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ORIGINAL ARTICLE

Effects of apple pomace-mixed silage on growth performance and meat quality in finishing pigs

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ABSTRACT

We measured the growth performance and meat quality of 10 crossbred (Yorkshire × Duroc × Landrace) neutered male pigs to evaluate the effects of apple pomace-mixed silage (APMS). The pigs were divided into two groups and were respectively fed the control feed and the AMPS *ad libitum* during the experiment. No difference was found in the finished body weight, average daily gain, carcass weight, back fat thickness or dressing ratio between the control and the AMPS treatments, but average dairy feed intake (dry matter) was significantly lower and feed efficiency was significantly higher using the APMS treatment ($P < 0.05$). With regard to meat quality, the APMS increased the moisture content but decreased the water holding capacity ($P < 0.05$) compared with the control treatment. Furthermore, the APMS affected the fatty acid composition of the back fat by increasing linoleic acid (C18:2n6), linolenic acid (C18:3) and arachidic acid (C20:0) levels, while decreasing palmitic acid (C16:0), palmitoleic acid (C16:1) and heptadecenoic acid (C17:1) levels, compared with the control treatment. These results indicate that feeding fermented apple pomace to finishing pigs increases the feed efficiency and affects the meat quality and fatty acid composition of back fat.

Key words: *apple pomace, finishing pigs, growth performance, meat quality, silage.*

INTRODUCTION

In recent years, the worldwide demand for grain production has been increasing due to the needs of biomass ethanol production and shortages of feed grain. The use of food by-products as feed components may be an effective means of addressing this problem.

Apple pomace is a by-product of apple juice production and is produced in huge amounts in many countries. As feed material, the chemical composition of fresh apple pomace is characterized by high moisture and sugar content, together with a low content of crude protein (CP) (Gasa *et al*. 1992; Kennedy *et al*. 1999). Many studies have evaluated the effects of feeding fresh apple pomace to ruminants (Bovard *et al*. 1977; Fontenot *et al*. 1977; Oltjen *et al*. 1977). However, studies of the effects of apple pomace on pigs are lacking and only dried apple pomace has been used (Bowden & Berry 1958; Yamamoto *et al*. 2002a, b). At present, the drying process for high-moisture food by-products consumes large amounts of energy, is high in cost and has environmental consequences. In turn, dried apple pomace is not recommended for use as a feed component. In recent years, liquid feeding systems have gradually become more dominant as effective methods of feeding pigs high-moisture food by-products. Apple pomace is particularly suitable for liquid feeding systems, due to its high moisture content and the ease with which it homogenizes with other materials after mixing with water.

Moreover, apple pomace contains many functional ingredients, such as dietary fiber (Wang & Thomas 1989) and polyphenols (Lu & Foo 2000), which help to regulate intestinal function and provide antioxidants, respectively. Fresh apple pomace is easy to ferment both alone and mixed with other materials and produces many organic acids and ethanol (Alibes *et al*. 1984). Notably, ethanol has a positive effect on stress reduction and relaxation when ingested in small amounts (Promotion Committee of Alcohol Feed (PCAF) 1991). These functional ingredients may promote pig health and in turn, improve growth performance and meat quality.

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In this study, fresh apple pomace was mixed with control feed at a dry matter (DM) level of 5% and the moisture content was adjusted to 50% to prepare the silage. The silage was fed to finishing pigs. The growth performance and meat quality of the pigs were measured to evaluate the effect of fresh apple pomace feeding methods.

MATERIALS AND METHODS

Animals and diet

Experiments were conducted according to the institutional guidelines for animal experiments of the Faculty of Agriculture and Life Science, Hirosaki University, Hirosaki, Japan.

Ten crossbred (Yorkshire × Duroc × Landrace) neutered male pigs, with body weights of approximately 70 kg, were used in the growth trial. The pigs were randomly assigned into two dietary treatment groups: one consisting of formula feed (the control treatment) and one consisting of apple pomace-mixed silage (APMS). A commercial formula feed (THK-Nikuton-EXA, Kyodo Shiryo Co. Ltd., Aomori, Japan) for finishing pigs was used as the control feed (Table 1). The feed for the APMS treatment was prepared by mixing the control feed, fresh apple pomace (Aoren, Aomori, Japan), and water together in a ratio of 55.0% to 14.8% to 30.2%, respectively, to produce an apple pomace DM proportion of 5% and a moisture content of 50%. A total of 2000 kg of APMS was prepared and ensiled in 200 L plastic drum silos (Maeda Manufacturing, Ichihara, Japan), which were stored outdoors (9.7-20.1°C) for 21 days of fermentation.

During the experimental period, the pigs were reared individually in exclusive cage (207 cm × 53 cm × 83 cm) with concrete floors. The pigpen building was naturally ventilated (with windows and curtains) and not environmentally controlled. The pigs had *ad libitum* access to feed and water during the 53 days of the experimental period. For each pig, weekly weight and daily feed intake were measured to evaluate growth performance.

Sampling and chemical analyses

The moisture, CP, ether extract (EE) and ash components of the feed were analyzed according to methods 934.01, 976.05, 920.39, and 942.05, respectively, of the Association of Official Analytical Chemists (AOAC 1990). Acid detergent fiber (ADFom) and neutral detergent fiber (aNDFom) were analyzed according to the method of Robertson and Van Soest (1981) and Van Soest *et al.* (1991). Heat-stable amylase and sodium sulfite were used in the aNDFom procedure; the results are expressed without residual ash. Fermentation products of APMS were determined from cold-water extracts. Wet silage (100 g) was homogenized with 300 mL sterilized distilled water and stored at 4°C overnight (Cao *et al.* 2009). The filtrate pH was measured using a glass-electrode pH meter (Horiba D-21, Horiba, Tokyo, Japan). The organic acid levels of the APMS were determined by the method of Cao *et al.* (2014) and the ethanol content of the APMS was determined using the method of Xu *et al.* (2001).

At the end of the experimental period, all of the pigs were transported to a local commercial abattoir (Oirase, Aomori, Japan) for slaughter. After the carcasses were chilled for 48 h at 1°C, the carcass weight and back fat thickness (using the thinnest section between the ninth and 13th ribs) were measured. The Longissimus thoracis muscle between the fifth and sixth thoracic vertebrae was collected for physical and chemical characteristic analysis. 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 and refrigerated drip loss rate of the meat were measured using the method of Irie (2002). The water-holding capacity (pressuring method) 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 cooked on both sides for 2.5 min at 200°C using a hotplate; cooking loss rate was calculated by the change of meat weight. The moisture, CP, EE and ash contents of the meat were measured using the same method used for the experimental feed after being minced. The melting point of the inner layer of back fat was measured using the method of Nishioka and Irie (2005). Lipids from the back fat were extracted with a chloroform and methanol solution and they were then assessed for fatty acid composition. After methyl esterification with boron trifluoride methanol, fatty acid composition was determined using a gas chromatograph (Shimazu Co. Kyoto, Japan).

Table 1 Ingredient proportion of control feed

Item	Proportion (%)
Corn	57.0
Wheat	10.0
Corn by-products[†]	8.0
Soybean meal	7.0
Rapeseed meal	7.0
Defatted rice bran	5.0
Brown rice	2.0
Mineral and vitamin premix	4.0

[†]Gluten feed and corn dried distiller's grain with soluble

Statistical analyses

The data from the two treatments were analyzed using the general linear model procedure in SAS (1990); analysis of variance (ANOVA) was used to identify differences between means. Variability of the data was expressed with standard error. A probability level of $P < 0.05$ was considered statistically significant.

RESULTS AND DISCUSSION

Chemical compositions of materials and total mixed ration silages

Although the CP content of the apple pomace was lower, and ADFom and aNDFom content were higher than in the control feed, the change in composition between the control feed and the APMS was not remarkable when the apple pomace proportion was 5% DM (Table 2). In turn, the APMS feed was fed to pigs without adjusting the composition.

Past studies have shown that fresh apple pomace is particularly suitable for fermentation, due to its high soluble carbohydrate content, whether used alone or mixed with other materials, although ethanol production is characteristic of apple pomace fermentation (Alibes *et al*. 1984; Pirmohammadi *et al*. 2006; Fang 2009). In this study, the APMS was well fermented and had a low pH (4.6) and high lactic acid content (1.08%). Ethanol was produced at a 0.99% level in the APMS (Table 3). Propionic acid and butyric acid were not detected, which indicates that the APMS was of good fermentation quality.

Table 2 Chemical composition of experimental feed and ingredient proportions of APMS

Item	Experimental feed		
	Control feed	Apple pomace	APMS
Ingredient (% FM)			
Control feed			55.0
Apple pomace			14.8
Water			30.2
Chemical composition			
Moisture (%)	13.6	83.1	49.7
Crude protein (% DM)	17.9	6.6	17.4
Ether extract (% DM)	4.4	5.6	4.5
ADFom (% DM)	7.5	46.0	9.3
aNDFom (% DM)	23.5	55.8	25.0
Crude ash (% DM)	6.4	3.9	6.3

ADFom, acid detergent fiber expressed exclusive of residual ash; APMS, apple pomace-mixed silage; Control feed, commercial formula diet; DM, dry matter; FM, fresh matter; aNDFom, neutral detergent fiber assayed with a heat stable Amylase and expressed exclusive of residual ash.

Table 3 Fermentation product of APMS

Item	
pH	4.60
Lactic acid (% FM)	1.08
Acetic acid (% FM)	1.04
Propionic acid (% FM)	ND
Butyric acid (% FM)	ND
Ethanol (% FM)	0.99

APMS, apple pomace-mixed silage; FM, fresh matter; ND, not determined.

Growth performance and carcass traits

In the growth performance study, the finished body weight and average daily gain (ADG) were similar for the two treatments. However, the average daily feed intake (ADFI) of DM was significantly lower in the APMS treatment group ($P < 0.05$) and the feed efficiency of DM was significantly higher in the APMS treatment group ($P < 0.05$) (Table 4). The reason that the ADFI decreased in the APMS treatment group is unclear, but may be caused by the high fiber in the apple pomace. Bowden and Berry (1958) reported that ADG and feed efficiency decreased when dried apple pomace was fed to finishing pigs. In the present study, apple pomace was used in fresh form and lactic acid and acetic acid were produced at levels over 1% during the APMS fermentation. Canibe and Jensen (2003) have reported that fermented liquid feed that contained lactic acid tended to improve the feed efficiency compared with non-fermented liquid feed. Kim *et al*. (2006) and Lee *et al*. (2009) reported that feeding finishing pigs fermented persimmon shell or fermented off-grade apple improved feed efficiency compared with a control group fed with ordinary feed. Other studies have also reported that organic acids improve growth performance and feed efficiency of growing pigs and piglets (Roth & Kirchgessneer 1998; Partanen *et al*. 2002). In this study, the effects were similar to those reported above with regard to pig growth. Moreover, PCAF (1991) reported that ethanol added feed improved feed efficiency of fattening pigs under a condition of narrow space and the reason given was its positive effect on stress reduction and relaxation; therefore, the result of feed efficiency in the APMS treatment group may have been caused by ethanol ingestion. Based on the information above, the increased feed efficiency may be related to the organic acid and ethanol of the APMS. The APMS had no significant effects on carcass weight, back fat thickness or dressing ratio, although, the carcass weight and dressing ratio tended to be higher in the APMS treatment group (Table 4).

Meat quality

With regard to meat quality, no differences were found in pork color standard, marbling score, back fat color standard, or back fat melting point between the control and the APMS treatment groups (Table 5). The moisture in the APMS treatment group was higher than in the control group ($P < 0.05$), whereas the EE tended to be lower. The water holding capacity (WHC) was significantly lower in the APMS treatment group ($P < 0.05$), whereas the drip loss tended to be higher than in the control treatment group. Reports on the effect of fermented feed (silage) containing food products on meat chemical components have been diverse (Kim *et al*. 2006; Shimazawa *et al*. 2008; Lee *et al*. 2009; Yan & Kim 2011; Yan *et al*. 2012). In this study, ingestion of the

Table 4 Growth performance and carcass characteristics of finishing pigs fed APMS

Item	Treatment		SEM	*P*-value
	Control	APMS		
Initial body weight (kg)	70.8	71.6	0.410	0.182
Finished body weight (kg)	112.2	112.4	0.121	0.921
Dairy gain (kg)	0.78	0.77	0.006	0.763
Dairy feed intake (kg of DM)	2.64[a]	1.81[b]	0.414	<0.001
Feed efficiency (gain/feed)	0.29[b]	0.42[a]	0.063	<0.001
Carcass weight (kg)	68.1	69.1	0.500	0.659
Back fat thickness (cm)	1.44	1.41	0.021	0.659
Dressing ratio (%)	60.7	61.4	0.372	0.707

APMS, apple pomace-mixed silage; DM, dry matter; SEM, standard error of the mean, $n = 5$. Means within a row with different letters differ ($P < 0.05$).

Table 5 Physical and chemical characteristics of meat of finishing pigs fed APMS

Item	Treatment		SEM	*P*-value
	Control	APMS		
pH	5.6	5.5	0.020	0.242
Moisture (%)	72.8[b]	74.0[a]	0.570	0.009
Crude protein (%)	23.4	23.0	0.180	0.113
Ether extract (%)	2.4	2.1	0.163	0.511
Ash (%)	1.4[a]	1.3[b]	0.071	0.024
Drip loss (%)	2.4	2.9	0.222	0.181
Cooking loss (%)	27.4	29.3	0.981	0.098
Water holding capacity (%)	79.7[a]	75.6[b]	2.024	0.015
Marbling score	1.7	1.6	0.050	0.545
Pork color standard	3.0	3.2	0.100	0.141
Back fat color standard	1.0	1.1	0.050	0.347
Back fat melting point (°C)	42.9	43.4	0.210	0.819

APMS, apple pomace-mixed silage; SEM, standard error of the mean, $n = 5$. Means within a row with different letters differ ($P < 0.05$).

APMS increased the moisture and drip loss, but decreased the WHC compared with the control treatment groups. Because these outcomes are affected by many factors (Irie 2002), it is difficult to confirm whether the changes were caused by intake of the apple pomace or the fermented products, such as the organic acid. The decreasing WHC in the APMS treatment groups agrees with the findings of Kim *et al.* (2006), who reported that a diet of over 5% fermented persimmon shells decreased the WHC of pork.

In terms of the fatty acid composition of back fat, the APMS feed led to higher linoleic acid (C18:2n6), linolenic acid (C18:3), and arachidic acid (C20:0) levels ($P < 0.05$) than the control feed (Table 6), which may have affected the increase ($P < 0.05$) in polyunsaturated fatty acids (PUFA). Notably, lower levels of palmitic acid (C16:0), palmitoleic acid (C16:1) and heptadecenoic acid (C17:1) ($P < 0.05$) were a result of the APMS treatment. No difference was observed in the levels of total saturated fatty acids (SFA), unsaturated fatty acids (UFA), SFA/UFA ratio, or monounsaturated fatty acids (MUFA) and iodine values between treatments. Many past studies have reported that the fatty acid composition of pork was mainly affected by the fatty acid composition

Table 6 Fatty acids composition in back fat of finishing pigs fed APMS

Item	Treatment		SEM	*P*-value
	Control	APMS		
C14:0	1.32	1.26	0.027	0.464
C16:0	26.46[a]	24.07[b]	1.197	0.010
C16:1	1.28[a]	1.01[b]	0.134	0.002
C17:0	0.43	0.38	0.026	0.221
C17:1	0.23[a]	0.16[b]	0.034	0.011
C18:0	19.39	19.79	0.200	0.674
C18:1	38.33	38.78	0.228	0.687
C18:2	10.20[b]	11.52[a]	0.662	0.019
C18:3	0.40[b]	0.63[a]	0.114	<0.001
C20:0	0.25[b]	0.29[a]	0.017	0.043
C20:1	0.80	0.96	0.080	0.057
Other	0.90[b]	1.13[a]	0.117	0.005
SFA	47.86	45.79	1.033	0.231
UFA	51.24	53.08	0.916	0.270
MUFA	40.64	40.92	0.140	0.814
PUFA	10.60[b]	12.15[a]	0.776	0.012
SFA/UFA	0.94	0.87	0.034	0.264
Iodine value	56.15	59.38	1.614	0.111

APMS, apple pomace-mixed silage; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SEM, standard error of the mean, $n = 5$; SFA, saturated fatty acids; UFA, unsaturated fatty acid. Means within a row with different letters differ ($P < 0.05$).

and amount of feed (Irie 1990; Irie & Sakimoto 1992; Pascual *et al*. 2007). Mayanka *et al*. (2013) reported that the fatty acid component of apple pomace is mainly composed of oleic acid (C18:1) and linoleic acid (C18:2n6) (about 90%), and almost all as a result of apple seeds. In this study, although we did not measure the fatty acid composition of the feeds used in the experiment, we can infer that the difference in fatty acid composition between the APMS and control feeds was negligible when APMS was prepared by mixing fresh apple pomace with the control feed at levels of 5% DM. Furthermore, undigested apple seeds in pig feces indicate that the influence of the experimental feed on the fatty acid composition of back fat is small. Another difference in the composition of the control feed and the APMS is the fermentation products, such as lactic acid, acetic acid and ethanol; the generation of these products was around 1% in the fresh matter of the APMS treatment group. Few studies have investigated the effect of lactic acid or acetic acid on animal lipid metabolism, and notably, the studies of the effect of ethanol on animal lipid metabolism have focused almost entirely on ruminants (Emery *et al*., 1959; Orskov & Hemken 1967; Orskov *et al*. 1967; Pradhan & Hemken 1970). However, in the field of medicine and food science, some reports indicate that ethanol affects lipid metabolism (Baraona & Lieber 1979; Robert & Norman 2004), and Lieber and Schmid (1961) reported that ethanol ingestion affects the fatty acid composition of lower back fat on rats. Moreover, Endo and Nakano (1999) reported that probiotics can increase the linolenic acid (C18:3) content of broilers and the reason given was its positive effect on intestinal flora. Therefore, the increase of linolenic acid (C18:3) in the APMS treatment group in this study may have been caused by the intestinal regulatory effect of dietary fiber from the apple pomace. Based on this information, the results of the back fat fatty acid composition tests may be related to the ethanol and the dietary fiber in the APMS feed. Because the fatty acid composition of meat is related to health and taste (Irie 2002), the mechanism underlying the effects of APMS feed on the lipid metabolism of fatting pigs should be further investigated.

Conclusion

In summary, fermented feed containing fresh apple pomace at the level of 5% DM obtained similar growth performance compared with a control feed, but significantly improved the feed efficiency. However, the APMS feed showed some negative effects on meat quality (such as decreased WHC, increased cooking loss and increased PUFA, which is related to causing soft fat.). It is necessary to consider apple pomace addition levels and length of the feeding period to identify the best effect on feed efficiency and meat quality. Furthermore, from a practical perspective, when the fresh apple pomace was fed to pigs using a liquid feeding system, there was no time for fermentation, and so the non-fermented apple pomace needed to be used immediately after production. In such cases, confirmation is needed on whether the effect was caused by organic acid or ethanol.

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