Effects of Dietary Supplementation of Conjugated Linoleic Acid (CLA) on Piglets' Growth and Reproductive Performance in Sows

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ABSTRACT : The objective of this study was to investigate effects of dietary level of CLA and the duration of feeding CLA-containing diets on reproductive performance in sows and piglet growth rate. Tallow (3% in gestation diet and 5% in lactation diet, respectively) was incorporated as a fat source in control diet, and each 50% (dietary CLA level of 0.75% in gestation diet, and 1.50% in lactation diet, respectively) or 100% (dietary CLA level of 1.50% in gestation diet, and 2.50% in lactation diet, respectively) of tallow was replaced by a commercial CLA preparation containing 50% CLA isomers. Diets containing CLA were fed either from d 15 pre-mating to weaning or d 74 post-mating to weaning. The level of dietary CLA and feeding duration did not affect litter size. High dietary level of CLA, however, decreased piglet weights at birth ($p<0.01$) and tended to decrease backfat thickness of sows at weaning. Long-term feeding of CLA-containing diets decreased piglet weights at weaning ($p<0.05$) and backfat thickness of sows at weaning ($p<0.05$). CLA supplemented in sow diet was transferred to fetus and piglets during pregnancy and nursing period, respectively. CLA contents of femoral muscle of piglets were 2.08 to 2.57 mg per g of fat at birth, and 2.36 to 4.47 mg at 10 days of age in CLA groups, while CLA was not detected in the control group. In conclusion, dietary supplementation of CLA tended to lower backfat thickness of sow and piglets' weight at birth or weaning, but did not affect total litter size. Dietary CLA was transferred efficiently during prenatal and postnatal periods of time through the placenta and milk, respectively. ***(Asian-Aust. J. Anim. Sci. 2005. Vol 18, No. 2 : 249-254)***

Key Words : Conjugated Linoleic Acid, Sow's Reproductive Performance, Piglet Growth

INTRODUCTION

Conjugated linoleic acids (CLA) are geometric and positional isomers of the 18-carbon fatty acid with two *cis* double bonds, linoleic acid (C18:2; *cis*9, *cis*12). Dietary sources of CLA include milk fat, meat products and vegetable oils. Pigs fed diets supplemented with CLA had greater gain:feed efficiency and leaner carcasses than pigs not fed CLA (Dugan et al., 1997; Eggert et al., 1999). A portion of the increase in efficiency and lean growth could perhaps be attributed to CLA's modulation of the immune response in swine (Bassaganya-Riera et al., 2001). In addition, CLA has been shown to stimulate the immune system (Cook et al., 1993) and protect against chemically induced cancers (Pariza et al., 1983; Ip et al., 1994,1997; Belury et al., 1996) and atherosclerosis (Lee et al., 1994; Nicolosi et al., 1997).

Performance during the nursing phase of growth is dependent on both the supply and pattern of nutrients in milk secreted by the lactating sow (Boyd et al., 1995). In addition, piglets are born with extremely little body fat (Le Dividich et al., 1994) and low reserves of stored glycogen (Boyd et al., 1978), thus, sufficient energy uptake after birth is important. Several studies have examined various means to increase the total supply of nutrients to nursing pigs by increase in milk yield, such as nutrition (Boyd et al., 2000), and nursing stimuli (Sauber et al., 1994).

Suckling newborn piglets are unable to synthesize fatty acids from carbohydrate (Le Dividich et al., 1994), and deposition of body fat depends in large part on the amount of fat intake (Le Dividich et al., 1997). The most promising strategy to improve neonatal piglet growth rate is to increase the fat content of the maternal milk (Averette et al., 1999).

Bee (2000a) reported that compared with a control treatment (linoleic acid), dietary CLA in the sow lactation diet resulted in a significant increase in the level of saturated fatty acids and decreased that of monounsaturated fatty acids in the milk lipids. In addition, dietary CLA isomers were excreted in colostrum and milk and, therefore, were available to the sucking pigs.

However, little is known about the effect of dietary CLA on the reproductive performance in sows. Thus, this study was conducted to investigate effects of dietary level of CLA and feeding duration of CLA-containing diets on the changes in sow's reproductive performance and piglet growth rate.

MATERIALS AND METHODS

A randomized complete block design was used with 2×2 factorial arrangements and control group resulting in 4 treatment combinations [two CLA levels (50% or 100% of tallow used in the control diet was replaced by a

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Received July 17, 2004; Accepted October 16, 2004

Table 1. Chemical composition of control diet

	Gestation	Lactation
Ingredients:	--------------------- % ---------------------	
Corn	65.20	52.39
Soybean meal (44%)	15.00	29.00
Wheat	5.00	7.83
Wheat bran	8.00	2.00
Tallow	3.00	5.00
L-lysine HCl (95%)	0.10	0.20
DL-methionine (50%)	-	0.05
Limestone	0.90	0.83
Tricalcium phosphate	2.00	1.90
Salt	0.30	0.30
Vit.-min. mixture[1]	0.40	0.40
Antibiotics	0.10	0.10
Total	100.00	100.00
Chemical composition[2]		
Crude protein (%)	14.00	18.60
ME (kcal/kg)	3,274.00	3,386.00
Lysine (%)	0.76	1.19
Methionine (%)	0.23	0.31
Calcium (%)	0.91	0.90
Phosphorus (%)	0.74	0.73

[1] Vit.-min. mixture per kg: 2,000,000 IU of vitamin A; 400,000 IU of vitamin D_3; 250 IU of vitamin E; 200 mg of vitamin K_3; 20 mg of vitamin B_1; 700 mg of vitamin B_2; 10,000 mg of riboflavin; 3,000 mg of Ca; 30,000 mg of choline chloride; 8,000 mg of niacin; 200 mg of folacin; 13 mg of vitamin B_{12}; 12,000 mg of Mn; 15,000 mg of Zn; 100 mg of Co; 500 mg of Cu; 4,000 mg of Fe; 5,000 mg of BHT.

[2] Calculated values.

commercial CLA preparation containing 50% CLA isomers), two feeding durations (d 15 pre-mating to weaning or d 74 post-mating to weaning)]. The control group (C) received a diet with tallow (3% in gestation diet and 5% in lactation diet, respectively) as a fat source. Thus the five dietary treatments were: C, 3.0 and 5.0% of tallow in gestation and lactation diet; T1, 0.75 and 1.50% of CLA in gestation and lactation diet for d 74 post-mating to weaning; T2, 0.75 and 1.50% of CLA in gestation and lactation diet for d 15 pre-mating to weaning; T3, 1.50 and 2.50% of CLA in gestation and lactation diet for d 74 post-mating to weaning; and T4, 1.50 and 2.50% of CLA in gestation and lactation diet for d 15 pre-mating to weaning. The chemical composition and fatty acid profile of the gestation or lactation diets are shown in Table 1 and 2. Other nutrients were provided and these diets met or exceeded NRC (1998) recommendations.

A total of fifty purebred sows (Duroc) were allotted to five dietary treatments with ten sows per treatment. Body weight and backfat thickness of sows were recorded at the time of initiation, d 74 post-mating, d 7 pre-farrowing and weaning. The number of pigs born alive and stillborn was recorded and body weight was measured at birth, 7 d, 21 d (weaning), 35 d and 56 d of age. A total of six piglets from each treatment were slaughtered at birth and 10 d of age and femoral muscle was taken for the analysis of fatty acid

Table 2. Fatty acids composition of experimental diets

CLA content	Gestation diet			Lactation diet		
in diet (%)	0	0.75	1.50	0	1.25	2.50
Components (%)						
14:0	1.32	0.82	0.36	1.28	0.86	0.32
16:0	21.47	16.04	13.40	21.63	16.21	10.98
16:1	1.72	1.10	0.56	1.74	1.21	0.50
18:0	9.05	5.25	3.68	9.75	6.93	3.27
18:1	37.82	36.83	36.33	38.46	35.41	31.89
18:2	28.45	33.66	35.94	26.99	22.85	24.84
CLA	0.16	6.31	9.74	0.16	16.55	28.22

profiles.

10^{th}-rib backfat thickness was measured by backfat thickness measurement (PIGLOG 105, SFK). Blood samples were collected before the morning feeding by anterior vena cava puncture of the sows at initial and d 74 of post-mating. After blood sampling, all samples were directly transferred into heparinized syringes and stored at 4°C before analysis. Blood characteristics were analyzed by hematology analyzer (HEMAVET850, CDC tech., USA) following a reference method recommended by the International Committee for Standardization in Hematology (ICSH Standard EP, 1977).

Lipids were extracted with chloroform and methanol as described by Folch et al. (1957). Fatty acid methyl esters were analyzed on a gas chromatograph (HP5890, USA) with an on-column injector port and flame-ionization detector. A fused silica capillary column (0.32 mm i.d.×60 m, Supelco) was used for the separation of the fatty acid methyl esters. Oven temperature on gas chromatograph was 50°C, and increased at a rate of 5°C/min to a final temperature of 200°C. The injector port and detector temperatures were set at 270°C. Fatty acid methyl ester (1 ml) was injected onto the split injection port (90:1 split ratio). The injection volume was 0.5 µl. The methyl esters were identified by comparison with the retention times of pure standards.

Statistical analyses of the data were performed with the GLM procedure of SAS (SAS Inst. Inc., Cary, NC, 1999). Duncan's Multiple Range Test was used to separate treatment means at $p<0.05$.

RESULTS AND DISCUSSION

Changes in body weight and backfat thickness of sows

As shown in Table 3, the level of dietary CLA and feeding duration of CLA-containing diets had no significant effects on body weights and backfat thickness of sows.

From the contrast procedure among treatments, however, backfat thickness generally tended to be thinner in treatments with higher dietary level of CLA and longer feeding duration ($p<0.1$). Especially, long-term feeding (T2+T4) of CLA reduced ($p<0.05$) backfat thickness of

Table 3. Effects of dietary CLA on body weight and backfat thickness in sows

Treatment	C	T1	T2	T3	T4	SEM
CLA level (%)						
Gestation	0	0.75	0.75	1.50	1.50	
Lactation	0	1.25	1.25	2.50	2.50	
Feeding duration[1]		Short	Long	Short	Long	
Sow's weight (kg)						
at initial	153.2	152.3	155.2	154.4	156.5	1.757
d 74 post-mating	198.3	198.5	195.1	198.7	203.8	1.773
d 7 pre-farrowing	214.2	214.5	216.8	217.8	218.8	1.664
at weaning	178.2	177.8	186.2	176.1	178.0	2.048
Backfat thickness (cm)						
at initial	1.32	1.52	1.39	1.32	1.42	0.032
d 74 post-mating	1.98	1.92	1.74	1.75	1.76	0.041
d 7 pre-farrowing	1.92	2.01	1.83	1.81	1.78	0.044
at weaning	1.57[ab]	1.74[a]	1.50[ab]	1.56[ab]	1.33[b]	0.045
Contrast	C vs. CLA	C vs. T4	T1 vs. T2	T3 vs. T4	(T1+T2) vs. (T3+T4)	(T1+T3) vs. (T2+T4)
Backfat thickness						
d 74 post-mating	#	#	NS	NS	NS	NS
at weaning	NS	#	#	#	#	*

[1] CLA diets were fed from d 74 post-mating (short) or d 15 pre-mating (long) to weaning.
[a, b] Means with different superscripts in the same row are significantly different ($p<0.05$). * $p<0.05$, # $p<0.1$, NS: Non significant.

Table 4. Effects of dietary CLA on litter size and body weight of piglets

Treatment	C	T1	T2	T3	T4	SEM
CLA level (%)						
Gestation	0	0.75	0.75	1.50	1.50	
Lactation	0	1.25	1.25	2.50	2.50	
Feeding duration[1]		Short	Long	Short	Long	
Litter size (heads)	9.78	9.25	9.63	10.67	10.78	0.299
Piglets weight (kg)						
at birth	1.47[a]	1.54[a]	1.55[a]	1.48[a]	1.28[b]	0.028
7 d of age	2.33	2.49	2.25	2.48	2.35	0.073
21 d of age (weaning)	5.00[a]	4.95[a]	4.51[ab]	4.80[ab]	4.06[b]	0.125
35 d of age	7.83	8.34	8.00	7.99	6.97	0.212
56 d of age	15.60	17.33	16.04	16.26	16.54	0.337
Contrast	C vs. T4	C vs. (T2+T4)	T2 vs. T4	T3 vs. T4	(T1+T2) vs. (T3+T4)	(T1+T3) vs. (T2+T4)
Weight of piglets (kg)						
at birth	*	NS	**	*	**	NS
at weaning	*	*	NS	#	NS	*

[1] CLA diets were fed from d 74 post-mating (short) or d 15 pre-mating (long) to weaning.
[a, b] Means with different superscripts in the same row are significantly different ($p<0.05$). ** $p<0.01$, * $p<0.05$, # $p<0.1$. NS: Non significant.

sows measured at weaning compared with short-term feeding (T1+T3).

These results were contrary to the results of Harrell et al. (2002), who demonstrated that sow's body weight and backfat changes were not affected by parity or CLA. Also, Chin et al. (1994) showed that feeding CLA to progeny Fisher rats during gestation and lactation reduced body fat but enhanced weight gain and improved feed efficiency in pups.

Eggert et al. (2001) reported that gilts fed CLA had higher average daily gain, but there were no effects of dietary treatment on feed intake or feed efficiency. Du and Ahn (2002) showed that supplementation of CLA has no significant effect on abdominal fat weight, the total body fat, and protein content in broilers. Dunshea et al. (2002) demonstrated that under commerical conditions dietary CLA could improve growth performance and decrease P2 in pigs of an improved genotype, particularly gilts.

Litter size and body weights of piglets

The reproductive performances of sows were shown in Table 4. Litter size was not affected by the level and duration of CLA feeding. Piglet weights at birth and weaning were lower ($p<0.05$) in when sows were fed diets containing 1.50% and 2.50% of CLA in gestation and lactation diets, respectively, compared to control group

Table 5. Effects of dietary CLA in sow diets on fatty acid composition of femoral muscle of piglets (at birth)

Fatty acid composition	C	T1	T2	T3	T4	SEM
CLA level (%)						
Gestation	0	0.75	0.75	1.50	1.50	
Lactation	0	1.25	1.25	2.50	2.50	
Feeding duration[1]		Short	Long	Short	Long	
15:0	0.67[e]	1.11[c]	1.33[a]	1.20[b]	0.74[d]	0.060
16:0	28.62[a]	27.93[b]	28.75[a]	26.71[c]	25.33[d]	0.289
17:0	1.00[b]	1.63[a]	0.94[b]	1.48[a]	1.77[a]	0.097
18:0	13.15[d]	15.35[b]	14.43[c]	15.31[b]	17.03[a]	0.278
ΣSFA	43.43[d]	46.02[a]	45.44[b]	44.69[c]	44.87[c]	0.203
16:1	6.13[a]	5.87[b]	5.76[b]	5.43[c]	3.64[d]	0.193
18:1	27.51[c]	30.58[a]	27.79[c]	28.96[b]	26.03[d]	0.372
18:2	14.35[a]	7.06[d]	8.59[c]	8.56[c]	13.46[b]	0.670
CLA	0.00[e]	2.08[d]	2.20[c]	2.57[a]	2.37[b]	0.199
20:4	8.26[c]	7.84[d]	9.67[a]	9.12[b]	9.16[b]	0.175
22:3	0.36[e]	0.62[b]	0.56[c]	0.68[a]	0.49[d]	0.025
ΣUFA	56.60[a]	54.04[d]	54.56[c]	55.31[b]	55.14[b]	0.202

[1] CLA diets were fed from d 74 post-mating (short) or d 15 pre-mating (long) to weaning.

SFA: Saturated fatty acid; UFA: Unsaturated fatty acid.

[a, b, c, d, e] Means with different superscripts in the same row are significantly different ($p<0.05$).

Table 6. Effects of dietary CLA in sow diets on fatty acid composition of femoral muscle of piglets (at 10 days of age)

Fatty acid composition	C	T1	T2	T3	T4	SEM
CLA level (%)						
Gestation	0	0.75	0.75	1.50	1.50	
Lactation	0	1.25	1.25	2.50	2.50	
Feeding duration[1]		Short	Long	Short	Long	
15:0	0.30[e]	0.34[c]	0.51[a]	0.37[b]	0.29[d]	0.021
16:0	26.83[a]	25.30[b]	29.76[a]	29.61[c]	29.64[d]	0.490
17:0	0.66	1.36	0.41	0.43	0.77	0.103
18:0	11.99[d]	14.56[b]	13.52[c]	15.02[b]	15.28[a]	0.322
ΣSFA	39.77[d]	41.56[a]	44.20[b]	45.42[c]	45.97[c]	0.632
16:1	6.14[a]	3.11[b]	1.82[b]	2.96[c]	2.17[d]	0.409
18:1	33.33[c]	29.02[a]	25.87[c]	22.50[b]	22.70[d]	1.093
18:2	15.73[a]	17.22[d]	18.51[c]	19.98[c]	20.59[b]	0.476
CLA	0.00[e]	2.79[d]	2.36[c]	3.01[a]	4.47[b]	0.387
20:4	4.87[c]	6.06[d]	7.25[a]	5.88[b]	3.93[b]	0.301
22:3	0.18[e]	0.27[b]	0.00[c]	0.27[a]	0.18[d]	0.026
ΣUFA	60.24[a]	58.45[d]	55.80[c]	54.59[b]	54.03[b]	0.633

[1] CLA diets were fed from d 74 post-mating (short) or d 15 pre-mating (long) to weaning.

SFA: Saturated fatty acid; UFA: Unsaturated fatty acid.

[a, b, c, d, e] Means with different superscripts in the same row are significantly different ($p<0.05$).

(Table 4) for d 15 pre-mating to weaning than in those fed control diets containing 3.0% and 5.0% of tallow in gestation and lactation diets, respectively. Although the longer the duration of CLA feeding the lower the piglet weaning weight at d 21 ($p<0.05$). No difference was observed in body weights at d 35 and d 56 postweaning pigs among dietary treatments. In general, piglet weights at birth were lower in treatments with higher dietary level of CLA and longer feeding duration ($p<0.05$ or $p<0.01$).

Aydin et al. (2001) showed that dietary CLA induced embryonic mortality in laying hens. The mechanism for chick embryonic mortality resulting from maternal ingestion of CLA has yet to be determined. When laying hens were fed a diet containing 0.5% CLA, yolks hardened and fertile eggs failed to hatch, possibly due to increased 16:0 and 18:0 and decreased 18:1(n-9) in the egg yolk. However, CLA supplementation in the present study did not affect the reproductive performance in terms of litter size. Pettersen and Opstvedt (1991) indicated that the dietary inclusion of CLA reduced sow milk fat content but did not influence litter size or body weight of weaning pigs. In addition, feeding sows *trans*-18:1 fatty acids reduced milk fat content, growth performance. Contrary to the results of Pettersen and Opstvedt (1991), body weights of piglets at birth and weaning (21 d) tended to be reduced when reared by sows fed CLA in the present study.

Harrell et al. (2002) showed no improvement in growth rate of neonatal piglets born to dams fed supplemental CLA.

Table 7. Effects of CLA supplementation on fatty acid composition of colostrum[1]

	CLA level (%)		
	0	1.25	2.50
14:0	1.93 [b]	2.87 [a]	2.85 [a]
16:0	27.06 [c]	28.84 [b]	29.43 [a]
17:0	0.49 [b]	0.55 [a]	0.58 [a]
18:0	9.15 [b]	10.22 [a]	10.10 [a]
ΣSFA	38.64 [b]	42.48 [a]	42.96 [a]
16:1	3.08 [b]	3.10 [a]	2.43 [c]
18:1	41.20 [a]	32.24 [b]	31.70 [b]
18:2	16.20 [a]	13.46 [b]	12.84 [c]
18:3	0.88 [a]	0.81 [b]	0.72 [c]
CLA	0.00 [c]	7.96 [b]	8.30 [a]
ΣUFA	61.36 [a]	57.53 [b]	57.04 [c]

[1] CLA diets were fed from d 74 post-mating to weaning.
SFA: Saturated fatty acid; UFA: Unsaturated fatty acid.
[a, b, c] Means with different superscripts in the same row are significantly different (p<0.05).

and Bontempo et al. (2004) reported that the body weights of sows and piglets were not affected by CLA supplementation. In contrast to our results, Bee (2000b) reported that irrespective of the starter diet fed in the 35 d postweaning period, pigs born to and reared by sows fed 2% CLA had greater feed intake, daily weight gain, and final body and warm carcass weights than pigs reared by sows fed the control diets.

Fatty acid composition of muscle of piglets

Regarding the fatty acid profiles of femoral muscle of piglets, feeding CLA diets increased saturated fatty acid contents in the muscle (p<0.05). CLA contents of femoral muscle of piglets were 2.08 to 2.57 mg per g of fat at birth, and 2.36 to 4.47 mg at 10 days of age in CLA groups (Tables 5 and 6). CLA contents were the highest in the group with 1.50% CLA in gestation diet, and 2.50% CLA in lactation diet (p<0.05), while CLA was not detected in the control group.

Bee (2000a) showed that feeding sows a CLA-enriched diet during gestation and lactation could increase the concentration of CLA and markedly affect the fatty acid composition of backfat tissue, colostrums and mature milk lipids. Estimated transfer efficiency for adipose tissue and mature milk ranged from 41 to 52% and 55 to 69%, respectively, and seemed to be higher than that measured in cows.

When weaned piglets were fed a CLA-enriched starter diet, the effects on fatty acid composition were even more pronounced. The elevated SFA deposition by dietary CLA supplementation was related to an inhibition of the Δ9-desaturase activity and probably other desaturases, rather than elevated de novo synthesis rate (Bee, 2000b).

Fatty acid composition of colostrum

When sows were fed CLA, higher CLA was secreted in colostrum (Table 7). Total CLA concentration in colostrum was significantly increased in proportional to dietary level of CLA (p<0.05). The ratio of saturated fatty acids (SFA) in colostrum was higher in the CLA group than in the control group (p<0.05), whereas, CLA supplementation decreased the concentration of unsaturated fatty acids (UFA) (p<0.05).

CLA supplementation was reported to profoundly affect lipid metabolism (Evans et al., 2002) and to increase the CLA content of milk fat in dairy cows, subsequently altering the fatty acid composition of the milk and lowering the yield of milk fat (Chouinard et al., 1999). Bontempo et al. (2004) reported that the proportion of CLA isomers was higher in colostrum when sows were fed CLA than the control group.

Bee (2000a) reported that dietary CLA supplementation during gestation significantly reduced MUFA and increased the SFA content in colostrums. The present experiment showed that CLA supplementation significantly increased the SFA and reduced UFA content in colostrums.

CLA supplementation lowered the proportion of palmitoleic acid (16:1) possibly by lowering the activity of Δ9-desaturase. Bretillon et al. (1999) and Lee et al. (1998) reported that both the activity and gene expression of hepatic Δ9-desaturase were inhibited by dietary CLA. The result of this experiment demonstrated that CLA supplementation significantly lowered the linolenic acid (18:3) content of colostrums, which is consistent with the reports of Bontempo et al. (2004).

In conclusion, dietary supplementation of CLA tended to lower backfat thickness of sow and piglets' weight at birth or weaning, while it did not affect total litter size. And dietary CLA was transferred efficiently during prenatal and postnatal period of time through the placenta and milk, respectively.

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