Evaluation of the Effect of Low Dietary Fermentable Carbohydrate Content on Growth Performance, Nutrient Digestibility, Blood Characteristics, and Meat Quality in Finishing Pigs

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ABSTRACT: A total of 96 pigs (49.23±3.20 kg) were used in an 11 wk growth trial to evaluate the effect of fermentable carbohydrate (FC) content on growth performance, apparent total tract digestibility (ATTD) of nutrient, blood profile, and meat quality. The dietary treatments were: i) negative control (NC), basal diet, ii) positive control (PC), NC+antibiotics (positive control diet with 5 ppm flavomycin), iii) PCL, PC-13% lower FC, and iv) NCL, NC-13% lower FC. The growth performance (average daily gain, average daily feed intake, and gain/feed) didn't differ among treatments through the whole experiment. These pigs fed the PCL diet had the greater (p<0.05) apparent total tract digestibility (ATTD) of dry matter than those from PC and NC treatment at the end of the experiment. No differences were observed in white blood cell (WBC), red blood cell (RBC), and lymphocyte concentration among different treatments. After the feeding period, meat samples were collected from the pigs at slaughter. The pigs in NCL and PCL treatments had greater (p<0.05) backfat thickness and lower lean percentage. The color value of loin was higher (p<0.05) in NCL treatment compared to PCL treatment. Also, the NCL treatment had higher (p<0.05) marbling value than PC treatment. The drip loss was depressed by PCL and NCL treatment comapared to NC treatments. The water holding capacity (WHC) was higher (p<0.05) in NC and PCL treatment. In conclusion, the low FC can improve digestibility and meat quality of finishing pigs. (**Key Words:** Blood Profile, Digestibility, Fermentable Carbohydrate, Finishing Pig, Growth Performance, Meat Quality)

INTRODUCTION

Because of the increasing public awareness and objection to the use of antibiotics as growth promoters in animal diets, scientists are searching for the method and alternatives. Based on the simply thoughts that to improve the digestibility of feed and the ability to digest of feed through the better health status of animals themselves. Except from those kinds of potential additives, such as organic acids, probiotics, prebiotics, enzymes, and photogenic extract, the simply high quality feed may also be considered.

Non-starch polysaccharides (NSP) are the main carbohydrates lies in the walls of cereal grains such as, soybean, wheat, rye, tapioca, and triticale. The digestive tracts of nonruminant animals do not contain the enzymes necessary to hydrolyze the NSP, which limited the utilization of cheaper cereal grain and their byproducts (Wang et al., 2009a). Fermentation of non-starch polysaccharides in the gut (mainly hindgut) of pigs results in the formation of short chain fatty acids (VFA). Experimental data show that growing and fattening pigs can cover about 17 to 24% of their maintenance requirement for energy via the metabolism of VFA, while sows can even cover up to 25 to 35% (Rérat et al., 1987; Shi and Noblet, 1993; Johnston et al., 2002). Dietary fermentable carbohydrates (FC), as part of the NSP, decrease the dressing percentage and the backfat thickness (Zhu et al., 1990; Shriver et al., 2003). The former indicates that VFA resulting from an increased fermentation in the digestive tract may alter the body composition of pigs. It is also said that reducing CP content and increasing FC level may counteract the negative effects of protein fermentation in weaning pigs fed high CP diets (Bikker et al., 2006). Because of high fiber content in DDGS and limited concentration of fiber degrading enzymes in the intestinal system of nonruminants, the 3.5% of distiller's dried grains with soluble (DDGS) were used in the high CP treatment as the control.

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Therefore, one experiment is conducted to evaluate the effects of the lower level of fermentable carbohydrates inclusion to antibiotics-free diet of finishing pigs on growth performance, nutrient digestibility, blood profile, and meat quality.

MATERIALS AND METHODS

Animal and experimental design

The protocols used for the current experiment were approved by the Animal Care and Use Committee of Dankook University.

A total of 96 crossbred pigs [(Landrace×Yorkshire)× Duroc] with an average initial BW of 49.23±3.20 kg were selected for this 11 wks growth assay. Pigs were allocated to one of four treatments according to their BW and sex with six replicates per treatment and four pigs per pen (two gilts and two barrows). The dietary treatments were: i) negative control (NC), basal diet, ii) positive control (PC), NC+antibiotics (positive control diet with 5ppm flavomycin), iii) PCL, PC-13% lower FC, and iv) NCL, NC-13% lower FC. All nutrient diets were formulated to exceed or met National Research Council (NRC, 1998) recommendation (Table 1). Pigs were housed in an environmentally controlled, slatted-floor facility in 24 adjacent pens (1.8×1.8 m) and were allowed *ad libitum* access to feed and water.

Data and sampling collection

For the growth assay, the pig weights and feed disappearance were recorded weekly to calculate the average daily gain (ADG), average daily feed intake (ADFI), and gain/feed (G/F). Chromium oxide (0.20%) was added as an inert indicator to calculate the apparent digestibility of DM and N. After the pigs were fed the diets containing the indicator for 7 d, fresh fecal grab samples were obtained from each pen at 0800. The fecal samples were then dried at 50°C for 72 h and finely ground to be able to pass through a 1 mm screen. All of the feed and feces samples were then frozen at -20°C until further analysis. After the concentration of dry matter (DM) and nitrogen (N) was determined (AOAC, 2000), the DM and N digestibilities were calculated according to the indicator method, with the concentration of chromium being analyzed by UV absorption spectrophotometry (Shimadzu, UV-1201, Japan) following the method described by Williams et al. (1962). The gross energy in the feed and feces was determined using calorimeter (Mode 1241, Parr Instrument Co., USA).

For the blood characteristics assay, two pigs were randomly selected from each pen and venous blood samples were collected into both nonheparinized tubes and vacuum tubes containing K_3EDTA (Becton, Dickinson and Co.,

Table 1. Compositions of basal finishing pig diets (as-fed basis)[1]

Item (%)	NC	PC	PCL	NCL
Corn	33.51	33.42	36.96	37.15
Wheat	25.00	25.00	25.00	25.00
Soybean meal (45% of CP)	16.58	16.64	19.40	19.37
Rice bran	8.00	8.00	8.00	8.00
Wheat bran	0.80	0.80	-	-
Canola meal	2.00	2.00	-	-
DDGS	3.50	3.50	-	-
Limestone	0.69	0.56	0.83	0.76
Tallow	4.15	4.20	4.10	4.07
Molasses cane	4.00	4.00	4.00	4.00
NaCl	0.30	0.30	0.30	0.30
DL-met (99%)	0.01	0.01	0.06	0.06
L-lys (78%)	0.20	0.20	0.22	0.22
Dicalcium phosphate	0.46	0.48	0.23	0.26
Premix[2]	0.80	0.80	0.80	0.80
Flavomycin (5 g/kg)	-	0.10	0.10	-
Analyzed composition				
Crude protein (%)	16.50	16.50	15.71	15.69
Ether extract (%)	7.75	7.86	7.52	7.54
Crude fibre (%)	4.05	4.28	3.19	3.19
Ash (%)	4.81	5.05	4.45	4.61
Ca (%)	0.63	0.62	0.59	0.69
P (%)	0.58	0.57	0.46	0.51
Lys (%)	0.96	0.96	0.96	0.96
Met (%)	0.29	0.29	0.31	0.31
FC (g/kg)	129.03	127.45	110.00	110.00
NSP (g/kg)	145.0	145.0	130.0	130.0

[1] Each mean represents 6 pens with 4 pigs each per treatment. Dietary treatments were as follows: NC = Negative control diet; PC = Control diet with 5 mg/kg Flavomycin; PCL = PC-low FC; NCL = NC-low FC.
[2] The vitamin and mineral premix supplied per 1 kg of the diet: 4,000 IU of vitamin A, 800 IU of vitamin D_3, 15 IU of vitamin E, 4 mg of riboflavin, 15 μg of vitamin B_{12}, 10 mg of d-pantothenic acid, 20 mg of niacin, 15 mg of Cu from $CuSO_4 \cdot 5H_2O$, 90 mg of Fe from $FeSO_4 \cdot 7H_2O$, 40 mg of Mn from MnO_2, 40 mg of Zn from $ZnSO_4 \cdot H_2O$, 0.2 mg of Se from $Na_2SeO_3 \cdot 5H_2O$, 0.5 mg of Co from $CoSO_4 \cdot 7H_2O$.

Franklin Lakes, NJ, USA) to obtain serum and whole blood, respectively. After collection, serum samples were centrifuged (2,000×g) for 30 min at 4°C. Serum total protein was determined using an automatic biochemistry analyzer (HITACHI 747, Hitachi, Tokyo, Japan). The white blood cells (WBC), red blood cells (RBC) and lymphocyte percentage in the whole white blood were determined using an automatic blood analyzer (ADVIA 120, Bayer, NY, USA).

Two pigs of each pen were slaughtered when average BW in the heaviest pen of the weight block reached 110 kg and back fat, muscle percentage and lean ratio measurement was performed using a real time ultrasound instrument (Piglot 105, SFK Technology, Herlev, Denmark). After chilling at 2°C for 24 h, one 2.54-cm-thick longissimus

muscle (LM) sample was abstained at the 10th rib (right side of the carcass). Sensory evaluation (color, marbling and firmness scores) was evaluated according to National Pork Producers Council standards (NPPC, 2000). Drip loss was determined as a percentage of the original weight using 2 g of meat sample according to the method of Honikel (1998). Duplicate pH values of each sample were measured via an glass-electrode pH meter (WTW pH 340-A, WTH Measurement Systems Inc., Ft. Myers, FL). Water holding capacity (WHC) was measured followed the guide of Kauffman et al. (1986). Longissimus muscle area (LMA) was measured by tracing the longissimus muscle surface at the 10th rib, which also used the above mentioned digitizing area-line sensor. The last rib backfat thickness (measured on the midline of the split carcass) for each pig were adjusted (using regression analysis) to the average final BW before being pooled using the equation proposed by the National Pork Producers Council (NPPC, 2000).

Statistical analysis

All data generated in this experiment were subjected to the GLM procedures of SAS (SAS Institute, 2001) as a randomized complete block design. Each pen served as the experimental unit. Additionally, Duncan's multiple range test was used to compare the means of the treatments (Duncan, 1955). Variability in the data was expressed as the pooled standard error (SE) and a $p < 0.05$ was considered to be statistically significant.

RESULTS

Growth performance

The ADG, ADFI, and G/F were unaffected by the

Table 2. Effect of low fermentable carbohydrates (FC) on growth performance of finishing pigs[1]

Items	NC	PC	PCL	NCL	SE[2]
0 to 35 d					
ADG (g)	739	761	797	795	36
ADFI (g)	1,840	1,898	1,915	1,870	62
FCR	2.490	2.494	2.403	2.352	0.14
36 to 77 d					
ADG (g)	735	755	799	793	35
ADFI v	2,190	2,305	2,290	2,318	88
FCR	2.980	3.053	2.866	2.923	0.13
0 to 77 d					
ADG (g)	737	758	798	794	30
ADFI (g)	2,015	2,101	2,103	2,094	66
FCR	2.734	2.772	2.635	2.637	0.11

[a,b] Within a row, mean with different superscripts differ ($p < 0.05$).
[1] Each mean represents 6 pens with 4 pigs each per treatment. Dietary treatments were as follows: NC = Negative control, basal diet; PC = NC with 5 mg/kg Flavomycin; PCL = PC-13% lower FC; NCL = NC-13% lower FC.
[2] Pooled standard errors.

Table 3. Effect of low fermentable carbohydrates (FC) on nutrient digestibility of finishing pigs[1]

Items	NC	PC	PCL	NCL	SE[2]
35 d					
DM	77.84	78.14	80.37	79.66	0.79
Nitrogen	75.57	76.49	77.10	76.59	1.25
Energy	76.33	77.44	78.80	77.92	0.98
77 d					
DM	74.50[b]	74.64[b]	77.11[a]	76.28[ab]	0.67
Nitrogen	72.66	72.08	74.56	74.20	0.87
Energy	73.75	73.41	76.43	75.85	0.96

[a,b] Within a row, mean with different superscripts differ ($p < 0.05$).
[1] Each mean represents 6 pens with 4 pigs each per treatment. Dietary treatments were as follows: NC = Negative control, basal diet; PC = NC with 5 mg/kg Flavomycin; PCL = PC-13% lower FC; NCL = NC-13% lower FC.
[2] Pooled standard errors.

dietary treatments throughout the whole experiment (Table 2).

Apparent total tract digestibility of nutrient

The PCL treatment had the greater ($p < 0.05$) ATTD of DM than PC and NC treatments at d 77 (Table 3).

Blood characteristics

No differences have been observed in WBC, RBC, and lymphocyte concentration (Table 4).

Meat quality

The effects of FC on the meat quality were presented in Table 5. The pigs in NCL and PCL treatments had greater ($p < 0.05$) backfat thickness and lower lean percentage. The color value of loin was higher ($p < 0.05$) in NCL treatment related to PCL treatment. Also, the NCL treatment had higher ($p < 0.05$) marbling value than PC treatment. The drip loss was depressed by PCL and NCL treatment than NC

Table 4. Effect of low fermentable carbohydrates (FC) on blood characteristics of finishing pigs[1]

Items	NC	PC	PCL	NCL	SE[2]
WBC, $10^3/\mu l$					
35 d	6.57	6.83	6.50	6.82	0.19
77 d	6.99	7.19	7.10	7.29	0.24
RBC, $10^6/\mu l$					
35 d	19.71	17.35	17.77	17.93	1.15
77 d	19.29	18.74	18.31	19.05	0.79
Lymphocyte (%)					
35 d	50.73	52.20	54.83	53.10	2.61
77 d	59.39	63.35	60.62	62.57	2.18

[1] Each mean represents 6 pens with 4 pigs each per treatment. Dietary treatments were as follows: NC = Negative control, basal diet; PC = NC with 5 mg/kg Flavomycin; PCL = PC-13% lower FC; NCL = NC-13% lower FC.
[2] Pooled standard errors.

Table 5. Effect of low fermentable carbohydrates (FC) on meat quality of finishing pigs[1]

Items	NC	PC	PCL	NCL	SE[2]
Color					
L* (Lightness)	56.04	54.29	56.22	55.17	1.52
a* (Redness)	16.8	16.96	17.22	17.35	0.39
b* (Yellowness)	7.64	6.92	7.78	8.19	0.63
Sensory evaluation[3]					
Color	1.7[bc]	1.7[ab]	1.6[c]	1.8[a]	0.04
Marbling	1.8[ab]	1.7[b]	1.8[ab]	1.9[a]	0.08
Firmness	1.7	1.8	1.9	1.8	0.07
Drip loss (%)					
1 d	4.1	5.8	4.5	4.3	0.82
3 d	2.5[b]	3.0[ab]	4.1[a]	4.2[a]	0.49
5 d	2.2	3.1	3.1	3.0	0.43
7 d	0.9	0.9	1.1	0.7	0.22
pH	5.6	5.5	5.6	5.6	0.04
Water holing capacity (%)	40.0[a]	35.4[b]	40.6[a]	38.0[ab]	1.05
Lean muscle area (cm^2)	64.3[a]	62.6[a]	58.3[b]	57.6[b]	1.62
Backfat thickness (mm)					
0 d	9.0	8.9	8.9	8.8	0.20
35 d	10.8	11.3	11.3	11.0	0.29
77 d	12.7[b]	12.5[b]	14.2[a]	14.0[a]	0.38

[a,b] Within a row, mean with different superscripts differ (p<0.05).

[1] Each mean represents 6 pens with 4 pigs each per treatment. Dietary treatments were as follows: NC = Negative control, basal diet; PC = NC with 5 mg/kg Flavomycin; PCL = PC-13% lower FC; NCL = NC-13% lower FC.

[2] Pooled standard errors.

[3] According to the NPPC (2000) that is determined on a freshly-cut surface on the color scale of 1 to 5); Firmness (3 or greater on the scale of 1 to 5); Marbling (3 or greater on the scale of 1 to 5).

treatments. The WHC was higher (p<0.05) in NC and PCL treatments.

DISCUSSION

In the current study, the growth performance was not affected by the levels of FC and the antibiotics inclusion, but the lower levels (-13%) of FC were shown to increase the DM digestibility. The fermentable carbohydrate, which can't be well utilized by the non-ruminant because of the insufficient secretion of endogenous enzymes, may serve as the energy for microbial when moving to the large intestine. This increasing microbial can compete the nutrients and energy with the host (Shriver et al., 2003; Wang et al., 2009b). Meanwhile, FC may depress the digestibility of other nutrient by increasing the viscosity of the gastrointestinal digesta. Through this mechanism, the lower FC may have higher digestibility of DM than higher FC. This is partly consistent with our result. However this effect is not so obvious (only in 77 d) when come to the finishing pigs. This may due to that the finishing pig is in a relatively physiological maturity stage through the whole life of the swine, which may tolerate the certain levels of FC in their feed. Similarly, Shriver et al. (2003) found that the different FC levels cause no differences for growth performance of

finishing pigs. In this study, the author lowered the CP levels by addition of fiber source (10% of soybean hull), and found no difference in nitrogen intake, absorption, and retention too. Similarly, Kornegay (1981) reported that the addition of up to 15% soybean hull to the diet of growing-finishing pigs did not affect growth performance. Shriver et al. (1999) and Knowles et al. (1998) suggested that up to 20% wheat middling may be added to finishing pigs diets without affecting growth performance. On contrary, Hansen et al. (2008) reported that the addition of 25% lupine in the diet had a negative effect on pig performance (growth rate and feed conversion). This inconsistent result may due to the high the high levels of FC. For example, Fernandez and Danielsen (2006) found that by inclusion of 12.5% lupines (same variety, Prima) observed no affect on performance whereas they by inclusion of 25% observed a negative effect. The authors also concluded that if less than 15% of lupine was added to the diet the negative effects of the supplementation on performance could be avoided.

Furthermore, a positive effect of antibiotics on growth responses may occurs primarily as a result of its specific antimicrobial activity, which may be more evident when animals are raised in an inferior hygienic environment. Therefore, the lack of a growth response to antibiotics in the present experiment may also be a result of pigs having a

high health status and being reared in a hygienic environment.

As the largest immunologically competent organ in the body, the gastrointestinal system and its associated lymphoid is the largest immunologically competent organ in the body, and maturation and optimal development of the immune system after birth depend on the development and composition of the indigenous microflora and vice versa (Michael and Marteau, 2007). The short-chain organic acid can modify the immunity-related blood profile (WBC and lymphocyte concentration) in both weaning and growing pig (Wang et al., 2009b). It is also maybe associated with that a reduction in subclinical infections because of their antimicrobial effects may contribute to improved nutrient digestibility and a reduction in the demand for nutrients by the gut-associated immune tissue.

It is evident that the high dietary FC content reduced the backfat thickness and therefore increases the lean percentage (Zhu et al., 1990; Shriver et al., 2003; Szabó et al., 2007). This is consistent with the result of our study. The dietary lysine to energy ratio primarily determines the rate of protein and fat deposition. In the present study diets were formulated to have a similar ratio of apparently ileal digestible lysine to the net energy. Therefore, the suggested underestimation of the energetic value of treatment with the high FC diet, should affect the protein deposition in the body as well. Möhn et al. (2000) reported, that reduced energy intake decrease the protein deposition in the body. Acetyl CoA is a metabolite shared in common by the metabolism of glucose, fatty acids and some amino acids. The carbon atoms in acetyl CoA can arise from carbohydrate via pyruvic acid produced in the glycolysis or the catabolism of fatty acids and certain amino acids. Acetyl CoA is the fuel for the Krebs-cycle, which provides most of the energy needs of the cells. If the energy level of the cell is high because of carbohydrate catabolism, the flow of acetyl CoA into the Krebs cycle will be slowed down, and acetyl CoA could be diverted into the synthesis of fatty acids (lipid) (Conn et al., 1987). Fatty acids can be metabolized into triglycerides, which are transported as lipoproteins into the adipose tissue for storage and muscle for energy supply. Cells can utilize the triglycerides as energy source when they are degraded into free fatty acids and glycerol. This process is regulated by lipoprotein lipase. Under isocaloric conditions, this enzyme has a high level of activity in adipose tissue. However, in the case of a low energy supply, lipoprotein lipase is highly active in muscle, liver, and cardiac tissues. These mechanisms can explain why body fatness was clearly affected by VFA, whereas body protein deposition and content are not affected (Szabó et al., 2007).

The different levels of FC had no effects on the pH and colors (L*, a*, and b*), firmness which is the same with the result form Hansen et al. (2008). Typically, the consumptions of diets with high energy levels or fat tends to increase backfat thickness (Pettigrew and Moser, 1991), but no effects on any pork quality trait such as pH, drip loss, firmness, American color score (Apple et al., 2004). Previous studies also demonstrated that formulating diets based on CP, and energy has no effect on ultimate muscle pH, drip loss percent, WHC, subjective color scores, and firmness scores (Goerl et al., 1995; Witte et al., 2000). We found that that the lower FC can decrease the color and increase of the drip loss of the meat. This may explained by the pH and lactate in the meat (Pö sö and Puolanne, 2005). Therefore, further experiment is necessary to determine the lactate content in the muscle.

In conclusion, containing lower fermentable carbohydrates (13% lower) can improve the nutrient digestibility but have no effects on the growth performance. Lean tissue percentage, however, can be improved as a consequence to the reduced overall fat content of the body.

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