

Conjugated linoleic acid pork research¹⁻³

Michael ER Dugan, Jennifer L Aalhus, and John KG Kramer

ABSTRACT

The driving force behind most conjugated linoleic acid (CLA) research in swine has been related to potential improvements in animal production. Early work that used rodent models indicated that feeding CLA could potentially reduce body fat, increase lean content, increase growth rate, and improve feed conversion efficiency. Producer-backed funding organizations were, therefore, receptive to proposals to extend this research to pigs, and many studies have been completed worldwide. In general, improvements in body composition were found, but evidence indicating that CLA improves growth rate or feed conversion was limited. Inclusion of CLA into pig diets was, however, shown to increase muscle marbling fat and fat hardness, and both of these characteristics have the potential to increase carcass value. Currently, Badische Anilin- & Soda-Fabrik AG (BASF) has the international marketing license to include synthetic CLA in animal feeds, but to date this practice is not approved in Canada or the United States. If and when approval is granted, the next step in realizing CLA's economic potential would be to seek approval for claiming CLA enrichment in pork and pork products. Given the ability of swine to accumulate relatively high amounts of CLA in their tissues, pork and pork products could become an important vehicle for delivery of physiologically significant amounts of CLA to consumers. *Am J Clin Nutr* 2004;79(suppl):1212S-6S.

KEY WORDS Pigs, pork, CLA, conjugated linoleic acid, adipose tissue, lean tissue

INTRODUCTION

Pigs are monogastric animals, and their stomach contains few microorganisms relative to ruminant animals (eg, cattle). In addition, stomach contents in pigs have a greater rate of passage relative to ruminants, and this rate of passage further limits the potential for gastric hydrogenation of fatty acids and the production of conjugated linoleic acid (CLA). Consequently, only a small amount of CLA is produced by way of bacterial biohydrogenation in pigs, and pork usually contains a limited amount of CLA (0.1–0.2 mg/g fatty acids). Pork, however, is an ideal candidate for CLA enrichment by feeding synthetic CLA, because CLA will not be further saturated before absorption, CLA deposits in tissues with relatively high efficiency, and pork could become a physiologically significant source of CLA for human consumption.

Initial reasons for feeding CLA to pigs relate to early rodent work (1, 2), indicating that CLA has the potential to reduce body fat, increase lean, increase growth rate, and improve feed conversion efficiency. When feed-grade CLA became available in 1996–1997, funding was requested from pork producer groups

to determine whether CLA could improve production economics by improving animal performance and carcass composition and also to determine whether CLA would affect any aspect of pork quality. To date there are roughly 33 articles published that involve feeding CLA to pigs. Eight articles are mechanistic in nature (ie, studying how CLA might work) (3–11), 4 are related to CLA's potential to improve immune status (12–15), and the remaining 18 (16–33) are related to CLA's effects on pig performance, body composition, and pork quality.

ANIMAL PERFORMANCE AND CARCASS COMPOSITION

The weights of animals at the start and finish of tests in the 18 studies to be considered are listed in **Table 1**. Of the 18 studies, only 14 (16–22, 24–26, 28, 30–32) reported animal performance results (growth rates and feed conversions efficiency). Of those 14 studies, 2 included animals finishing at light weights (16, 17) and 2 studies included animals starting at heavier weights (31, 32), and these studies showed no effect of CLA on animal performance or carcass composition. Perhaps these animals were removed from test too early or started on test too late to see a response to CLA. Gatlin et al (31) apparently started feeding at a heavy weight according to days on test and feed conversion results. O'Quinn et al (22) conducted 2 trials with CLA; the first trial showed no effect, but the second trial, with tall oil as the source of CLA, showed effects. Of the remaining 10 studies, feed conversion efficiency (kilogram feed per kilogram gain) was improved in 7 cases by an average of 6.5%, but only one showed an improvement (8.2%) in average daily gain (**Table 2**).

By excluding the studies that indicated finishing or starting on test at light or heavy weights (16, 17, 31, 32), 12 studies reported carcass fat amounts with 11 showing reductions (18–22, 24–28, 30), and 10 studies reported carcass lean with 9 showing increases (18–23, 25, 26, 28). Changes in fat content were greater on a percentage basis relative to lean, and results for both were quite variable. Fat reduction ranged from 6.2% to 25%, and lean increase ranged from 2.3% to 9.7%. Some of this variation was likely due to the measurements taken to approximate carcass

¹ From Agriculture and Agri-Food Canada, Lacombe Research Centre (MERD and JLA), Lacombe, Canada, and Agriculture and Agri-Food Canada, Guelph Food Program (JKGK), Guelph, Canada.

² Presented at the workshop "The Role of Conjugated Linoleic Acid in Human Health," held in Winnipeg, Canada, March 13–15, 2003.

³ Address reprint requests to MER Dugan, Food Quality and Safety, Lacombe Research Centre, Lacombe, Alberta, Canada T4L 1W1. E-mail: duganm@agr.gc.ca.

TABLE 1
Summary of animal weights on and off test in research studies feeding conjugated linoleic acid

Reference	No. of animals per diet	Weight	
		Start	Finish
			<i>kg</i>
Demaree et al (16) ¹	6	5.6	26
Ramsay et al (17)	7	20	50
Tischendorf et al (18)	40	24	117
Thiel-Cooper et al (19)	8	26	116
Wiegand et al (20)	23	28	115
Dugan et al (21)	36	36	115
O'Quinn et al (22) ²	16	36	113
Swan et al (23)	32	40	115
Wiegand et al (24)	30	40	106
Ostrowska et al (25)	10	56	107
Ostrowska et al (26)	5	57	106
D'Souza et al (27)	72	60	105
Dugan et al (28, 29)	54	61	106
Dunshea et al (30) ²	76	64.5	105
Yatlen et al (31)	72	72	113
Eggert et al (32)	10	75	120
Joo et al (33) ³	5	77	105

¹ Assumed to be the same as reference 10.

² Averages of 2 trials.

³ A starting weight of 77 kg is estimated from the final weight of 105 kg, assuming an average daily gain of 1 kg/d.

composition. For lean content, a number of measures were used, including loin depth, loin area by tracing, loin area by ultrasound, loin weight, gram lean per kilogram sellable cuts, and proximate analysis of carcass sides. For fat measurements, 8 studies reported backfat depths, and 4 studies reported either actual fat mass by dissection or by chemical analysis.

Backfat and lean depths are used to calculate lean yield for price settlements (ie, producers get paid for lean and packers do not pay for extra carcass fat). The use of depth measurements is, however, relatively insensitive for detecting changes in lean genetic stock. This simple measurement is used commercially because carcass line speeds can be up to 8 pigs/min or faster, and,

TABLE 2
Improvement in performance in animals fed conjugated linoleic acid¹

Reference	ADG	FCE
	<i>kg</i>	<i>kg feed/kg groups</i>
Tischendorf et al (18)	—	—
Thiel-Cooper et al (19)	8.2	9.1
Wiegand et al (20)	—	Quadratic ²
Dugan et al (21)	—	—
O'Quinn et al (22)	—	—
Wiegand et al (24)	—	5.7
Ostrowska et al (25)	—	6.3
Ostrowska et al (26)	—	7.9
Dugan et al (28)	—	5.9
Dunshea et al (30)	—	3.8

¹ ADG, average daily gain; FCE, feed conversion efficiency; —, no significant improvement with feeding conjugated linoleic acid.

² Quadratic response was noted for animals slaughtered at different weights.

at 1 carcass every 7 s, only a limited number of minimally invasive measurements are possible.

As an example, data gathered in the same experiment but not reported in Dugan et al (28) showed poor agreement between estimated lean yield (from fat and lean depths) and actual lean yield (from carcass dissection) (**Figure 1**). Consequently, the increase in estimated lean yield (0.7%) was not significant, but the actual increase in lean yield (1.9%) by carcass dissection was significant. In addition, the reduction in backfat depth was not significant (−4.6%), but the actual reduction in fat mass (g/kg sellable lean cuts) was significant (−6.8%). Between trial variability could, in part, be explained by methods used, but further investigation into a number of variables (eg, breed, sex, diet interactions, CLA composition and level in diet, duration, and weight range of feeding) is needed to enable a full explanation. In addition, concurrent studies are necessary to further establish the mechanisms of CLA action and how these mechanisms could be further manipulated.

QUANTITY AND COMPOSITION OF THE CONJUGATED LINOLEIC ACID FED

In 14 studies, pigs were fed CLA that contained at least the 4 common *cis/trans* isomers (*trans*-8,*cis*-10; *cis*-9,*trans*-11; *trans*-10,*cis*-12; *cis*-11,*trans*-13), and in 2–3 studies pigs were fed 2 isomer preparations (*trans*-10,*cis*-12; *cis*-9,*trans*-11). Most of the CLA was in free fatty acid form. The CLA content of the CLA oil included in the diets averaged 69%. With the assumption that feed intake was 2.7 kg/d, CLA intake ranged from 3.4 to 135 g/d (**Table 3**), and the median amount consumed was 27.3 g/d. In contrast, Gaullier et al (34) reviewed 16 human trials; the median CLA consumption was 3.4 g/d, and 3.4 g/d appeared to be the threshold for showing effects on human body composition. Interestingly, the 2 pig studies feeding CLA at 3.4 g/d did not show any changes in body composition.

PORK QUALITY

Pork quality was initially investigated to determine whether feeding CLA would have a negative effect (29). In that study, a number of loin quality indexes were unaffected by CLA, and most have now been supported by other researchers (**Table 4**). The initial report (29) also indicated CLA increased both loin marbling scores and solvent extractable intramuscular fat amounts (3.8 g/kg loin). These results have now been supported by 3 studies (20, 24, 33), but 2 studies (18, 27) have shown no change. Interestingly, the subcutaneous fat depot has been consistently reduced by feeding CLA, but the intramuscular depot has shown signs of increasing. Potentially the difference in maturity of adipocytes in these depots could play a role in these phenomena. The subcutaneous fat depot is relatively mature, and the intramuscular depot contains a high proportion of preadipocytes that could be stimulated by CLA to mature and start to deposit triacylglycerol (6).

After the report of Lee et al (35) indicating that CLA inhibited Δ⁹-desaturase activity, there have been 8 reports that indicate CLA increases the amount of saturates in pig tissues (10, 17, 19, 20, 22, 31–33). Greater fatty acid saturation means firmer bellies and loins, as well as fewer problems with bacon slicing and sausage making. This characteristic can be of particular importance with elevated dietary oil or when pigs are very lean.

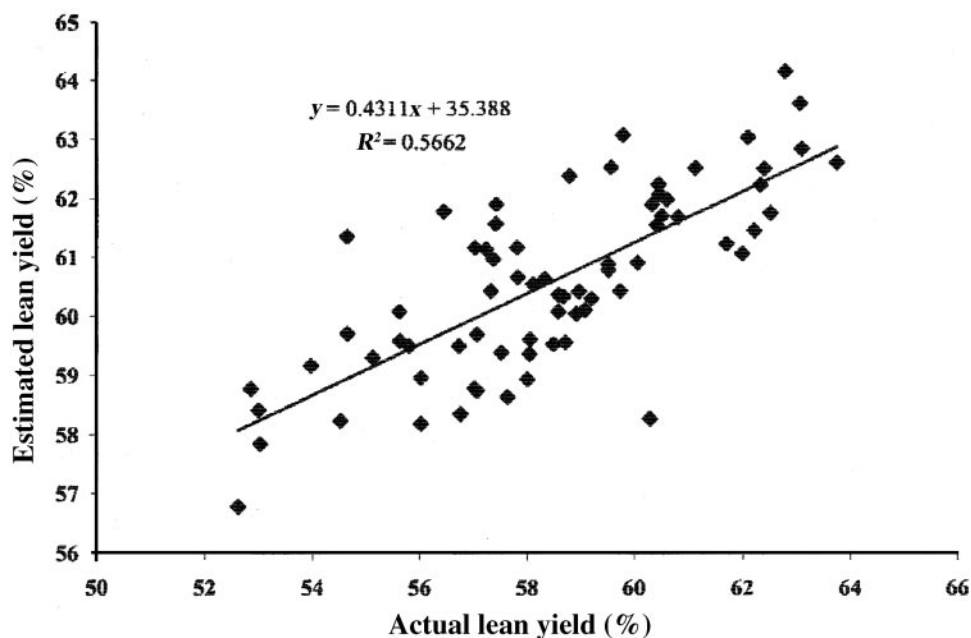


FIGURE 1. Comparison of actual lean yield from carcass dissection to estimated lean yield calculated from loin fat and lean depth.

Increased belly firmness was reported in 3 studies (19, 22, 32), CLA had no effect in 1 study (23), and 2 reports indicated CLA increases loin muscle oxidative stability (20, 33).

IS THERE VALUE IN THE PIG BARN?

The next obvious step in realizing CLA's potential is being able to market CLA-enriched pork and pork products. Eggs enriched with n-3 fatty acids are marketed at prices 50–100% greater than normal eggs, and the same potential could be possible for fatty acid-enriched pork and pork products. Pigs have the advantage, relative to ruminants, of being able to ingest fatty acids and deposit them with relatively high efficiency, and some fairly impressive enrichments can result (Table 5)

TABLE 3

Summary of daily conjugated linoleic acid consumption

Reference	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5
			<i>g/d</i>		
Demaree et al (16)	27.0	—	—	—	—
Ramsay et al (17)	13.5	27.0	54.0	—	—
Tischendorf et al (18)	54.0	—	—	—	—
Thiel-Cooper et al (19)	5.4	11.3	22.4	45.1	—
Wiegand et al (20)	33.8	—	—	—	—
Dugan et al (21)	6.8	13.5	—	—	—
O'Quinn et al (22)	13.5	—	—	—	—
Swan et al (23)	20.3	—	—	—	—
Wiegand et al (24)	33.8	—	—	—	—
Ostrowska et al (25)	3.4	6.8	13.5	20.3	27.0
Ostrowska et al (26)	3.4	6.8	13.5	20.3	27.0
D'Souza et al (27)	13.5	—	—	—	—
Dugan et al (28, 29)	54.0	—	—	—	—
Dunshea et al (30)	10.8	—	—	—	—
Gatlin et al (31)	27.0	—	—	—	—
Eggert et al (32)	27.0	—	—	—	—
Joo et al (33)	27.0	67.5	135.0	—	—

CLA content of loin muscle ranged from 0.71% to 2.8% of fatty acids, and CLA in subcutaneous fat ranged from 1.7% to 9.5% of fatty acids. Ramsay et al (17) reported the greatest CLA enrichment with 2.8% in loin fatty acids and 9.5% in subcutaneous fatty acids. They fed 0%, 0.25%, 0.5%, and 2% dietary CLA, and the CLA oil was reported to have 25% *cis-9,trans-11* and 35% *cis-10,trans-12* CLA. In addition, pigs were only fed from 20 to 50 kg. Ramsay et al (17) showed that with increasing dietary CLA, backfat CLA increased. In addition, with increasing dietary CLA, the *trans-10,cis-12:cis-9,trans-11* CLA increased. The CLA amounts were ≈ 2 times what would be expected in finished (110 kg) animals fed a similar amount of CLA. Higher CLA in tissues might, therefore, explain why feed conversion was enhanced earlier in a number of studies and could also explain why animals starting at heavier weights might be less responsive to dietary CLA.

How much pork or pork products would a person then have to eat daily to see an effect? As stated previously, 3.4 g/d of CLA was suggested by Gaullier et al (34) to be the threshold needed to see changes in body composition. This amount might not, however, be the amount needed to see other metabolic effects (eg, as an

TABLE 4

Summary of pork quality characteristics unaffected by conjugated linoleic acid consumption

Characteristic	Supporting references
Subjective color	18, 20, 22, 24, 29, 30, 32, 33
Subjective structure	22, 29 and 32 (no change); 20 and 24 (slightly firmer)
Drip loss	18, 22, 29, 30, 32, 33
pH	18, 20, 24, 32, and 33 (no change); 27, 29, and 30 (slightly higher)
Shear force	18, 29
Lactate concentration	29
Glycogen concentration	29

TABLE 5

Summary of the highest percentage of conjugated linoleic acid concentrations reported in loin muscle fatty acids and subcutaneous fat

Reference	Loin	Subcutaneous fat
Demaree et al (16)	1.75	2.33
Ramsay et al (17)	2.8	9.5
Thiel-Cooper et al (19)	0.8	4.85
Wiegand et al (20)	0.71	3.62
Gatlin et al (31)	1.7	1.7
Eggert et al (32)	0.55	1.56
Joo et al (33)	1.12	—

anticarcinogen). If it were, however, found that 3.4 g of CLA needed to be consumed to provide beneficial effects, then substantial quantities of pork (>2 kg) would need to be consumed per day to satisfy this requirement (assuming pork contained 5% fat and had 3% CLA in the fat). This amount would be impractical, unless part of the requirement could be satisfied by consuming other CLA-enriched products (eg, dairy or beef). Alternatively, if highly enriched subcutaneous fat from pigs (ie, containing ≈10% CLA) could be used to produce pork sausages or lard for baked products, a daily dose of CLA might be obtained by consuming 3–4 sausage links (25% fat) or by eating about 15 cookies (20% fat).

TAKING CONJUGATED LINOLEIC ACID-ENRICHED PORK TO MARKET

The first step in being able to bring CLA-enriched pork to market is getting approval for adding CLA to animal diets. BASF holds the international license to add CLA to animal feed and has applied for permission to do so in Canada and the United States, but approval has not been granted thus far. Step 2 will be to apply for approval to advertise CLA enrichments in pork, and applications will certainly require documentation that indicates why CLA enrichment would be beneficial for the public. At present, fatty acid (n–3)-enriched meats or meat products are not available in Canada but are available in other parts of the world (eg, Korea). Vertical integration or producer/packer alliances will likely be key factors in bringing CLA-enriched pork to market in North America. The cost of feeding CLA, the amounts of CLA needed to see a desired effect, and what consumers are willing to pay for CLA-enriched products will, however, ultimately determine whether CLA-enriched products can be marketed successfully.

SUMMARY

Feeding CLA to pigs has the potential to improve animal performance, carcass composition, and pork quality and to provide CLA-enriched pork for human consumption. Variations in CLA responses and enrichments still need to be addressed, but uniform production practices and vertical integration from production through marketing could very well bring CLA-enriched pork to market. Regulatory issues concerning the addition of CLA to animal feeds and the ability to claim CLA enrichments would, however, need to be addressed before enriched products can be marketed. In addition, it needs to be determined how

profitable it would be to feed CLA to pigs to provide enriched pork and pork products beneficial to the consumer. 

The authors had no conflict of interest.

REFERENCES

1. Chin SF, Storkson JM, Albright KJ, Cook ME, Pariza MW. Conjugated linoleic acid is a growth factor for rats as shown by enhanced weight gain and improved feed efficiency. *J Nutr* 1991;124:2344–9.
2. Park Y, Albright KJ, Liu W, Storkson JM, Cook ME, Pariza MW. Effect of conjugated linoleic acid on body composition in mice. *Lipids* 1997;32:853–8.
3. Bee G. Dietary conjugated linoleic acids affect tissue lipid composition but not de novo lipogenesis in finishing pigs. *Anim Res* 2001;50:383–99.
4. Ding S, McNeel RL, Mersmann HJ. Conjugated linoleic acid increases the differentiation of porcine adipocytes in vitro. *Nutr Res* 2000;20:1569–80.
5. Dugan MER, Rolland DC, Best DR, Meadus WJ. The effects of feeding conjugated linoleic acid on pig liver vitamin A and retinol binding protein mRNA. *Can J Anim Sci* 2002;82:461–3.
6. Meadus WJ, MacInnis R, Dugan MER. Prolonged dietary treatment with conjugated linoleic acid stimulates porcine muscle peroxisome proliferators activated gamma and glutamine-fructose aminotransferase gene expression in vivo. *J Mol Endocrinol* 2002;28:79–86.
7. Muller HL, Kirchgessner M, Roth FX, Stangl GI. Effect of conjugated linoleic acid on energy metabolism in growing finishing pigs. *J Anim Physiol Anim Nutr* 2000;83:85–94.
8. Muller HL, Stangl GI, Kirchgessner M. Energy balance of conjugated linoleic acid-treated pigs. *J Anim Physiol Anim Nutr* 1999;81:150–6.
9. Ostrowska E, Cross RF, Muralitharan M, Bauman DE, Dunshea FR. Effects of dietary fat and conjugated linoleic acid on plasma metabolite concentrations and metabolic responses to homeostatic signals in pigs. *Br J Nutr* 2002;88:625–34.
10. Smith SB, Hively TS, Cortese GM, et al. Conjugated linoleic acid depresses the delta-9 desaturase index and stearyl coenzyme A desaturase enzyme activity in porcine subcutaneous adipose tissue. *J Anim Sci* 2002;80:2110–5.
11. Stangl GI, Muller H, Kirchgessner M. Conjugated linoleic acid effects on circulating hormones, metabolites and lipoproteins, and its proportion in fasting serum and erythrocyte membranes of swine. *Eur J Nutr* 1999;38:271–7.
12. Bassaganya-Riera J, Hontecillas-Magarzo R, Bregendahl K, Wannemuehler WJ, Zimmerman DR. Effects of dietary conjugated linoleic acid in nursery pigs of dirty and clean environments on growth, empty body composition, and immune competence. *J Anim Sci* 2001;79:714–21.
13. Corino C, Bontempo V, Sciannimanico D. Effects of dietary conjugated linoleic acid on some aspecific immune parameters and acute phase protein in weaned pigs. *Can J Anim Sci* 2002;82:115–7.
14. Hontecillas R, Wannemuehler MJ, Zimmerman DR, et al. Nutritional regulation of porcine bacterial-induced colitis by conjugated linoleic acid. *J Nutr* 2002;132:2019–27.
15. Weber TE, Schinckel AP, Houseknecht KL, Richert BT. Evaluation of conjugated linoleic acid and dietary antibiotics as growth promotants in weanling pigs. *J Anim Sci* 2001;79:2542–9.
16. Demaree SR, Gilbert CD, Mersmann HJ, Smith SB. Conjugated linoleic acid differentially modifies fatty acid composition in subcellular fractions of muscle and adipose tissue but not adiposity of postweaning pigs. *J Nutr* 2002;132:3272–9.
17. Ramsay TG, Evock-Clover CM, Steele NC, Azain MJ. Dietary conjugated linoleic acid alters fatty acid composition of pig skeletal muscle and fat. *J Anim Sci* 2001;79:2152–61.
18. Tischendorf F, Schone F, Kirchheim U, Jahreis G. Influence of a conjugated linoleic acid mixture on growth, organ weights, carcass traits and meat quality in growing pigs. *J Anim Physiol Anim Nutr* 2002;86:117–28.
19. Thiel-Cooper RL, Parrish FC Jr, Sparks JC, Wiegand BR, Ewan RC. Conjugated linoleic acid changes swine performance and carcass composition. *J Anim Sci* 2001;79:1821–8.
20. Wiegand BR, Sparks JC, Parrish FC Jr, Zimmerman DR. Duration of feeding conjugated linoleic acid influences growth performance, carcass traits, and meat quality of finishing barrows. *J Anim Sci* 2002;80:637–43.
21. Dugan MER, Aalhus JL, Lien KA, Schaefer AL, Kramer JKG. Effects of

- feeding different levels of conjugated linoleic acid and total oil to pigs on live animal performance and carcass composition. *Can J Anim Sci* 2001; 81:505–10.
22. O'Quinn PR, Nelssen JL, Goodband RD, et al. Effects of modified tall oil versus a commercial source of conjugated linoleic acid and increasing levels of modified tall oil on growth performance and carcass characteristics of growing-finishing pigs. *J Anim Sci* 2000;78:2359–68.
 23. Swan JE, Parrish FC, Wiegand BR, Larsen ST, Baas TJ, Berg EP. Total body electrical conductivity (TOBEC) measurement of compositional differences in hams, loins, and bellies from conjugated linoleic acid (CLA)-fed stress genotype pigs. *J Anim Sci* 2001;79:1475–82.
 24. Wiegand BR, Parrish FC Jr, Swan JE, Larsen ST, Baas TJ. Conjugated linoleic acid improves feed efficiency, decreases subcutaneous fat, and improves certain aspects of meat quality in stress-genotype pigs. *J Anim Sci* 2001;79:2187–95.
 25. Ostrowska E, Muralitharan M, Cross RF, Bauman DE, Dunshea FR. Dietary conjugated linoleic acids increase lean tissue and decrease fat deposition in growing pigs. *J Nutr* 1999;129:2037–42.
 26. Ostrowska E, Suster D, Muralitharan M, et al. Conjugated linoleic acid decreases fat accretion in pigs: evaluation by dual-energy X-ray absorptiometry. *Br J Nutr* 2003;89:219–29.
 27. D'Souza DN, Mullan BP. The effect of genotype, sex and management strategy on the eating quality of pork. *Meat Sci* 2002;60:95–101.
 28. Dugan MER, Aalhus JL, Schaefer AL, Kramer JKG. The effect of conjugated linoleic acid on fat to lean repartitioning and feed conversion in pigs. *Can J Anim Sci* 1997;77:723–5.
 29. Dugan MER, Aalhus JL, Jeremiah LE, Kramer JKG, Schaefer AL. The effects of feeding conjugated linoleic acid on subsequent pork quality. *Can J Anim Sci* 1999;79:45–51.
 30. Dunshea FR, Ostrowska E, Luxford B, et al. Dietary conjugated linoleic acid can decrease backfat in pigs housed under commercial conditions. *Asian-Aust J Anim Sci* 2002;15:1011–7.
 31. Gatlin LA, See MT, Larick DK, Lin X, Odle J. Conjugated linoleic acid combination with supplemental dietary fat alters pork fat quality. *J Anim Sci* 2002;132:3105–12.
 32. Eggert JM, Belury MA, Kempa-Steczko A, Mills SE, Schinckel AP. Effects of conjugated linoleic acid on the belly firmness and fatty acid composition of genetically lean pigs. *J Anim Sci* 2001;79:2866–72.
 33. Joo ST, Lee JI, Ha YL, Park GB. Effects of dietary conjugated linoleic acid on fatty acid composition, lipid oxidation, color, and water-holding capacity of pork loin. *J Anim Sci* 2002;80:108–12.
 34. Gaullier J, Berven G, Blankson H, Gudmunson O. Clinical trial results support preference for using CLA preparations enriched with two isomers rather than four isomers in human trials. *Lipids* 2002;37:1019–25.
 35. Lee KN, Pariza MW, Ntambi JM. Conjugated linoleic acid decreases hepatic stearoyl-CoA desaturase mRNA expression. *Biochem Biophys Res Commun* 1998;248:817–21.