Effects of Level of Fresh Apple Pomace in Mixed Silage on Growth Performance, Meat Quality and Serum Metabolites in Finishing Pigs

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Abstract : Fifteen crossbred (Yorkshire×Duroc×Landrace) castrated male finishing pigs were used to evaluate differences in the growth performance, meat quality, and serum metabolites associated with mixed silages prepared with various proportions of fresh apple pomace (FAP). A basal feed consisting primarily of brown rice was used as the control. For the different treatments, FAP was added to basal feed at levels of 2% (AP2%), 4% (AP4%), 6% (AP6%), and 8% (AP8%) on a dry-matter (DM) basis and prepared into silage. The pigs were divided into five groups, each of which was fed either the control feed or one of the four FAP-supplemented feeds ad libitum during the experiment. Feed treatment did not significantly affect finished body weight, average daily gain, carcass weight, back fat thickness, or dressing ratio. However, average daily feed intake (ADFI) increased, and feed efficiency decreased, when the level of FAP supplementation was greater than 4%, and there were significant differences among the treatments ($P<0.05$). Compared with the control, frozen drip loss and cooking loss of meat decreased significantly when the FAP level was greater than 4% ($P<0.05$). The fatty acid composition of meat was not affected by feed components. However, serum HDL-cholesterol level related to animal health tended to ($P=0.079$) improve in the AP2%. These results suggest that 2% AP supplementation is favorable for pig growth performance, meat quality, and health.

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Key words : fresh apple pomace, growth performance, meat quality, finishing pigs, serum metabolites

Introduction

Apple pomace (AP) is a byproduct of apple juice that is produced in large quantities in many countries. Historically, fresh AP (FAP) has been considered difficult to use as feed because of its high moisture content. In comparison, dried AP is easy to incorporate into rations, and some studies have evaluated its use as pig feed (Bowden and Berry, 1958 ; Yamamoto et al., 2002a, b). However, drying FAP consumes large amounts of energy and is expensive. Therefore, using FAP in feed is recommended to save energy. In recent years, liquid feeding systems have become popular in many countries as means of using high-moisture food byproducts as pig feed, enabling the widespread use of FAP. However, few studies have examined the effects of FAP supplementation in pig feed. Fang et al. (2016b) reported that mixed silage containing 5% FAP improved feed efficiency but was associated with negative effects on meat quality : decreased water-holding capacity, increased cooking loss, and

increased levels of monounsaturated fatty acids related to soft fat. Therefore, it is necessary identify the levels of FAP required for optimal feed efficiency and meat quality. In recent years, the utilization of domestic forage rice has increased to reduce dependency on imported grain ; additionally, the proportion of rice in feed is increasing. Some farms that use homemade feed have replaced all of the corn with forage rice. Since most of these farms also use food byproducts, the combined effects of forage rice and food byproducts on fattening pigs should be investigated.

In the present study, FAP was mixed with basal feed consisting primarily of brown rice at various levels (2%, 4%, 6%, and 8% on a dry-matter (DM) basis), and the moisture content of mixtures was adjusted to prepare a silage. The mixed silages were then fed to finishing pigs, and the growth performance, meat quality, and serum metabolites were measured to determine the optimal proportion of FAP in pig feed.

Materials and methods

Preparation of experimental feed

FAP was obtained from a commercial juice factory (Aoren, Aomori, Japan). A basal feed consisting primarily of brown rice for finishing pigs was used as the control feed (Table 1). The cultivar of brown rice and unhulled rice in control feed was *Minayutaka* and they were pulverized in sizes of 1.0 mm and 0.7 mm, respectively. For the different treatments, FAP was added to control feed at levels of 2% (AP2%), 4% (AP4%), 6% (AP6%), and 8% (AP8%) on a DM basis. Before the experiment, small amounts of FAP and mixed silage were prepared at

different proportions and moisture levels to determine the optimal parameters with respect to fermentation quality and pig preference. We identified a moisture content of 40% as ideal. Before adjustment, the moistures of AP2%, AP4%, and AP6% were less than 40%, whereas the moisture of AP8% was greater than 40%. Therefore, we adjusted the moistures of AP2%, AP4%, and AP6% to 40% by adding water (Table 2). All silages were stirred well using a heavy mixer (SA-6, Owaki Industrial, Aichi, Japan), and the moisture contents were adjusted by gradually adding water. A total of 800 kg of each silage was prepared for each treatment and ensiled in equal quantities into four 200-L plastic drum silos (Maeda Manufacturing, Ichihara, Japan) after being fully compressed. The silos were then stored outdoors at 19.0–27.6℃ to ferment for 21 days.

Growth trial

Experiments were conducted according to the guidelines for proper conduct of animal experiments of the Science Council of Japan ; significant attention was devoted to animal ethics.

In total, fifteen crossbred (Yorkshire×Duroc× Landrace) castrated male pigs with an average ini-

Table 1. Ingredient proportion of basal feed

	Proportion (%)
Brown rice	73.8
Unhulled rice	7.0
Soybean meal	16.0
Palm oil	1.0
L-lysine	0.1
Compound enzymes	0.1
Mineral and vitamin premix	2.0

Table 2. Ingredient proportions (% FM1) of control feed and apple pomace mixed silages

	Control	AP2%[2]	AP4%[3]	AP6%[4]	AP8%[5]
Basal feed	100.0	68.0	66.6	65.5	59.1
Fresh apple pomace	0.0	11.7	23.0	33.9	40.9
Water	0.0	20.3	10.4	0.6	0.0

[1] Fresh matter.

[2,3,4,5] Mixed silage prepared by adding apple pomace to basal feed at ratio of 2%, 4%, 6% and 8% on dry matter basis, respectively.

tial body weight (BW) of 71.3±1.2 kg were used in the growth trial. Each pig was assigned to one of five diet treatments using a randomized complete block design according to BW. The treatments included AP2%, AP4%, AP6%, AP8%, and a control (basal feed). Pigs were housed individually in pens (207 cm×53 cm×83 cm) with concrete floors. The pigpen building was naturally ventilated (with windows and curtains), and pens were not environmentally controlled. All pigs were provided with ad libitum access to feed and water throughout the 49-day experimental period. Weekly BW and daily feed intake of each pig were measured to evaluate feed efficiency and growth performance.

Blood was collected from the jugular vein of each pig using a heparinized vacuum tube before the morning feeding on the first and last days of the experimental period. The blood samples were centrifuged at 1200×g for 10 minutes at 4℃. The serum was separated and stored in a plastic tube and preserved at 4℃ for analysis.

Sampling and chemical analyses

Silage samples for chemical analyses were taken in equal quantities from the upper, middle, and lower parts of drum silos. They were combined and mixed fully before final samples were collected. Silage fermentation products were determined from cold-water extracts. Wet silage (100 g) was homogenized with 300 mL sterilized distilled water and stored at 4℃ overnight (CAO *et al.*, 2009). The filtrate pH was measured using a glass-electrode pH meter (Horiba D-21 ; Horiba, Tokyo, Japan). The lactic acid content of silages was determined using the method of BARKER and SUMMERSON (1941). Volatile fatty acid was steam-distilled and measured qualitatively and quantitatively by gas chromatography (G-5000A ; Hitachi, Tokyo, Japan). The ethanol content of silages was determined using the method of XU *et al.* (2001). To determine chemical compositions, basal feed and silages were dried in a forced-air oven at 60℃ for 48 h and ground to pass through a 1-mm screen using a sample mill. The DM, crude protein (CP), ether extract (EE), and ash were analyzed according to methods 934.01, 976.05, 920.39, and 942.05, respectively, of the AOAC (1990).

Acid detergent fiber (ADFom) and neutral detergent fiber (aNDFom) were analyzed according to the method of VAN SOEST *et al.* (1991). Heat-stable amylase and sodium sulfite were used in the aNDFom procedure, and results are expressed without residual ash. The total phenolic compound content of FAP was determined using a modification of the Folin– Ciocalteu method. Briefly, FAP (0.5 g) was extracted with 5 mL 80% ethanol for 24 h. The extract solution was collected by centrifugation (1000 rpm, 10 min). Then, 0.2 mL of the extracted solution was mixed with 0.2 mL of Folin–Ciocalteu's Reagent Solution (Nacalai Tesque, Inc., Kyoto, Japan) and 3.2 mL diluted water, and 0.2 mL of a saturated sodium carbonate was added. The mixture was allowed to stand for 30 min at room temperature, and the absorbance was measured at 760 nm. The phenolic compound content was expressed as pyrogallol equivalent. Analyses of the serum lipid components triacylglycerol (TAG), phospholipids (PL), total cholesterol (T-Chol), high-density lipoprotein-cholesterol (HDL-C), and low-density lipoprotein-cholesterol (LDL-C)) were performed by a commercial service (Japan Medical Laboratory, Osaka, Japan).

At the end of the experimental period, all pigs were transported to a local commercial abattoir for slaughter. After the carcasses were chilled for 48 hours at 1℃, we measured carcass weight and back fat thickness (using the thinnest section between the 9th and 13th ribs). The longissimus thoraces muscle between the 5th and 6th thoracic vertebrae was collected for analysis of physical and chemical characteristics. Meat color was measured using the Japanese pork color standards based on a six-point scale for meat (1＝extremely pale pink, 6＝extremely dark red). The marbling scores were assessed according to the National Pork Producers Council standards. The pH, frozen and refrigeration drip loss rates of the meat were measured using the method of IRIE (2002). The water-holding capacity of the meat was measured using the method of SHIMAZAWA *et al.* (2008). Cooking loss was measured using chunks of meat cut into cubes measuring 30 mm×30 mm×10 mm. The meat chunks were cook-

ed on both sides for 2.5 minutes at 200℃ using a hot plate ; the cooking loss rate was calculated by the change in meat weight. The moisture, CP, EE, and ash contents of the meat were measured after the meat was minced using the same method used for the experimental feed. The melting point of the inner layer of back fat was measured using the method of Nishioka and Irie (2005).

The total lipids of the meat were extracted with a mixture of chloroform/methanol (2 : 1, v/v) and transmethylated using sodium methoxide (0.5 M) to obtain the fatty acid methyl esters. The methyl esters were further analyzed by gas chromatography (Shimadzu GC-14B, Shimadzu Corporation, Kyoto, Japan). The gas chromatograph was equipped with flame ionization detector (FID) and Omegawax 320 (Sigma-Aldrich, St. Louis, USA) fused silica capillary columns (30 m, 0.32 mm i.d.). The detector, injector, and column temperatures were 260℃, 250℃, and 200℃, respectively.

Statistical analyses

The results were expressed as mean±standard error (S.E.). Statistical analyses involving multiple groups were conducted using ANOVA. Statistical comparisons were made using Tukey–Kramer tests. Differences were considered as significant at a threshold of $P < 0.05$. Analyses were performed using Stat View-J software (ver. 5.0 ; Abacus Concepts Inc., CA, USA).

Results

Chemical compositions of experimental feed

FAP had a very high moisture content (83.1%, Table 3). Furthermore, total phenolic compound content was 1.02 mg/g. The CP content of FAP was lower than that of control feed, whereas the ADFom and aNDFom content of FAP were higher than those of control feed. Therefore, the CP content of four mixed silages decreased, whereas the ADFom and aNDFom content increased, with increasing levels of FAP. As a fermentation product, lactic acid content decreased with FAP level, ranging from 0.25−1.08% (Table 4). However, acetic acid and ethanol content increased with FAP level ; they ranged from 0.11% to 0.33% and 0.37% to 2.34%, respectively, reaching their highest values at 6% FAP. No propionic or butyric acid was detected in any of the four silages.

Growth performance, carcass traits and serum compositions

With respect to growth performance, finished BW and average dairy gain (ADG) were not significantly affected by the feed treatment (Table 5). However, the average daily feed intake (ADFI) of dry matter in the control group was significantly lower than that of the group receiving AP6% treatment ($P < 0.05$), and the feed efficiency of the control and AP2% treatments was higher than those of the other treatments ($P < 0.05$). There was no significant dif-

Table 3. Chemical composition of fresh apple pomace, control feed and mixed silsges

	Apple pomace	Control	AP2%[1]	AP4%[2]	AP6%[3]	AP8%[4]
Moisture (%)	83.1	13.6	41.7	40.2	41.6	45.2
Crude Protein (% DM[5])	6.6	14.8	14.6	14.5	14.3	14.2
Ether Extract (% DM)	5.6	2.4	2.5	2.5	2.6	2.6
ADFom[6] (% DM)	46.0	3.4	4.2	5.0	5.8	6.5
aNDFom[7] (% DM)	55.8	6.4	7.4	8.3	9.2	10.1
Ash (% DM)	3.9	4.0	4.0	4.0	4.0	4.0
Phenolic (mg/g)	1.02	—	—	—	—	—

[1,2,3,4] Mixed silage prepared by adding apple pomace to basal feed at ratio of 2%, 4%, 6% and 8% on dry matter basis, respectively.

[5] Dry matter.

[6] Acid detergent fiber.

[7] Neutral detergent fiber.

Table 4.　Fermentation product of apple pomace mixed silages

	AP2%[1]	AP4%[2]	AP6%[3]	AP8%[4]
pH	4.5	4.5	4.8	4.9
Lactic acid (% FM[5])	1.08	0.69	0.38	0.25
Acetic acid (% FM)	0.11	0.23	0.33	0.26
Propionic acid (% FM)	ND[6]	ND	ND	ND
Butyric acid (% FM)	ND	ND	ND	ND
Ethanol (% FM)	0.37	1.48	2.34	1.98

[1,2,3,4] Mixed silage prepared by adding apple pomace to basal feed at ratio of 2%, 4%, 6% and 8% on dry matter basis, respectively.
[5] Fresh matter.
[6] Not determined.

Table 5.　Growth performance and carcass characteristics of pigs fed experimental feed

	Control	AP2%[1]	AP4%[2]	AP6%[3]	AP8%[4]
	Mean±SE[5]				
Initial body weight (kg)	70.3±0.33	70.7±0.67	71.3±0.67	72.3±0.67	71.7±0.88
Finished body weight (kg)	109.3±2.60	114.7±2.03	107.7±1.45	112.0±0.58	107.0±1.00
Average dairy gain (kg)	0.80±0.06	0.89±0.04	0.74±0.04	0.81±0.02	0.72±0.01
Average dairy feed intake (kgDM[6])	2.43±0.09^{ab}	2.75±0.03^{ab}	2.82±0.19^{ab}	2.95±0.02^{b}	2.65±0.05^{ab}
Feed efficiency (gain/feed)	0.33±0.01^{a}	0.33±0.01^{a}	0.26±0.00^{b}	0.27±0.01^{b}	0.27±0.01^{b}
Carcass weight (kg)	73.8±1.01	74.2±0.83	70.0±2.08	71.5±1.15	69.8±1.09
Back fat thickness (cm)	2.3±0.25	2.3±0.31	1.8±0.25	1.7±0.35	1.9±0.29
Dressing ratio (%)	67.6±1.45	64.7±1.43	65.0±1.78	63.8±1.24	65.3±0.42

[1,2,3,4] Mixed silage prepared by adding apple pomace to basal feed at ratio of 2%, 4%, 6% and 8% on dry matter basis, respectively.
[5] Standard error (n=3).
[6] Dry matter.
[a,b] Means within a row with different letters differ ($P<0.05$).

ference in carcass weight, back fat thickness, or dressing ratio among the treatments, although the carcass weight and back fat thickness tended to be lower in the AP4% ($P=0.065$) and AP8% ($P=0.056$) treatment groups. Table 6 presents the serum composition of each diets groups. The triacylglycerol level of the AP6% was significantly higher ($P<0.05$) than that of the control group. The HDL cholesterol level of the AP2% and AP6% treatment groups tended to be higher (AP2%, $P=0.079$; AP6%, $P=0.061$) than that of the control group, but the difference was not significant. The LDL/HDL cholesterol ratio, which indicates cardiovascular disease risk was not different in AP2%, AP4%, AP8% treat-

ment groups compared with the control group. However, the ratio was lower ($P<0.05$) in AP6% treatment groups (Table6).

Meat quality

The physical and chemical characteristics of meat were not affected by diet treatment, with the exception of refrigeration drip loss, frozen drip loss, and cooking loss (Table 7). Although the refrigeration drip loss in the AP2% group was higher than that in the AP6% group ($P<0.05$), the results for other treatments indicated that the change was not related to FAP level. Frozen drip loss and cooking loss decreased significantly when the FAP level was greater than 4%, and there were significant differ-

Table 6.　Serum compositions of pigs fed experimental diet

	Control	AP2%[1]	AP4%[2]	AP6%[3]	AP8%[4]
	Mean±SE[5]				
Triacylglycerol (mg/dL)	19.0±4.6[a]	30.7±14.5[a]	21.7±4.6[a]	56.0±25.2[b]	39.3±4.7[a]
Phospholipids (mg/dL)	111.7±17.4	138.7±24.9	123.3±28.9	148.7±10.3	121.7±22.5
Total cholesterol (mg/dL)	85.3±11.0	98.7±1.5	87.7±14.0	97.3±8.1	88.0±15.1
HDL cholesterol (mg/dL)	40.0±5.2	51.0±6.2	45.3±10.3	54.0±6.0	42.3±11.1
LDL cholesterol (mg/dL)	44.3±6.7	46.7±7.2	41.0±8.7	38.3±4.7	44.3±6.0
LDL/HDL ratio[6]	1.11±0.08[b]	0.94±0.16[b]	0.93±0.14[b]	0.71±0.06[a]	1.08±0.12[b]

[1,2,3,4] Mixed silage prepared by adding apple pomace to basal feed at ratio of 2%, 4%, 6% and 8% on dry matter basis, respectively.
[5] Standard error (n=3).
[6] LDL/HDL ratio was calculated by serum LDL cholesterol divided by serum HDL cholesterol.
[a,b] Means within a row with different letters differ ($P<0.05$).

Table 7.　Physical and chemical characteristics of longissimus thoraces muscle of pigs fed experimental diet

	Control	AP2%[1]	AP4%[2]	AP6%[3]	AP8%[4]
	Mean±SE[5]				
pH	5.4±0.06	5.4±0.00	5.3±0.00	5.5±0.03	5.4±0.00
Moisture (%)	73.3±0.52	73.5±0.22	72.7±0.87	72.2±0.65	72.2±0.26
Crude protein (%)	22.7±0.38	23.4±0.03	23.6±0.50	23.5±0.25	23.3±0.09
Ether extract (%)	2.5±0.19	1.9±0.30	2.3±0.95	3.0±0.84	3.2±0.26
Refrigeration drip loss (%)	2.3±0.57[ab]	3.8±0.48[a]	2.8±0.38[ab]	1.9±0.35[b]	3.6±0.12[ab]
Frozen drip loss (%)	7.4±0.99[a]	7.0±0.61[a]	3.2±0.15[b]	1.5±0.03[b]	3.4±0.56[b]
Cooking loss (%)	28.7±1.99[a]	29.1±0.30[a]	27.5±0.58[a]	25.0±0.72[a]	22.7±0.22[b]
Water holding capacity (%)	79.2±0.23	79.6±0.50	80.2±0.44	80.2±0.41	80.8±0.29
Marbling score	1.7±0.17	1.7±0.17	1.5±0.29	2.3±0.44	2.7±0.33
Pork color standard	2.2±0.17	1.5±0.00	1.5±0.29	2.5±0.29	1.5±0.00
Back fat color standard	1.3±0.17	1.8±0.33	1.7±0.17	1.0±0.00	1.5±0.29
Back fat melting point (℃)	41.9±0.52	45.2±0.57	42.9±0.62	42.8±1.07	42.6±0.76

[1,2,3,4] Mixed silage prepared by adding apple pomace to basal feed at ratio of 2%, 4%, 6% and 8% on dry matter basis, respectively.
[5] Standard error (n=3).
[a,b] Means within a row with different letters differ ($P<0.05$).

ences among the treatments ($P<0.05$). The main fatty acids in meat were oleic acid (C18 : 1), palmitic acid (C16 : 0), and stearic acid (C18 : 0). Fatty acid composition did not significantly differ between control and FAP treatment groups (Table 8).

Discussion

Many studies have evaluated the effects of feeding FAP to ruminants, and these studies have shown that, whether used alone or mixed with other materials, FAP is particularly suitable for silage preparation owing to its high soluble carbohydrate content (ALIBES et al., 1984 ; PIRMOHAMMADI et al., 2006 ; FANG, 2009 ; FANG et al., 2016a). However, few studies have focused on FAP silage as pig feed. In the present study, we prepared four types of silage containing different levels of FAP (AP2%, AP4%, AP6%, and AP8%) with favorable preser-

Table 8. Fatty acids composition (%, w/w) in back fat of pigs fed experimental diet

	Control	AP2%[1]	AP4%[2]	AP6%[3]	AP8%[4]
			Mean±SE[5]		
C14 : 0	1.38±0.095	1.51±0.130	1.35±0.051	1.76±0.410	1.54±0.160
C16 : 0	27.5±0.46	29.2±0.66	27.3±0.50	30.0±2.10	28.4±0.87
C16 : 1 n-7	2.42±0.240	2.42±0.018	2.22±0.110	2.94±0.930	2.68±0.390
C17 : 0	0.186±0.020	0.103±0.089	0.231±0.014	0.150±0.130	0.207±0.051
C17 : 1	0.164±0.006	0.091±0.079	0.215±0.018	0.141±0.120	0.191±0.037
C18 : 0	16.6±0.83	17.4±0.97	16.6±0.25	15.5±2.00	16.0±0.89
C18 : 1 n-9	42.6±0.51	40.5±0.60	42.3±0.44	40.5±0.49	41.6±1.10
C18 : 1 n-7	2.62±0.072	2.79±0.081	2.83±0.053	2.99±0.420	2.87±0.210
C18 : 2 n-6	4.69±0.300	4.33±0.170	5.05±0.510	4.54±0.630	4.70±0.380
C18 : 3 n-3	0.205±0.032	0.106±0.093	0.194±0.033	0.121±0.100	0.178±0.005
C20 : 0	0.230±0.011	0.194±0.170	0.193±0.017	0.131±0.110	0.201±0.019
C20 : 1 n-11	0.807±0.064	0.991±0.270	0.822±0.110	0.814±0.086	0.770±0.110
C20 : 2 n-6	0.203±0.018	0.128±0.110	0.213±0.002	0.151±0.130	0.129±0.110

[1,2,3,4] Mixed silage prepared by adding apple pomace to basal feed at ratio of 2%, 4%, 6% and 8% on dry matter basis, respectively.
[5] Standard error (n=3).

vation qualities, as indicated by low pH and high lactic acid levels. PCAF (1991) reported that ethanol had an antiseptic effect when added to high-moisture silage at levels of 1–2% of silage DM. In the present study, the high ethanol content of the prepared silage may have promoted long-term preservation. The relationships between fermentation products and FAP levels in feed were consistent with those reported by FANG et al. (2016a).

As a feed material, FAP is characterized by high fiber and low CP content (GASA et al., 1992 ; KENNEDY et al., 1999). This has raised concerns about possible negative effects on growth performance when high levels of FAP are used without adjusting CP and energy content. BOWDEN and BERRY (1958) reported that ADG and feed efficiency were not affected by dried AP when it comprised less than 20% of feed after CP was supplemented to reach the same levels as the control. FANG et al. (2016b) prepared a mixed silage by adding FAP to a basal feed consisting primarily of corn without adjusting the composition ; they fed the mixed silage to pigs to evaluate their growth performance. Their results showed that FAP supplementation at a level of 5% did not affect ADG, and it improved feed efficiency without the need to adjust composition.

In the present study, we added 2–8% FAP to a basal feed consisting primarily of brown rice without adjusting feed compositions. In terms of growth performance, we found that FAP supplementation did not affect ADG. However, FAP supplementation did decrease feed efficiency at levels greater than 2%, owing to increased ADFI. Therefore, our results were inconsistent with those of FANG et al. (2016b). In both FANG et al. (2016b) and the present study, lactic acid, acetic acid, and ethanol were produced at various levels during silage fermentation. Some previous studies indicate that organic acid and ethanol ingestion affect growth performance and feed efficiency. For instance, for fatting pigs, CANIBE and JENSEN (2003) reported that fermented liquid feed containing lactic acid tended to improve ($P=$ 0.05) feed efficiency compared with non-fermented liquid feed. Other studies have also reported that organic acids improve growth performance and feed efficiency for growing pigs and piglets (ROTH and KIRCHGESSNEER, 1998 ; PARTANEN et al., 2002). PCAF (1991) reported that the addition of ethanol improved feed efficiency for fatting pigs raised in confined spaces, and this effect was attributed to the

positive effects of ethanol on stress reduction and relaxation. However, these previous studies did not investigate the interacting effects of ethanol and organic acids. In the present study, lactic acid, acetic acid, and ethanol levels ranged from 0.25% to 1.08%, 0.11% to 0.35%, and 0.37% to 2.34%, respectively. These levels significantly differed from those of FANG et al. (2016b), which were 1.08%, 1.04%, and 0.99%, respectively. Therefore, the observed difference in feed efficiency between the present study and FANG et al. (2016b) may have been partially caused by interactions between organic acids and ethanol in addition to the difference in main feed components (brown rice and corn, respectively). The significant decreases in feed efficiency for the AP6% and AP8% treatments may have been related to the high levels of crude fiber from FAP in feed and without compensatory adjustment to CP, lysine and energy content. Since ethanol, which is generated naturally in feed, has a high energy concentration, the energy loss caused by ethanol volatilization during feeding may help explain the decreasing feed efficiency of the AP4%, AP6%, and AP8% treatments. Furthermore, MACPHERSON and VIOLANTE (1966) reported that lysine can be decomposed in silage and KATSUMATA et al. (2005) reported that low-lysine feed decreased the feed efficiency of fattening pigs. Although the lysine level in the control feed and four FAP-added silages was not determined, the decreased feed efficiency of AP4%, AP6% and AP8% may be related to lysine decomposition in silage. Thus, lysine metabolism in silage for fattening pigs must be considered seriously in the future.

As FAP level had inconsistent effects on feed efficiency for pigs, further studies should be conducted using larger sample sizes. Although carcass weight, back fat thickness and dressing ratio were not affected by diet treatment, the differences in relative lower carcass weight and back fat thickness for the AP4%, AP6%, and AP8% treatments indicate that feed composition should be considered when FAP supplementation is employed at levels greater than 4%.

Recently, high-nutrient feed types (in particular,

fatty feed) have been used for domestic animals to improve meat quality in short-term fattening. However, this feeding management is known to induce stress for animals and may cause disease. Therefore, various natural bioactive components, such as phenolic compounds, have been used in feed material (ISHIDA et al., 2004). Apples contain phenolic compounds, such as procyanidins, catechin, epicatechin, and the chlorogenic acid polyphenol (SHOJI et al., 2003). Human and animal studies have shown that these compounds help prevent obesity-related diseases (FRANKEL et al., 1993 ; EBERHARD et al., 2000), improve lipid metabolism, increase HDL cholesterol level, and prevent coronary heart disease (NAGASAKO et al., 2005). However, it has also been reported than animal feed containing phenolic compounds is associated with decreased feeding efficiency, which represents an obstacle to their practical use (SUZUKI et al. 2002). In this study, although FAP supplementation affected the feed efficiency and drip loss and cooking loss of meat, but the HDL cholesterol levels in the FAP 2% treatment groups tended to be higher ($P=0.079$) than those in the control group. FAP6% treatment groups also tended to ($P=0.061$) improve HDL cholesterol level (Table6), but its triacylglycerol level was significantly ($P<0.05$) increased compared with control group. This suggests that dietary FAP helps to prevent pig diseases related to high-nutrient feed and reduces stress on domestic animals, but to prevent a decrease in feed efficiency, the feed composition should be adjusted when FAP supplementation is used at levels exceeding 4%.

Reports on the effects of food products containing fermented feed (silage) on the physical and chemical characteristics of animals have provided a wide range of results (KIM et al., 2006 ; SHIMAZAWA et al., 2008 ; LEE et al., 2009 ; YAN and KIM, 2011 ; YAN et al., 2012). However, these previous studies rarely discussed the relationship between meat quality and the levels of fermentation products. In the present study, we noted a decrease in frozen drip loss and cooking loss in the AP4%, AP6%, and AP8% treatments. Because these variables can be affected by a number of factors (IRIE 2002) and because the levels

of ethanol, acetic acid, and lactic acid varied inversely with FAP level, it is difficult to determine whether the observed changes were caused by FAP levels or by fermentation products. As described above, we found that water-holding capacity was not affected by diet treatment, and our findings regarding cooking loss differed from those of Fang *et al.* (2016b) for unclear reasons.

The fatty acid composition of meat is affected by feed composition. Feed supplemented with 3% green tea containing polyphenol upregulated 18 : 2n-6 and 18 : 3n-3 fatty acid content in pork loin (Suzuki *et al.* 2002). However, in the present study, the fatty acid composition of meat did not vary among experimental groups. The total phenolic compound content in FAP was 1.02 mg/g and, therefore, even lower in the feed. We suspect that FAP supplementation did not affect the fatty acid composition of meat because of the levels of polyphenol administration.

Based on our results, the relationship between meat quality and the level of FAP supplementation or silage fermentation products remains unclear in many respects and should be investigated further.

Conclusion

The results of the present study indicate that FAP is easy to ferment benignly when mixed with formula feed for pigs. From a practical perspective, when FAP is fed to pigs using a liquid feeding system, it should be used immediately after production (i.e., without fermentation). If FAP cannot be used immediately after production, excessive fermentation should be prevented by adjusting the moisture content or adding organic acids.

Although we found no difference in growth performance among the treatments, FAP levels greater than 4% were associated with reduced final BW, ADG, and feed efficiency. We observed decreased frozen drip loss and cooking loss in the AP4%, AP6%, and AP8% treatments, indicating some positive effects of FAP on meat quality. Fatty acid levels did not differ among treatments. Serum HDL-cholesterol parameters related to animal health tended to improve in the AP2% and AP6%

(AP2%, $P=0.079$; AP6%, $P=0.061$) treatment. However, serum triacylglycerol level related to index degree of arteriosclerotic significantly ($P<0.05$) worsened in AP6%.

Based on our results for growth performance and feed efficiency, we conclude that FAP should be added to feed at a level no less than 2% on a DM basis.

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リンゴ粕混合発酵飼料の給与が肥育豚の発育，
肉質および血液成分に及ぼす影響

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要　約　　青森県ではリンゴ果汁加工業者から排出されるリンゴジュース搾り粕（以下：リンゴ粕）の処理が問題となっている。特に乾燥加工処理されていない生リンゴ粕は含水量が高く，飼料としての活用が困難な素材である。近年，日本で広がりつつあるリキッドフィーディング養豚システムは，水分含量の高い食品残さでも乾燥加工費をかけることなく使用できる方法である。また，効率的な給与が可能であることから，今後益々の利用の拡大が期待される。
　本研究では，生リンゴ粕を使用したリキッドフィーディングに最適な生リンゴ粕の添加割合について検討をおこなった。慣行飼料（対照区）に対し，生リンゴ粕を乾物割合で2%（AP2%），4%（AP4%），6%（AP6%），8%（AP8%）加えた後，水分を調整した混合サイレージを作製し，それぞれの飼料の化学成分および発酵品質を分析した。次に平均体重約70kgの三元交雑種去勢豚15頭を各区に3頭ずつ割り当て，それぞれの飼料にて49日間の肥育試験を実施した。肥育試験終了後，発育成績，肉質，及び血清脂質成分について分析をおこなった。
　対照区と比較し，リンゴ粕添加した各試験区では終了体重，増体量，枝肉重量および背脂肪厚に差は認められなかった。一方，AP4%，AP6%，AP8%区では対照区と比較し飼料摂取量が増加し，飼料効率が低下した（P＜0.05）。肉の凍結ドリップ損失率および加熱損失率はAP8%において対照区に比べ有意に低下した（P＜0.05）。肉の脂肪酸組成は各試験区間で差は認められなかった。また血清脂質成分にも差はなく，豚の健康状態に影響はなかった。以上の結果から本実験の割合での生リンゴ粕の添加では増体重や枝肉重量に影響がないものの，飼料効率の低下を防ぐためには添加割合2%以内にすることが望ましいことが示唆された。

キーワード：リンゴ粕混合発酵飼料，発育成績，肉質，肥育豚，血液成分