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The effects of dietary medium-chain triacylglycerols on growth performance and intestinal microflora in young pigs

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ABSTRACT. Ninety-six young pigs were used to investigate the effect of dietary supplementation with medium-chain triacylglycerols (MCT) on growth performance and intestinal microbial counts. The pigs were divided into four treatments, with four replicates per treatment. Six pigs were assigned per replicate and were fed diets supplemented with 1. 6.0% soyabean oil (SO), 2. 4.8% SO + 1.2% MCT, 3. 3.0% SO + 3.0% MCT, or 4. 1.2% SO + 4.8% MCT for 28 days. The results showed that dietary supplementation with 4.8% MCT improved the gain-to-feed ratio of the pigs ($P < 0.05$). Dietary supplementation with 3.0% MCT decreased the lactic acid bacteria (L) counts in the stomach and caecum, while supplementation with 4.8% MCT decreased the L counts in the stomach and the small intestine ($P < 0.05$). Dietary supplementation with MCT increased the L-to-coliforms (C) ratio in the colon and rectum ($P < 0.01$) and decreased L+C in the stomach ($P < 0.05$). In conclusion, dietary supplementation with 4.8% MCT may change the intestinal microbiota and improve the feed utilization efficiency of young pigs.

Introduction

Medium-chain triacylglycerols (MCT) have fatty acids that are 6–12 carbon atoms long and can be easily utilized as an energy source by humans (Bach and Babayan, 1982), pigs (Chiang et al., 1990b) and chickens (Chiang et al., 1990a; Furuse et al., 1992).

During the late 1970s and the early 1980s, researchers found that a high dietary level of MCT (i.e. 10%–35%) either does not affect, or negatively affects the growth performance of young pigs (Allee et al., 1972; Newport et al., 1979) and rats (Lavau and Hashim, 1978; Travis et al., 1979; Baba et al., 1982). Recently, however, researchers have found that a low dietary level of MCT (i.e. 0.2%–5%) could improve the growth performance of weanling pigs (Dierick et al., 2002b; Hanczakowska et al., 2011; Hong et al., 2012) and broilers (Chiang et al., 1990a).

The bactericidal effect of medium-chain fatty acids (MCFA) has been documented for decades (Nieman, 1954). Recently, however, it was found that dietary MCFA could inhibit *Lactobacillus*, *Streptococcus* and *Escherichia coli* in the stomach and small intestine (Dierick et al., 2002a,b) and *Clostridium perfringer* in the small intestine (Hanczakowska et al., 2011) of weanling pigs. The bactericidal effect of antibiotics is one of the reasons for their growth-promoting effects in animals. Nevertheless, due to the cross-resistance issue of antibiotics, the European Union and other countries have completely or partially banned their use for disease prevention purposes. The bactericidal and cross-resistance-free properties of MCT make them a good alternative to antibiotics.

The purpose of the present study was to investigate the effect of dietary supplementation with lower levels of MCT on the growth performance of young pigs and their intestinal microbial counts.

Material and methods

All animal-related protocols in the study followed the Guide for the Care and Use of Laboratory Animals (NRC, 1996). Ninety-six crossbred young pigs [Duroc × Landrace × Yorkshire; 17.4 ± 3.0 kg of body weight (BW)] were assigned by BW and sex to four treatments, with four replicates per treatment and six pigs (3 barrows and 3 gilts) per replicate. Each pen was 2.5 × 2.5 m in size with a concrete floor, two nipple waterers, and a four-hole self-feeder.

Pigs were fed diets based on maize, soyabean meal and whey powder supplemented with 1. 6.0% soyabean oil (SO), 2. 4.8% SO + 1.2% of medium-chain triacylglycerols (MCT), 3. 3.0% SO + 3.0% MCT and 4. 1.2% SO + 4.8% MCT for 28 days (Table 1). The fatty acid compositions of SO (Fusow Company, Taichung, Taiwan) and MCT (Yihai Kerry Group, Shanghai, China) are shown in Table 2. Dietary nutrients were provided to meet or exceed requirements for weanling pigs (NRC, 1998). Feed and water were fed *ad libitum*. Feed was provided in meal form.

Pigs were weighed individually and feed intake was measured on a pen basis weekly. The weight gain, feed intake and gain-to-feed ratio (G:F) were calculated weekly on a pen basis. Chromic oxide (0.25%) was added in the diets as the digestibility marker during the last week of the trial. Fresh faeces were collected for 3 days followed by 3 days after the marker was added. Faeces were frozen at –30°C for until analysis.

At the end of the trial, two pigs (1 barrow and 1 gilt) with a BW nearest to the replicate average were selected from each replicate and electrically stunned; all of the contents in the stomach, small intestine (including the duodenum, jejunum and ileum), caecum and colon and rectum were collected; and lactic acid bacteria (L) and coliforms (C) were counted immediately. Briefly, intestinal contents were homogenized and aliquots were taken and diluted with phosphate-buffered saline (Amresco, Solo, OH, USA). They were then incubated aerobically on MRS agar (Becton, Dickinson and Company, MD, USA) or Coliform agar (Merck KGaA, Damstadt, Germany) at 37°C for 48 or 24 h, and the colonies of L and C were counted.

Table 1. Composition of experimental diets, as fed basis

Indices	Treatment			
	6.0% soya oil	4.8% soya oil + 1.2% MCT[1]	3.0% soya oil + 3.0% MCT	1.2% soya oil + 4.8% MCT
Ingredient, %				
yellow maize	45.59	45.59	45.59	45.59
soyabean meal (47.5% CP)	24.33	24.33	24.33	24.33
fish meal (63.3% CP)	5.00	5.00	5.00	5.00
wheat middling	6.00	6.00	6.00	6.00
whey protein	12.00	12.00	12.00	12.00
sodium chloride	0.25	0.25	0.25	0.25
dicalcium phosphate	0.30	0.30	0.30	0.30
limestone	0.08	0.08	0.08	0.08
Premix[2]	0.20	0.20	0.20	0.20
Cr_2O_3	0.25	0.25	0.25	0.25
soyabean oil	6.0	4.8	3.0	1.2
MCT	0.0	1.2	3.0	4.8
total	100.00	100.00	100.00	100.00
Calculated values				
ME, MJ · kg^{-1} [3]	15.03	15.00	14.96	14.92
crude protein, %	20.92	20.92	20.92	20.92
lysine, %	1.27	1.27	1.27	1.27
crude fat, %	9.11	9.11	9.11	9.11
Ca, %	0.78	0.78	0.78	0.78
total P, %	0.66	0.66	0.66	0.66
Analysed values, %				
crude protein, %	20.01	20.71	20.15	20.34
total fatty acids, %	8.24	8.32	8.22	8.35
C6:0	0.00	0.44	0.81	1.10
C8:0	0.00	0.60	1.24	1.77
C10:0	0.00	0.34	0.78	1.14
C14:0	0.56	0.57	0.61	0.61
C16:0	1.34	1.62	1.31	0.87
C18:0	0.48	0.60	0.49	0.33
C18:1	2.04	2.01	1.51	1.00
C18:2	3.51	1.99	1.37	1.44
C18:3	0.31	0.15	0.10	·

[1] MCT – medium-chain triacylglycerols; [2] provided per kg of diet: IU: vit. A 12,000, vit. D_3 2,000, vit. E 40; mg: vit. K_3 4, vit. B_1 1.5, vit. B_2 1.5, vit. B_6 4, vit. B_{12} 0.05, niacin 15, pantothenic acid 16, folic acid 1, biotin 0.2, Fe 150, Mn 40, Zn 100, Cu 20, Se 0.3, I 0.35; [3] the ME of MCT and soyabean oil used for the calculation were 32.92 (Lee and Chiang, 1994) and 35.15 MJ · kg^{-1} (NRC, 1998), respectively

Table 2. Fatty acid composition of experimental oil

Fatty acid, %	Soya oil	MCT[1]
C6:0	–	24.9
C8:0		47.6
C10:0	–	26.8
C14:0	–	–
C16:0	14.9	–
C18:0	4.5	0.4
C18:1	25.0	0.3
C18:2	52.4	–
C18:3	3.2	–

[1] MCT – medium-chain triacylglycerols

Table 3. Effects of dietary MCT[1] on growth performances of young pigs

Indices	Treatment 6.0% soya oil	4.8% soya oil + 1.2% MCT	3.0% soya oil + 3.0% MCT	1.2% soya oil + 4.8% MCT	SEM	*P*
Initial body weight						
kg	17.35	17.36	17.41	17.36	0.03	0.62
CV[2], %	16.52	16.37	18.03	17.64	1.49	0.82
Final body weight						
kg	32.55	32.63	32.78	32.86	0.45	0.98
CV[2], %	17.08	19.06	21.17	20.82	2.26	0.58
Weight gain, g · day^{-1}						
week						
1	343	355	362	368	20.4	0.92
2	521	459	530	495	15.6	0.14
3	611	548	616	675	38.0	0.35
4	691	822	698	679	69.5	0.61
overall	543	545	549	554	13.3	0.96
Feed intake, g · day^{-1}						
week						
1	672	680	717	714	20.9	0.55
2	949	914	997	868	24.9	0.10
3	1094	1088	1027	1060	35.5	0.70
4	1512	1658	1465	1434	53.6	0.17
overall	1056	1085	1051	1019	22.1	0.26
Gain : feed ratio						
week						
1	0.511	0.523	0.505	0.515	0.027	0.98
2	0.548	0.502	0.533	0.570	0.017	0.23
3	0.559	0.505	0.601	0.636	0.038	0.30
4	0.457	0.492	0.478	0.473	0.038	0.97
overall	0.513^{a}	0.503^{a}	0.522^{ab}	0.543^{b}	0.006	0.05

[1] MCT – medium-chain triacylglycerols; [2] CV – coefficient of variation; [a,b] least-squares means within a row lacking a common superscript letter differ at $P < 0.05$

Samples of feed and freeze-dried faeces were ground. Crude protein contents were measured by the Kjeldahl method (AOAC, 1984). Fatty acids were transmethylated according to Sukhija and Palmquist (1988), and their contents were quantified using gas chromatography with a flame ionization detector (Hitachi G-3000, Tokyo, Japan) and a 30 m 0.25 mm Rtx-2330 fused silica capillary column (Restek Inc., Bellefonte, PA, USA) with C15:0 as the internal standard. Chromium contents were measured by the method of Williams et al. (1962) using atomic absorption spectrophotometry (Hitachi 170-30, Tokyo, Japan).

The apparent digestibility (AD) of fatty acids and crude protein was calculated by the following equation:

AD of fatty acid or crude protein =

$$100 - 100 \times \frac{\text{chromium\% in diet} \times \text{fatty acid or crude protein in faeces}}{\text{chromium\% in faeces} \times \text{fatty acid or crude protein in diet}}$$

Data were analysed using the GLM procedures of SAS (2003). The differences between each treatment were detected by the probability values generated by the least significant difference test. Differences were considered significant at $P < 0.05$.

Results

Dietary supplementation with MCT did not affect the weekly weight gain, feed intake, or G:F (Table 3). However, dietary supplementation with 4.8% MCT increased the overall (weeks 1–4) G:F of pigs by 6% ($P < 0.05$; 0.543 vs 0.513). Dietary supplementation with MCT had no effect on the uniformity (coefficient of variation, %) of the final body weight of pigs (Table 3).

Dietary supplementation with 1.2% MCT increased L in the small intestinal content ($P < 0.05$; Table 4). However, a further increase in the MCT level to 3.0% decreased L in stomach and caecal contents ($P < 0.05$). Dietary supplementation with 4.8% MCT decreased L in the stomach and small intestinal contents ($P < 0.05$). Dietary supplementation with MCT did not affect L in the colon and rectal content or C in any of the contents of the intestinal tract sections.

Table 4. Effects of dietary MCT[1] on microbial counts in intestinal tract contents of young pigs, $\log_{10}$ CFU · g^{-1} fresh content

Indices	Treatment 6.0% soya oil	4.8% soya oil + 1.2% MCT	3.0% soya oil + 3.0% MCT	1.2% soya oil + 4.8% MCT	SEM	*P*
n	8	8	8	8	–	–
Stomach						
L[2]	7.36^{b}	7.93^{b}	6.54^{a}	5.99^{a}	0.221	0.001
C[3]	4.83	4.36	4.37	3.06	0.502	0.145
L/C	1.51	1.74	1.70	2.63	0.329	0.153
L+C	12.19^{b}	11.92^{b}	10.91^{b}	9.05^{a}	0.576	0.019
Small intestine						
L[2]	7.90^{b}	9.23^{c}	7.23^{ab}	7.13^{a}	0.218	0.001
C[3]	6.52	6.18	5.95	5.94	0.299	0.514
L/C	1.24^{a}	1.47^{b}	1.22^{a}	1.22^{a}	0.033	0.001
L+C	14.42^{ab}	15.41^{b}	13.22^{a}	13.07^{a}	0.496	0.027
Caecum						
L[2]	9.20^{bc}	10.07^{c}	8.03^{a}	8.45^{ab}	0.351	0.012
C[3]	6.91	6.54	6.67	5.99	0.576	0.212
L/C	1.36^{ab}	1.58^{c}	1.20^{a}	1.41^{b}	0.049	0.003
L+C	16.11	16.53	14.70	14.44	0.581	0.079
Colon + rectum						
L[2]	9.59	9.97	9.16	9.24	0.231	0.120
C[3]	7.23	6.80	6.76	5.90	0.325	0.078
L/C	1.34^{a}	1.47^{b}	1.36^{a}	1.58^{c}	0.032	0.002
L+C	16.88	16.76	16.76	15.14	0.546	0.156

[1] MCT – medium-chain triacylglycerols; [2,3] L – lactic acid bacteria; C – coliforms; [a–c] least-squares means within a row lacking a common superscript letter differ at $P < 0.05$

Table 5. Effects of dietary MCT[1] on apparent digestibility (%) of medium-chain fatty acid and protein on young pigs

Indices	Treatment				SEM	*P*
	6.0% soya oil	4.8% soya oil + 1.2% MCT	3.0% soya oil + 3.0% MCT	1.2% soya oil + 4.8% MCT		
C6:0	–	97.5[a]	98.6[ab]	99.2[b]	0.35	0.034
C8:0	–	98.1	98.8	99.3	0.34	0.120
C10:0	–	99.3	99.2	99.4	0.30	0.916
Protein	78.1[a]	79.2[ab]	80.7[bc]	81.9[c]	0.82	0.040

[1] MCT – medium-chain triacylglycerols; [a–c] least-squares means within a row lacking a common superscript letter differ at $P < 0.05$

Dietary supplementation with 1.2% MCT resulted in the highest L-to-C ratio in small intestinal and caecal contents ($P < 0.05$; Table 4). Dietary supplementation with 4.8% MCT resulted in the lowest L+C in the stomach content and the highest L-to-C ratio in the colon and rectal content ($P < 0.05$). Dietary supplementation with 3.0% and 4.8% MCT led to lower L+C in the small intestinal content compared with supplementation with 1.2% MCT ($P < 0.05$).

The apparent digestibility (AD) of MCFA was high (> 97%). Dietary supplementation with 4.8% MCT increased the AD of C6:0 ($P < 0.05$; Table 5). Dietary supplementation with 4.8% MCT increased the AD of crude protein ($P < 0.05$; Table 5).

Discussion

The finding that dietary supplementation with 4.8% MCT increases the feed utilization efficiency of young pigs agrees with the findings in weanling pigs (Dierick et al., 2002b; Hanczakowska et al., 2011) and in broilers (Chiang et al., 1990a) when lower levels of MCT (i.e. 0.2%–5% in the diet) were fed. On the other hand, researchers have found that supplementing higher levels of MCT in diets (i.e. 10%–20%) did not affect the weight gain or feed utilization efficiency of young pigs (Allee et al., 1972; Newport et al., 1979) or rats (Travis et al., 1979). Furthermore, Lavau and Hashim (1978) and Baba et al. (1982) reported that dietary supplementation with 20%–35% MCT decreased the weight gain of rats. These results indicate that supplementation with a lower level of MCT in diets may improve the growth performance of animals. A higher level of MCT in diets (i.e. more than 5%–10%) may not be beneficial, and even detrimental, to the growth performance of animals.

The metabolizable energy (ME) of MCT was determined to be 32.92 MJ $\cdot$ kg^{-1} (Lee and Chiang, 1994), which is lower than the ME of 35.15 MJ $\cdot$ kg^{-1} in SO (NRC, 1998). Therefore, replacing the dietary supplement SO by MCT would decrease the ME content in the diet, thus decreasing feed utilization efficiency. However, the opposite was observed in the present study and in other research (Chiang et al., 1990a; Dierick et al., 2002b). These results indicate that besides ME, other physiological factors in MCT might be involved in improving the feed utilization efficiency in animals.

The observation that dietary supplementation with 4.8% MCT decreases L+C in the stomach and small intestinal contents agrees with the finding of Dierick et al. (2002a,b). These authors showed that dietary MCFA could inhibit *Lactobacillus*, *Streptococcus* and *Escherichia coli* in the stomach and small intestine of weanling pigs. We also observed that dietary supplementation with MCT increased the L-to-C ratio, indicating a favourable shift of microbiota, in the small and large intestinal contents. The bactericidal effect of antibiotics, especially on harmful bacteria, is one of the reasons for their growth-promoting effect observed in animals (Vervaeke et al., 1979; Dierick et al., 1986a,b; Jensen, 1993; Chesson, 1994; Anderson et al., 1999).

In our study pigs digested more than 97% of ingested MCFA. According to Dierick et al. (2002b), the AD of C8:0 and C10:0 were higher than 98% in weanling pigs. After being absorbed, MCFA could be transported *via* the portal vein directly to the liver, entering the mitochondrial matrix for β-oxidation without using carnitine as a carrier (Bremer, 1980). MCFA could thus be used more efficiently as an energy source compared with long-chain fatty acids.

The finding that dietary supplementation with MCT improves the AD of crude protein of young pigs aligns with recent findings (Hanczakowska et al., 2011; Hong et al., 2012). Hanczakowska et al. (2011) indicated that MCT changes the structure of small intestinal mucosa, i.e. increased villus height, and may increase the AD of crude protein of young pigs. In addition, MCT stimulated secretion of cholecystokinin (CCK) in the small intestine in pigs (Stubbs and Stabile, 1985), rats (Douglas et al., 1990) and humans (Isaacs et al., 1987). CCK could stimulate the secretion of pancreatic proteases (i.e. trypsin, chymotrypsin and carboxypeptidase) and intestinal peptidases (i.e. aminopeptidase, dipeptidase, tripeptidase and tetrapeptidase; Tortora and Anagnostakos, 1984). Therefore, dietary MCT may stimulate the secretion of CCK and the enzymatic digestion of protein, thus improving the AD of crude protein in young pigs.

The improvement of crude protein digestibility may provide more protein for deposition in pigs. It was found that dietary MCT increased body protein deposition (Chiang et al., 1990a) and decreased body fat deposition (Lavau and Hashim, 1978; Newport et al., 1979; Travis et al., 1979; Baba et al., 1982) in animals. The decreasing effect of MCT on body fat deposition may be due to the lower energy content in MCT-containing diets and a reflection of the increasing effect of MCT on protein deposition. Because about five times less energy is needed to deposit a unit of lean tissue compared with fat tissue (Van Es, 1977), dietary MCT may increase and decrease the deposition of protein and fat, respectively, and thus improve the feed utilization efficiency of pigs.

Conclusions

In conclusion, dietary supplementation with 4.8% medium-chain triacylglycerols could be used to modify intestinal microbiota and improve feed utilization efficiency in young pigs.

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