).

Counting of Bacteria from Cecal Content

Samples from the cecum of the carcasses after evisceration at the slaughterhouse were collected into a sterilized polyethylene pouch. The pouch containing

the sample was immediately placed into an oxygen-impermeant bag with an oxygen absorber (AneroPouch; Mitsubishi Gas Chemical Company, Inc., Tokyo, Japan), and the bags were closely sealed with an electric sealer. All samples were then stored in an ice-cooled box until further laboratory analysis.

A wet cecal sample (1 g) was suspended in a stomacher bag containing 9 mL of 0.1% peptone water containing 0.05 M sodium phosphate buffer, pH 7.2. Multiple dilutions of the suspension were prepared with 0.1% buffered peptone water, and aliquots (0.1-1.0 mL) of the dilutions were spread onto MRS agar (Oxoid Ltd., Hampshire, UK) for *Lactobacilli*, modified CCDA agar (Oxoid Ltd.) for *Campylobacter* spp., TSC agar with egg yolk (Oxoid Ltd.) for *Clostridium* spp., Pro-media Agar Tricolor (Elmex Co., Ltd., Tokyo, Japan) for *Escherichia coli* and coliform, Petrifilm™ EC for *Enterobacteriaceae*, and EL Plates (Sumitomo 3M Ltd., Tokyo, Japan) for *Listeria* spp. Pro-media Agar Tricolor plates, Petrifilm, MRS agar plates and TSC agar plates were aerobically incubated at 37°C for 1–2 days (depending on colony growth). Modified CCDA agar plates were incubated 37°C for 1 day in a microaerophilic atmosphere with an oxygen absorber (Anearo Pack–MicroAero; Mitsubishi Gas Chemical Company, Inc.). The number of colonies that grew on the plates was counted after cultivation, and bacterial counts were determined.

Statistical Analysis

All data obtained in this study were analyzed with analysis of variance (ANOVA). When significant effects were observed from the *F*–test, we carried out a post–hoc t–test (Tukey–Kramer's test) to compare the means.

Results and Discussion

As shown in Table 1, SCRS quality was assessed based on the Frieg score (score = 100) and the V–score (score = 97) (Takahashi *et al.* 2005), which indicated that the SCRS has comparable quality as silage. Diets into which SCRS was incorporated had lower crude protein and ash than the conventional diet (Table 2). Dry matter, TDN, and NFE decreased with the increasing proportion of SCRS in the diets, whereas crude fat and crude fiber increased with increasing levels of SCRS.

The effect on the growth performance of finishing pigs fed SCRS is shown in Table 3. The daily gain (g/day) was higher ($P < 0.05$) in pigs fed the C diet than in those of both the T1 and T2 diets. The T3 group showed an intermediate value between those dietary groups. Feed intake was lowest with the C diet and increased with the T1, T2, and T3 diets, with significant differences ($P < 0.05$) observed between the C and the T2 or T3 diet. Feed intake differed significantly between the T1 and T3 diets. Feed conversion was significantly higher ($P < 0.05$) with the T1, T2, and T3 diets than with the C diet. Total digestible nutrient intake and TDN conversion did not differ significantly among the treatments. Similar results have been noted in certain previous studies. For example, Niwa and Nakanishi (1995) observed no difference in feed conversion ratio or growth performance in fattening pigs between control and groups fed 47% or 66% tofu cake silage. Pigs fed a conventional diet showed greater weight gain compared with pigs fed 100% tofu cakes (Osawa *et al.* 2004).

Table 1 Composition of SCRS †

Parameters	
Ingredient, % ‡	
SCR	35
Fermented tuberous taro	25
Wheat bran	20
Barley	10
Lucerne	10
Chemical analysis	
DM, %	46.9
NFE, % DM	60
Crude protein, %	19.1
Ash, % DM	5.3
Crude fat, % DM	4.2
Crude fiber, % DM	11.5
Lactic acid, %	1.89
Acetic acid, %	0.09
Butyric acid, %	0.04
pH	< 4.7
V score	97
Frieg score	100

† SCRS (soybean curd residue silage).
‡ As-fed basis.

The above findings suggest that SCRS does not improve growth performance. The inferior growth performance in pigs fed SCRS was probably due to the nutritional imbalance of the diets, including the absence of tryptophan in SCR as described by Tarachai *et al.* (1999). However, a trend toward improved growth performance with the levels of SCRS was observed. This improvement may be due to fermented feed containing beneficial bacteria that alter the gut environment of pigs (Hong and Lindberg 2007), the organic acids in feed (Bach Knudsen *et al.* 1991; Jensen 2001), the properties of the diet, and the fraction of dietary fiber (Pedersen and Lindberg 2003). The observation that the pigs consumed more feed with

Table 2 Ingredient proportion and chemical composition of experimental diets

Parameters	Treatment †			
	C	T1	T2	T3
Ingredient, % ‡				
Concentrate mixture	100	–	–	–
SCRS §	–	15.0	30.0	60.0
Corn	–	51.2	46.5	37.0
Wheat bran	–	30.0	20.0	–
Lucerne	–	2.7	2.4	1.9
Vitamin mix	–	0.1	0.1	0.1
Mineral mix	–	1.0	1.0	1.0
Chemical composition				
DM, %	88.2	80.6	74.4	60.2
TDN, % DM	88.4	81.3	81.2	80.9
NFE ¶, % DM	77.1	74.0	73.3	71.7
Crude protein, %	14.7	13.4	13.4	13.4
Ash, % DM	5.7	3.3	3.3	3.5
Crude fat, % DM	2.8	3.6	3.8	4.3
Crude fiber, % DM	5.7	5.8	6.2	7.1

† C (0% SCRS), T1 (15% SCRS), T2 (30% SCRS), T3 (60% SCRS).
‡ As-fed basis.
§ SCRS (soybean curd residue silage).
¶ NFE (nitrogen-free extract).

Table 3 The effect on the growth performance of finishing pigs fed SCRS †

Parameters	Treatment ‡			
	C	T1	T2	T3
Initial body weight (kg)	67.1 ± 2.3	68.1 ± 2.1	68.3 ± 2.9	67.6 ± 2.4
Final body weight (kg)	118.5 ± 5.9^{a}	102.6 ± 8.3^{b}	107.0 ± 9.5^{ab}	112.2 ± 7.4^{ab}
Daily gain (g/day)	923 ± 97^{a}	560 ± 173^{b}	643 ± 175^{b}	764 ± 145^{ab}
Feed intake (kg of feed)	162.2 ± 11.7^{a}	194.8 ± 20.0^{ab}	224.7 ± 28.0^{bc}	254.6 ± 50.3^{c}
Feed conversion (kg intake /kg gain)	3.2 ± 0.3^{a}	6.1 ± 2.3^{b}	6.0 ± 1.3^{b}	5.8 ± 1.3^{b}
TDN intake (kg)	126.3 ± 9.1	127.7 ± 13.1	135.6 ± 16.9	127.7 ± 25.2
TDN conversion (kg intake/kg gain)	2.46 ± 0.3	4.03 ± 1.5	3.60 ± 0.8	2.9 ± 0.7

Values are means ± standard deviations of the means.
† SCRS (soybean curd residue silage).
‡ C (0% SCRS), T1 (15% SCRS), T2 (30% SCRS), T3 (60% SCRS).
a,b,c Within a row, means without a common superscripts differ statistically (P<0.05).

increasing SCRS levels could be explained in several ways: (i) an improvement in physical characteristics and palatability of the SCRS diet (Niwa and Nakanishi 1995), (ii) the low CP and TDN of the diet (Ikeda *et al.* 2005), and (iii) the higher dietary fiber, resulting in decreased digestibility and metabolic energy of the diet. Pigs may consequently attempt to consume more feed to maintain the digestible energy intake (Baird *et al.* 1975; Kennelly and Aherne 1980; Low 1985; García *et al.* 1999). Thus, our data suggest that diets containing 30% or 60% SCRS could be fed to finishing pigs.

Feeding of SCRS to pigs altered both the carcass traits and the pork quality (Table 4). The carcass weight was significantly lower ($P < 0.05$) with the T1 and T2 diets compared to the C diet, but this was not the case with the T3 diet. However, SCRS feeding did not affect carcass yield (%) or subcutaneous fat thickness (cm) in either the outer or inner levels. For pork quality, no noticeable differences were observed in the pork color standard number (PCS No.), pork-fat color standard number (PFS No.), marbling score, or cooking loss (%) among the groups. The shear force value was significantly

Table 4 The effect on carcass traits and pork quality of finishing pigs fed SCRS †

Parameters	Treatment ‡			
	C	T1	T2	T3
Carcass weight (kg)	81.4 ± 6.1[a]	64.7 ± 7.1[b]	68.9 ± 4.9[b]	72.7 ± 6.7[ab]
Carcass yield (%)	63.0 ± 2.7	64.5 ± 1.6	64.8 ± 4.9	68.5 ± 1.8
Subcutaneous fat (cm)				
Outer layer thickness	3.6 ± 0.4	3.0 ± 0.5	3.1 ± 0.3	3.2 ± 0.5
Inner layer thickness	2.7 ± 0.4	2.2 ± 0.5	2.3 ± 0.3	2.3 ± 0.3
PCS No (1 – 6) §	2.7 ± 0.8	2.9 ± 0.2	3.1 ± 0.4	2.8 ± 0.3
PFS No (1 – 4) ¶	1.0 ± 0.1	1.3 ± 0.5	1.1 ± 0.2	1.3 ± 0.4
Marbling score (1 – 6 & 10)	1.8 ± 0.8	2.2 ± 0.6	2.7 ± 0.8	2.1 ± 0.4
Cooking loss (%)	32.7 ± 1.3	30.1 ± 2.2	32.7 ± 1.8	32.7 ± 2.4
Shear force (kg)	6.8 ± 0.6[a]	5.3 ± 1.2[ab]	5.1 ± 1.2[b]	5.9 ± 0.7[ab]

Values are means ± standard deviations of the means.
† SCRS (soybean curd residue silage).
‡ C (0% SCRS), T1 (15% SCRS), T2 (30% SCRS), T3 (60% SCRS).
§ PCS No (pork color standard number).
¶ PFS No (pork fat color standard number).
a,b Within a row, means without a common superscripts differ statistically (P<0.05).

lower (P < 0.05) with the T2 diet and marginally but not significantly lower (P > 0.05) for the T1 and T3 diets when compared with the C diet. Oshawa *et al.* (2004) observed no significant differences in the fat color of meat from pigs fed tofu cake when compared with the control group, in agreement with our current results. They also noted that the meat from pigs fed tofu cake tended to be tastier.

Because our data indicated a decrease in the amount of meat (carcass weight) as a consequence of weight gain, the quality parameters of the meat appeared to be improved with a tendency toward less subcutaneous fat, increased carcass yield, increased PCS No., increased PFS No., and in particular, a greater marbling score and lower shear force value in pigs fed SCRS compared with those fed the normal diet. Nevertheless, those parameters were not statistically significant except for the shear force value. Thus, we suggested that a diet containing SCRS improves pork quality.

The fat and fatty acid characteristics of the meat from finishing pigs fed SCRS are shown in Table 5. No significant differences in both saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA) were observed among the diets. On the other hand, total polyunsaturated fatty acids (PUFA) was lower (P < 0.05) in pigs fed the T2 or T3 diet as compared to those fed the C or T1 diet. Consequently, the PUFA/SFA ratio was less (P < 0.05) in pigs fed the T2 or T3 diet than in those fed the C or T1 diet. The PUFA mainly decreased in the T2 and T3 groups was n-6 fatty acids such as linoleic and arachidonic acids. The ratio of n–6/n–3 was slightly lower in pigs fed the T2 or T3 diet compared with those fed the C or T1 diet. The fat content (g/100 g meat) was higher (P < 0.05) in pigs fed the T2 or T3 diet than in those fed the C or T1 diet. In addition, there was no significant difference among the groups with respect to the melting point of fat.

Niwa and Nakanishi (1995) reported that tofu cake silage led to increased unsaturated fatty acids and lower body fat melting points in fattening pigs. Surprisingly, Osawa *et al.* (2004) indicated that meat from pigs fed tofu cake had higher inter-muscle fat and higher body fat melting points. On the other hand, the melting point of the fat in our experiment did not differ among pigs fed the various treatments, although we observed a lower total PUFA and PUFA/SFA ratio in pigs fed diets containing 30% or 60% SCRS than in those fed diets with 15% SCRS or a conventional diet. The differences in fat melting points between previous reports and our findings may be due to differences in fatty acid composition because fats containing different fatty acids have different melting points (Wood *et al.* 2008). The meat from pigs fed 30% or 60% SCRS had a higher fat content compared with diets containing 15% SCRS or the commercial ration. Huff-Lonergan *et al.* (2002) reported that increased lipid content in pork improves its firmness and the sensory characteristics involved in flavor. Furthermore, Brewer *et al.* (2001) reported that consumers evaluated highly marbled pork with fat, i.e., more fatty pork, to be more tender, juicy, and flavorful. Therefore, inter-muscle fat content is a remarkable characteristic of pork.

It is well known that dietary nutrition for animals

Table 5 The effect on fat and fatty acid profiles in meat from finishing pigs fed SCRS †

Parameters	Treatment ‡			
	C	T1	T2	T3
Fatty acid composition (wt %)				
C14:0	1.1 ± 0.3	1.1 ± 0.1	1.1 ± 0.1	1.2 ± 0.2
C16:0	25.0 ± 1.3	25.4 ± 0.4	25.5 ± 0.8	25.9 ± 0.9
C16:1 n-7	2.4 ± 0.3	2.9 ± 0.4	2.6 ± 0.3	2.8 ± 0.4
C18:0	14.1 ± 0.7	13.8 ± 1.1	14.1 ± 0.8	13.2 ± 0.6
C18:1 n-9	46.3 ± 2.2	46.1 ± 1.7	47.7 ± 1.2	47.7 ± 1.2
C18:2 n-6	6.6 ± 0.6^{a}	6.4 ± 1.1^{a}	5.0 ± 0.5^{b}	5.0 ± 0.8^{b}
C18:3 n-3	0.15 ± 0.02	0.14 ± 0.03	0.15 ± 0.01	0.20 ± 0.05
C20:4 n-6	0.85 ± 0.08^{ab}	0.89 ± 0.15^{a}	0.68 ± 0.13^{b}	0.67 ± 0.12^{b}
Total SFA	40.6 ± 1.3	40.8 ± 0.7	41.2 ± 1.6	40.7 ± 1.1
Total MUFA	51.5 ± 1.2	51.5 ± 1.8	52.7 ± 1.2	53.1 ± 1.5
Total PUFA	7.9 ± 0.7^{a}	7.8 ± 1.3^{a}	6.1 ± 0.7^{b}	6.2 ± 1.0^{b}
PUFA/SFA	0.195 ± 0.020^{a}	0.191 ± 0.031^{ab}	0.149 ± 0.022^{b}	0.152 ± 0.024^{b}
n–6/n–3	54.2 ± 3.4^{a}	53.8 ± 5.4^{a}	39.6 ± 2.4^{b}	30.8 ± 4.3^{b}
Fat content (g/100g meat)	5.3 ± 0.6^{a}	5.4 ± 1.1^{a}	7.8 ± 1.2^{b}	7.3 ± 1.1^{b}
Melting point (°C)	33.4 ± 1.1	33.3 ± 0.7	32.7 ± 1.5	32.7 ± 0.7

Values are means ± standard deviations of the means.
† SCRS (soybean curd residue silage).
‡ C (0% SCRS), T1 (15% SCRS), T2 (30% SCRS), T3 (60% SCRS).
a,b Within a row, means without a common superscripts differ statistically (P<0.05).

affects their meat quality. A number of studies have shown substantial increase in intramuscular fat from feeding protein-deficient diets to pigs (Ellis and McKeith 1999). Da Costa *et al.* (2004) indicated that restriction of dietary proteins results in the accumulation of significantly more intramuscular fat in both longissimus thoracis muscle and psoas major muscle in growing pigs. They supposed that low protein intake restricts muscle growth, resulting in surplus energy being converted into intramuscular lipids. In our study, the levels of crude protein as-fed basis in the experimental diets were 13.0% (C diet), 10.8% (T1 diet), 9.97% (T2 diet), and 8.09% (T3 diet), respectively. The decreased protein level in the SCRS-contained diets seems to be one of possible explanation for significant increase of intramuscular fat in the pigs. In addition, feeding of reduced protein diet to growing/finishing pigs have increased protein expression level of stearoyl-CoA desaturase in longissimus thoracis muscle, resulting in elevating level of MUFA in the muscle (Doran *et al.* 2006). In the present study, the SCRS feeding tended to increase the level of MUFA in pork loin. This modification of MUFA level in meat may ease a drastic alteration in melting point of the fat.

The ratio of n-6 to n-3 essential fatty acids is an important indicator for evaluating the nutritional quality of food lipids, and an n-6/n-3 ratio less than 4:1 is generally preferred (Loh *et al.* 2009). In the current study, feeding SCRS (30% or 60%) to finishing pigs resulted in a decreased n-6/n-3 ratio in the meat lipids, although the value of 30.8 ± 4.3 (T3 diet) was still higher than that of the recommended value. If the balance of n–6 and n-3 fatty acids in pork was improved, which could lead to greater nutritional profiles of the meat. Further investigation involved in lipid nutrition of pork is needed to enhance marketable value of the pork.

The bacteriological profile of the cecal content of finishing pigs was modified by dietary SCRS (Figure 1). Both coliform and *E. coli* numbers (log CFU/g) decreased dramatically ($P < 0.05$) in pigs fed the T1, T2, or T3 diet compared with those fed the C diet. The *Enterobacteriaceae* counts (log CFU/g) were significantly lower ($P < 0.05$) in pigs fed the T1 diet, but not statistically lower in pigs fed the T2 or T3 diet compared to those fed the C diet. There were no significant differences in the numbers of other bacteria (log CFU/g) such as *Campylobacter* spp. However, *Lactobacilli* counts (log CFU/g) were slightly higher in pigs fed the T1, T2, or T3 diet compared to pigs fed the C diet. Meanwhile, *Clostridium* spp. and *Listeria* spp. were not detected in all the dietary groups.

There are no published reports on the effects of SCRS feeding to pigs on the bacterial population in the

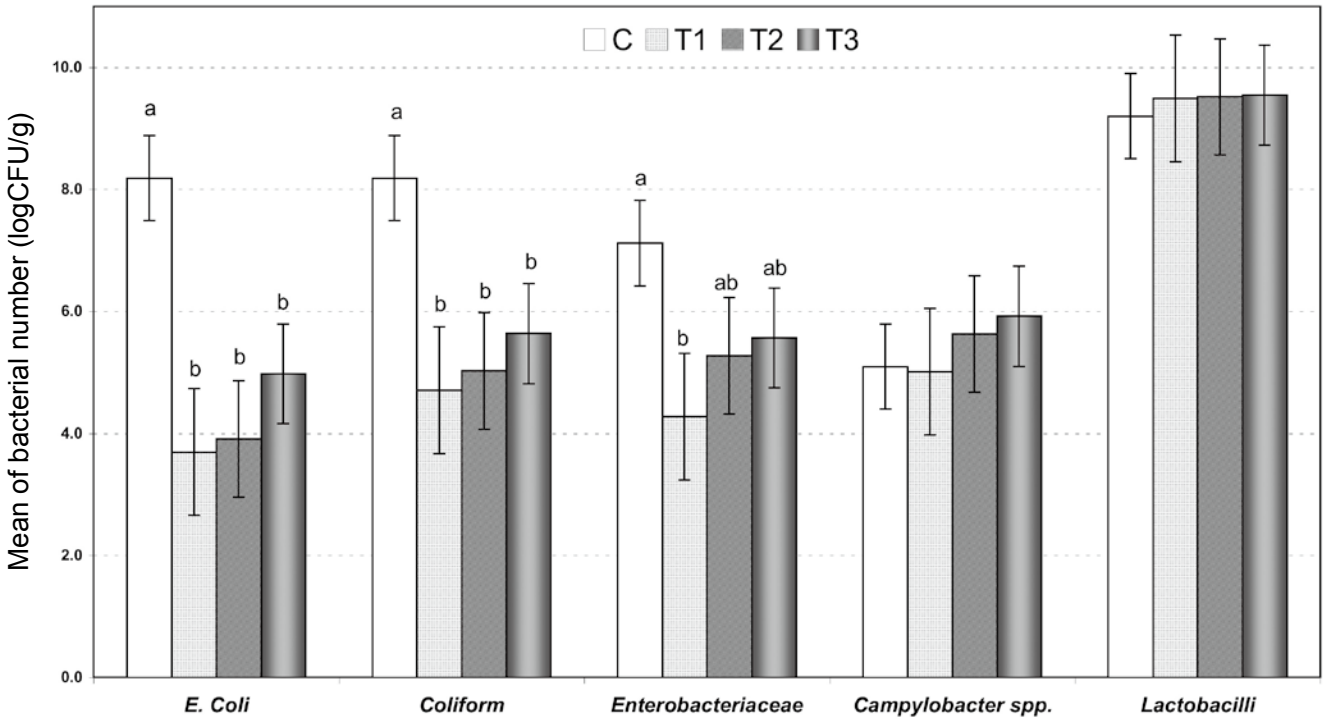

Figure 1 Bacterial numbers in the cecal content of pigs fed SCRS. From left to right, each group of 4 bars represents C (Control), T1 (15% SCRS), T2 (30% SCRS), and T3 (60% SCRS) diets. Within groups, means without a common superscript differ statistically ($P < 0.05$).

Table 6 The approximate estimate of economic aspects of pork production by means of SCRS † feeding

Parameters	Treatment ‡			
	C	T1	T2	T3
Price of feed (yen/kg) §	60.17	52.37	48.47	40.67
Feed cost per animal (yen/head) ¶	9748 ± 705	10203 ± 1047	10890 ± 1359	10356 ± 2046
Carcass price (yen/carcass)	28081 ± 3423	23810 ± 5646	28466 ± 2028	28436 ± 2521
Unit price of carcass (yen/kg)	348 ± 58	364 ± 56	413 ± 10	393 ± 58
Percentage of feed cost in carcass price	35.1 ± 4.3	45.6 ± 14.9	38.5 ± 6.4	36.4 ± 6.3

Values are means ± standard deviations of the means.
† SCRS (soybean curd residue silage).
‡ C (0% SCRS), T1 (15% SCRS), T2 (30% SCRS), T3 (60% SCRS).
§ Values are prices in fiscal year 2007.
¶ Values show only costs of the experimental feeds during experiment.

gastrointestinal tract (GIT). However, numerous works on feeding fermented feed to pigs have noted changes in GIT microbial ecology, including a reduction in *Enterobacteriaceae*, coliform, *E. coli* numbers, and/or an increase in lactic acid bacteria (LAB) counts (Prohaszka *et al.* 1990; Ravindran and Kornegay 1993; du Toit *et al.* 1998; van Winsen *et al.* 2001, 2002; Demecková *et al.* 2002). A reduction in the amount of enteropathogenic bacteria of the *Enterobacteriaceae* family may be due to events that occur during the fermentation process as follows: (i) competition for receptor sites of *lactobacilli* ingested from fermented feed (Mulder *et al.* 1997), (ii) lactic acids and VFAs created by LAB and fermented feed (Prohaszka *et al.* 1990), (iii) antimicrobial compounds produced by LAB (Apella *et al.* 1992; Olsen *et al.* 1995), (iv) low pH (Burnell *et al.* 1988; Ravindran and Kornegay 1993), and (v) a combination of these factors. In addition, the activity of bacteriocin in fermented taro could be another factor that reduces pathogenic bacteria (Muller *et al.* 2005). Therefore, the fermentation process of SCRS in our experiment may have induced the events mentioned above and may therefore be responsible for the changes in the cecal bacteria profile of the pigs. The reduction in *Enterobacteriaceae*, coliform, and *E. coli* numbers caused by feeding SCRS suggests

that SCRS feeding is safe to swine and produces a lower contamination level of enteropathogenic bacteria in the GIT.

Unit price of the SCRS used in this study was approximately half of the C diet. Thus, the prices of the experimental feeds fell with increasing amounts of added SCRS to feed (Table 6). However, the costs for each feed during finishing were higher in the SCRS-fed groups than in the C group because the feed intake increased in the SCRS-fed group (Table 3). On the other hand, carcass price were almost same between the C, T2, and T3 groups. The feed costs of those diets represented from 35 to 40 percent of each carcass price. These results suggest that use of the SCRS for pork production does not directly bring in pecuniary profit, while SCRS-preparation as a mean of food recycling could save huge energy costs. Ellis and McKeith (1999) noted that poorly balanced feeds reduce feed efficiencies and would be uneconomic in most situations. Further investigations to improve nutrition of SCRS-containing feeds are needed.

In conclusion, our results suggest that utilization of SCRS in feed for finishing pigs increases feed intake but does not change TDN intake. The growth performance did not differ significantly when pigs were fed 30% or 60% SCRS, but decreased when pigs were fed 15% SCRS. Feed containing SCRS improved the quality of the meat, as measured by a higher fat content and lower shear force, whereas feeding of SCRS to pigs almost did not affect fatty acid composition and melting point of the meats. Our data particularly suggests that incorporation of SCRS, even at a low level, had beneficial effects on cecal microbiology with a reduction in the *Enterobacteriaceae* population, coliform count, and *E. coli* number. Thus, SCRS may be interesting for bio-utilization as feed for finishing pigs when animal health and meat quality are the main objectives.

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要　約

オカラサイレージの給与が豚の発育成績，肉質，および盲腸内微生物数に及ぼす影響

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非加熱のリサイクル飼料製造法を開発する目的で、宮崎県内で発生した豆腐製造残さ（オカラ），親サトイモ発酵物等を混合した後、バッグ内で乳酸発酵させてオカラサイレージを調製した。さらに、このオカラサイレージを 15%，30% および 60% 含有し、トウモロコシ等で粗タンパク質量を調整した試験飼料を作製した。これらの飼料を仕上期の肥育豚に 60 日間自由摂食させた。同時に市販配合飼料を給与する試験区も設け、生産性の比較等を行った。肥育豚の発育成績はオカラサイレージ 15% 給与区のみが他の 3 区と比較して有意に低下した（$P<0.05$）。サイレージ 30% 区および 60% 区のロース肉は、他の 2 区のそれと比較して、脂肪含量が高く、剪断力価が低くなった。また、オカラサイレージの給与はロース肉の脂肪酸組成に明確な影響を及ぼさず、脂肪融点について試験区間で有意な差を認めなかった。また、他の 2 区と比較して、サイレージ 30% と 60%給与区では多価不飽和脂肪酸／飽和脂肪酸比および n-6/n-3 比が若干低下した。また、市販配合飼料を給与した豚と比較して、オカラサイレージを給与した豚の盲腸内容物では大腸菌群，エンテロバクター科細菌，および大腸菌の菌数が有意に減少した（$P<0.05$）。以上の結果から、オカラサイレージの肥育豚への給与は豚肉の品質を低下させず、肥育豚の衛生状態を改善できることが示唆された。

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