Final Report **Date:** September 15, 2001

Submitted to: **Fats and Proteins Research Foundation, Inc.**
R.R. #2, Box 298, Bloomington, Illinois 61704

Title: Improving the Feeding Value for Saturated Fats for Lean Genotype Swine: Effects of Tallow and Supplemental CLA

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Project Starting Date: June 1, 2000 **Completion Date:** September 1, 2001

Objectives: To determine the additive effects of dietary tallow and CLA supplementation on pig growth and performance and carcass quality, pork quality, and belly quality.

Industry Summary:

Introduction: The quality of pork fat can be defined as color, consistency and keeping quality and is affected by the size of fat depots in the pig and diet composition. As the industry strives for efficient production of leaner pigs, reduction in fat quality can occur which may adversely affect further processing, tissue separation and storage stability. Poor belly quality may be associated with leaner market pigs being slaughtered resulting in thinner bellies. Nutrition, genetics, management and pork processing technique influence belly quality. Slicing of pork bellies for bacon can be hindered if the belly is thin or has soft fat composition. Combining extreme leanness in the pig with diets composed of cereal grains and supplemented with soft fat that is often high in poly-unsaturated fatty acids (PUFA) in order to maximize grow-finish performance and efficiency can result in soft fat composition. Pork production techniques do help realize consumer demands for reduced total carcass fat and saturated fatty acids, but this is opposite from the optimal physical qualities of fat for further processing. Tallow has a lower linoleic acid content compared to higher IV fats (ex. choice white grease) which can improve fat firmness. Other researchers have recently shown that conjugated linoleic acid (CLA) has similar effects on pork fat quality. This polyunsaturated fatty acid has the potential to reduce de novo fat synthesis and increase the breakdown of fat in swine adipose tissue resulting in effects resembling those of other repartitioning agents. In addition, the behavior of this fatty acid in tissue membranes is similar to that of saturated fatty acids, possibly affecting fat firmness.

As swine adipose tissue directly reflects the dietary fatty acid composition, and because the combined effects of supplemental saturated fat and CLA have not been studied, the goal of this research was to determine the additive effects of dietary tallow and CLA supplementation on pig growth and performance and carcass quality, pork quality, and belly quality.

Summary: Swine producers are continuously searching for alternative energy sources to feed their market pigs. Since 1993 the pig/corn price ratio, which is an indicator of profitability, has averaged less than 20 (approximate break-even point). In 1999, from March to August, the ratio has ranged from 10 to 15 (USDA, 1999). The low price of hogs and relatively higher cost of corn causes rising interest in supplemental dietary fat because it is an inexpensive source of

calories. This is especially true in the Southeast where hog prices tend to be 5% lower than the national average and a bushel of corn is about $0.45 higher due to added transportation costs (Kelly Zering, personal comm.).

Southeastern producers have limited options for sources of supplemental fat. Tallow is available in mid-west markets. However, transportation is cost-prohibitive so increasing amounts of unsaturated fats, such as rendered restaurant grease, are being added to the diets. However, packers and processors such as Smithfield and Oscar Meyer are concerned about the effects of feeding unsaturated fat on the composition of pork fat (Morgan et al., 1994). One solution to the soft fat problem created by increased polyunsaturated fats in the diet is to remove supplemental fat altogether. Indeed, one large integrator's response to this concern was to remove supplemental fat completely from their finishing diets (Todd See, personal comm.).

Our data show that tallow and conjugated linoleic acid will significantly reduce the iodine value (IV) of belly fat and have an additive effect when supplemented together. This combination can enhance the value of tallow as a fat source. We did not detect any negative effects of tallow or CLA supplementation on growth, feed intake, feed efficiency or carcass quality. Fatty acid composition of belly fat was altered by both tallow and CLA addition. They both resulted in increased saturation of belly fat and when supplemented together resulted in a reduction of the IV to 62. This is within the range desired by the industry. However, supplementation of yellow grease led to increased linoleic acid in belly fat samples and could result in increased opportunity for lipid oxidation in pork products. Unfortunately, feeding yellow grease combined with CLA did not result in IVs of belly fat as low as those from pigs fed no supplemental fat, CLA alone, tallow or tallow combined with CLA. Further, our taste panel evaluation determined that flavor attributes of bacon and pork products from pigs fed CLA would be accepted by consumers and would not differ from commodity pork products.

Scientific Abstract:

Both conjugated linoleic acid (CLA) and tallow supplementation have been shown to increase firmness of pork bellies. However, effects of CLA on flavor of pork have not been described. This study evaluated the combined effects of dietary CLA and supplemental fat (SF) in lean-genotype gilts (n = 144) and on organoleptic characteristics of bacon and pork loin samples (n = 48). Gilts (49.3 kg) were randomly assigned to a 2 x 3 factorial arrangement of supplemental fat level and linoleic acid supplementation. Animals were slaughtered (96.9 kg) after a period of 47 d. Supplemental fat treatments included 0%, 4% yellow grease (YG), and 4% tallow (T). Linoleic acid treatments included 1% corn oil (CO) or 1% CLA (CLA-60, Natural Lipids, Norway). Lysine:calorie ratio was constant in all diets. A trained six member sensory panel developed a flavor profile on commercially cured bacon samples (12 descriptors) and center-cut boneless pork loin chops (19 descriptors) using a 14-point universal intensity scale. Samples were vacuum packaged and stored at -7° C, then thawed in a refrigerator 20 to 24 h and cooked immediately prior to analysis. There were no significant effects of CLA on ADG (0.87 kg), G/F (0.38), or ADFI (2.26 kg) (P> 0.10). No effects of CLA were detected on carcass measurements including longissimus muscle area, backfat depth, water holding capacity, or Minolta L*, a*, or b* values ($P > 0.10$). Four percent supplemental fat improved G/F (0.37 vs 0.40 ± 0.01; $P < 0.02$) and ADG 0.85 vs 0.88 ± 0.02 kg; $P < 0.09$). Feeding CLA resulted in an increase in C18:0 and a decrease in C18:1 ($P < 0.01$), suggesting a reduction in activity of the delta-9 desaturase enzyme. CLA supplementation improved green weight (2.51 vs 2.69 ± 0.05 kg; $P < 0.02$), pump weight (3.06 vs 3.28 ± 0.06 kg; $P < 0.02$), and smoke weight (2.30 vs 2.45 ± 0.06; $P < 0.08$) of pork bellies. No effects of supplemental fat level on belly weights were detected ($P > 0.10$). Bacon samples from pigs fed CO were considered to have a sweeter flavor (4.07 ± 0.07) than those fed 0% SF (3.89 ± 0.07; $P < 0.04$). The intensity of salty flavor was higher in bacon samples from pigs fed CO (6.18 ± 0.09) compared to those fed CLA (5.86 ± 0.10; $P < 0.02$). The intensity of salty aftertaste was greater when CO was combined with YG (5.21 ± 0.14; $P < 0.07$) or T (5.44 ± 0.14; $P < 0.01$) than CO alone (4.85 ± 0.14) but SF combined with CLA was not different from CLA alone (fat * la; $P < 0.02$). Sour flavor intensity

tended to be lower in loin samples from pigs fed CLA than from those fed CO (1.60 vs 1.73 ± 0.06; $P < 0.09$). Samples from animals fed 4% T tended to have slightly lower ($P < 0.09$) notes of astringent aftertaste (1.42 ± 0.08) compared to those fed 0% SF (1.62 ± 0.09) or 4% YG (1.66 ± 0.09). Minimal differences in flavor descriptors determined by the sensory panel were detected. In conclusion, CLA but not tallow supplementation increased belly weights and increased belly weight may result in improved processing characteristics. Panel results indicate consumer acceptance of bacon and pork products from pigs fed CLA will not differ from commodity pork products.

Key Words: Supplemental fat, tallow, yellow grease, conjugated linoleic acid, pork quality, belly firmness

Introduction:

Significant increases in belly firmness and positive improvements in belly fatty acid composition have been measured in pigs fed saturated fats (Averette et al., 1999). Tallow (IV = 40) is a saturated fat source that has been shown to reduce linoleic acid content of adipose tissue when fed to pigs. In addition, increasing dietary fat has resulted in increased amounts of preferred class 1 bacon (See et al., 1997). Supplementation of unsaturated fat sources such as sunflower oil leads to extremely high amounts of linoleic acid in backfat samples (Viljoen and Ras, 1991). Similar results were obtained in bacon samples when pigs are fed diets containing extruded full-fat soybeans (FFS) (Leszczynski et al, 1992).

Recently, researchers have also shown significant improvements in belly firmness when swine diets were supplemented with conjugated linoleic acid (CLA) (Thiel et al., 1998; Eggert et al., 1999a, b, c) without negatively impacting ADG or feed conversion. Significant reduction of backfat depth has also been measured in CLA-fed pigs (Cook et al., 1998; Thiel et al, 1998; Sparks et al., 1999). Only one paper has been published examining the effects of CLA on pork quality and the focus was on the impact of CLA on longissimus thoracis quality and palatability (Dugan et al., 1999).

In understanding how CLA causes this myriad of effects, several enzymes in lipid

metabolism have been examined. CLA has been shown to reduce fat deposition and increase lipolytic enzyme activity in mice (Park et al., 1997; Park et al., 1999). The delta-9 desaturase enzyme catalyzes the synthesis of oleic acid (C18:1) from stearic acid (C18:0) and therefore, is an important factor in determination of the levels of these fatty acids in porcine adipose tissue. Therefore, we tested the hypothesis that CLA would alter lipid enzyme activity in the adipose tissue of pigs fed supplemental fat leading to changes in fatty acid composition which would positively impact belly firmness and the sensory quality of bacon. We further hypothesized, that supplementation of a more saturated fat source (tallow; IV = 47) and CLA combined would improve belly quality to a greater degree than CLA combined with a more unsaturated fat source (yellow grease; IV = 83).

Materials and Methods:

Live animal care and measurements: 144 gilts (avg. wt. 49.3 kg) of a lean genotype were randomly assigned to one of six treatments according to a 2 x 3 factorial design (24 pigs per treatment; 3 pigs/pen). Treatments included two sources of supplemental fat and three sources of linoleic acid as follows:

Treatment 1: 4% Yellow grease (YG) + 1% Linoleic Acid (LA)

2: 4% YG + 1% Conjugated linoleic acid (CLA)

3: 5% YG + 0% CLA

4: 4% Tallow + 1% LA

5: 4% Tallow + 1% CLA

6: 5% Tallow + 0% CLA

The source of conjugated linoleic acid contained approximately 60% conjugated isomers as shown in Table 2 (Conlinco, Inc.). Therefore, corn oil was chosen as the control because the linoleic acid content was also close to 60% (Table 2). The YG and Tallow had iodine values of 82.8 and 47.2, respectively. Dietary treatments (Table 1) were initiated after a 1 wk acclimation period. Animals received ad libitum access to their respective diet and to water for 6 wk until they reached an average slaughter weight of 250 lbs. Pigs were weighed prior to initiation of

treatments and then every two weeks until slaughter. Feed consumption was recorded throughout the study. Pigs were blocked by weight and divided into two replicates (n = 72) with one replicate beginning treatment and slaughtered 1 wk prior to the second replicate.

Carcass measurements: Hot carcass weight was determined on-line. Backfat depth and longissimus muscle depth were measured and lean percentage predicted with the Fat-O-Meater optical probe (FOM; SFK Technology A/S, Denmark). FOM measures were taken through a section of the longissimus dorsi between the 3rd and 4th last rib 7 cm off the mid-line split. Carcasses were chilled for 24 h at which time a 2.5 cm chop was removed between the 9th and 10th ribs. After allowing a minimum of 20 minutes bloom time, each chop was evaluated for color, ultimate pH and temperature. The longissimus muscle chop was measured in triplicate (middle, medial and lateral) and mean values were calculated for color lightness (L*), redness (a*) and yellowness (b*) using a Minolta Chromameter 200 (Minolta, Ramsey, NJ). The chromameter was set to D65 illuminant, a 2 degree standard observer, using an 8 mm optical port with glass insert, and calibrated with Minolta white standard color plate. A visual color score was also determined on a scale from 1 to 6 (1 = pale, 6 = very dark) using plastic Japanese color standards. Japanese color standards are closely related to the Minolta L* value but the scales are in the opposite direction. A lower Minolta L* value indicates a darker color. On the same sample ultimate pH was measured using an Engold electrode and a K21 pH meter (NWK Binar, Landeberg, Germany). Percentage drip loss was estimated by placing a pre-weighed Whatman #1 filter paper on a longissimus muscle section removed from between the 9th and 10th rib for 1 min. The filter paper was then re-weighed and purge loss determined.

Tissue collection: Immediately after slaughter, 50 g of backfat was removed from 8 pigs per treatment (n = 48), placed on ice, and prepared for analysis of delta-9-desaturase activity using the method of St. John et al. (1991). Backfat tissue cores were taken from each pig from a location approximately 10 cm below the mid point of the hanging carcass. Fat samples were placed in N_2 gas at the time of collection and analysis was completed withing 6 mo of collection.

Tissue Analysis. All backfat layers of the adipose tissue samples were combined and mixed thoroughly. Lipids were isolated from adipose tissue in duplicate by weighing 100 mg

into a glass tube with a teflon-lined cap. One ml of a reagent containing 3.75M NaOH dissolved in a 1:1 (v/v) methanol, distilled water mixture was added and the tubes were heated in a boiling water bath for 5 min, vortexed and returned to the water bath for 25 min. The samples were then placed into cool water and 2 ml of a 1.7:1 (v/v) methyl alcohol and hydrochloric acid mixture was added. The samples were placed into the boiling water bath for 10 min and then immediately placed in cool water. Three ml of a 1:1 (v/v) methyl tert-butyl ether and hexane mixture was then added to the samples. Samples were vortexed and mixed continuously for 10 min until clear and the lower, aqueous phase was discarded. Finally 3 ml of 0.3M NaOH was added to the remaining organic layer and the tubes were mixed and centrifuged. Two-thirds of the top, organic layer were removed to a clean vial and dried under N_2 gas. The methyl esters were re-dissolved in 250 µl of hexane. A Hewlett Packard 5890 GC (Hewlett Packard, Avondale, PA) equipped with a flame ionization detector was used with a 100 m fused silica capillary column with an i.d. of 0.25 mm and a .20 µm film coating (Supelco, Inc. Bellefonte, PA). Operating conditions were as follows: helium carrier gas, split ratio 1:100, injector temperature 220°C, detector temperature 220°C, initial oven temperature 140°C increasing to 225°C at a rate of 3.2°C/min. The oven was held at 225°C for 14 min, then temperature increased by 2°C/min to 230°C and held for 6 min. Finally, the temperature was decreased by 8°C/min to 140°C and held for 4 min. Total run time was 65 min. Methyl ester standards were used to identify sample fatty acid methyl esters. Integration software (Millenium, Waters, Inc.) was used to calculate the proportion of each fatty acid present. Iodine value (IV) was calculated using the following equation: C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723) (AOCS, 1998b).

Flavor analysis: A subset of bellies and longissimus muscle chops (n = 48 each cut) were collected for taste panel evaluation. Bellies were processed in a commercial facility and pumped for a 20% increase in raw weight with a cure containing salt, sodium nitrite (6.25%), sodium erythorbate (2.5%), sugar, flavorings, FD & C Red #3 (0.00022%) and not more than 1% sodium carbonate. Bellies were then smoked for 24 hours, sliced, vacuum-packaged, and frozen for storage until analysis. Longissimus muscle chops were vacuum-packaged and frozen. All

samples were analyzed within 3 months of collection. Flavor characteristics of cooked loin samples were determined utilizing a flavor profile panel, trained by the method of Caul (1957). The 6 member panel evaluated the aroma, flavor, and aftertaste according to the guidelines of Civille and Szczesniak (1973). A 14 point intensity scale was used to form lexicons for descriptive analysis (AD Little Co., 1950). Panelists were trained using boneless pork loin chops from a local grocery (3 training sessions) and Hormel Black Label bacon as references (3 training sessions). American Society of Testing Materials (ASTM) guidelines for training and screening panelists were used (STP 750, 1981).

Samples were removed from the freezer 20 to 24 h prior to cooking and thawed in the refrigerator. A Kitchen Aid grinder with a meat attachment was used to grind the LM chop samples and 28 g was weighed into glass jars. Samples were flattened in the jars, covered with foil and baked at 350°F for 15 minutes. Internal temperature was monitored using a thermocouple placed in pre-warmed jars for evaluation. Once cooked, glass jars were placed in sand trays (pre-heated to 200°F) and kept on warming trays throughout the evaluation. Samples were served in random order to each panelist.

In addition, the taste panel evaluated the flavor and aftertaste of bacon samples. Bacon samples were cooked on a commercial griddle for approximately 3 min on each side. The slices were then blotted on paper towels to remove excess grease, placed in a pan on foil and kept in the oven at 180°F until given to panelists in random order.

Statistical Analysis: Data were analyzed using the GLM procedure of SAS (SAS, Cary, NC). Least squares treatment means were obtained assuming fixed models that included the effects of block, fat source, linoleic acid source and fat source x linoleic acid source. The degrees of freedom (df) were partitioned into contrasts for the effects of supplemental fat source and supplemental fat level.

Results:

Performance: Feed consumption was not affected by fat supplementation or addition of CLA to the diets ($P < 0.10$) and averaged 2.26 kg/d (Table 3). Average daily gain during the 47

d experiment was improved by 4% supplemental fat ($P < 0.09$), but not affected by CLA consumption. Efficiency of gain was improved by supplemental fat ($P < 0.01$) with animals consuming 4% added fat diets gaining an additional 0.02 kg/kg feed.

Pork Quality: Backfat depth, longissimus muscle area, ultimate pH, and color were not affected by supplemental fat or CLA (Table 4; $P > 0.10$). Water holding capacity of longissimus chops was improved by 17.6% with 4% supplemental fat. Longissimus muscle (LM) pH from pigs fed 4% tallow was 2.5% higher at 45 min post-slaughter ($P < 0.04$). However, supplemental tallow did not affect ultimate pH at 24 h. Subjective marbling score was 18.8% greater in LM chops from pigs fed CLA ($P < 0.01$).

Fatty acid analysis: Conjugated linoleic acid supplementation increased the percentages of C14:0, C18:0 and C18:1*trans* and reduced the percentage of C18:1*cis* and C20:1*cis* ($P < 0.001$) in belly fat samples (Table 5). The percentage of linoleic acid was 12.5% greater in pigs consuming 4% yellow grease ($P < 0.001$). Both the 9c, 11t and the 10t, 12c isomers of CLA were increased in belly fat from animals fed CLA, and that increase was even greater when 4% supplemental fat was fed (fat source x linoleic acid interaction, $P < 0.001$). Linoleic acid concentration in belly fat was also increased with supplementation of 4% yellow grease ($P < 0.01$). Monounsaturates were reduced in belly fat from pigs consuming CLA ($P < 0.001$). The total percentage of polyunsaturates was increased with 4% supplemental fat ($P < 0.01$), especially in those animals consuming yellow grease ($P < 0.01$). CLA supplementation reduced the ratio of monounsaturates to polyunsaturates (MUFA/PUFA ratio) (2.50 vs 2.30 ± 0.05; $P < 0.001$). Most importantly, iodine value was affected by both fat and CLA. Addition of CLA reduced belly fat IV by 6.6% ($P < 0.001$) and the IV of fat from animals consuming tallow and CLA combined was 62.0 (Figure 1).

Similar to the belly fat analysis, animals fed CLA also had reduced iodine values in samples from the longissimus muscle chops ($P < 0.01$; Table 6). CLA supplementation increased the percentages of C14:0 and C18:0 ($P < 0.01$) and decreased the percentages of C18:1*cis*, C18:2 ($P < 0.01$) and C18:3 ($P < 0.05$). Again, the 9*c*, 11*t* and 10*t*, 12*c* isomers of CLA were increased with CLA feeding, especially in animals fed 4% supplemental fat ($P <$

0.01). Both the monounsaturates and the MUFA/PUFA ratio were reduced by CLA supplementation ($P < 0.01$). Feeding 4% yellow grease increased polyunsaturates in fat samples from longissimus muscle chops ($P < 0.01$).

Belly processing: The green weight of the cut bellies, prior to cure injection, was increased 7.2% by CLA supplementation ($P < 0.02$). The increased belly weights from pigs fed CLA were maintained after pumping ($P < 0.02$) and smoking ($P < 0.08$). Effects of supplemental fat level on belly weights were not detected ($P > 0.10$).

Taste panel analysis: Bacon samples from pigs fed 4% supplemental fat were considered to have a sweeter flavor than those fed 0% supplemental fat ($P < 0.04$). Salty flavor intensity was increased in samples from pigs fed corn oil compared to those fed CLA ($P < 0.02$). Feeding CLA increased the intensity of fat flavor in bacon from pigs fed 0% supplemental fat, but not those fed 4% supplemental fat ($P < 0.09$). Lean flavor of bacon was slightly reduced with CLA supplementation ($P < 0.10$). Overall burnt flavors were low on the intensity scale, but slightly higher with CLA supplementation in bacon samples from pigs fed 0% supplemental fat or 4% yellow grease but not in those fed 4% tallow ($P < 0.09$). The intensity of salty aftertaste was greater when corn oil was combined with yellow grease ($P < 0.07$) or tallow ($P < 0.01$) than corn oil alone, but supplemental fat combined with CLA was not different from CLA alone ($P < 0.02$).

For longissimus muscle chops, sour flavor intensity tended to be lower in samples from pigs fed CLA than from those fed corn oil ($P < 0.09$). The aftertaste associated with lipid oxidation of LM samples was greater in samples from pigs fed 4% yellow grease. Samples from animals fed 4% tallow tended to have slightly lower notes of astringent aftertaste ($P < 0.09$). Overall, dietary treatments appeared to affect LM aroma, flavor, and aftertaste to a lesser degree than bacon samples.

Discussion:

Demand for pork bellies has risen dramatically since the early 1990's and is reflected in the increased price of sliced bacon (NPPC, 1999). Packers and processors are now more concerned about the quality of pork bellies due to the greater demand in what used to be considered a low-value cut. Consistency and composition of pork fat are quality concerns

because thin bellies and soft fat produce more miss-cuts and a higher percentage yield of lower quality product (Morgan et al., 1994).

In addition, the number of genetically lean pigs has increased as the industry strives for more efficient production. Scott et al. (1983) has shown that genetically lean pigs have decreased endogenous fat synthesis. The relative proportion of fatty acids in adipose tissue of dietary origin increases in these pigs. That fact makes the characteristics of the fatty acids in the diet even more important. In this study, the backfat depth was only 14 mm on average and significant changes in the fatty acid composition were detected (Tables 5 and 6).

In searching for solutions to improve fat quality, it is important to understand the main factors influencing the quality of backfat. Wood and Enser (1989) stated that stearic acid is positively related to firmness and cohesiveness of fat, while linoleic acid is negatively related. This is probably due to an increase in membrane fluidity resulting from diets high in linoleic acid (Brasitus et al., 1985). Furthermore, lipogenic enzyme activities were increased in adipose tissue of pigs consuming diets with high levels of linoleic acid (Mourot et al., 1994). Therefore, one possible solution to the soft fat problem is to supplement diets with a highly saturated fat source. Research in our lab shows that feeding a saturated fat can reduce the polyunsaturated fatty acid composition of carcass fat without compromising ADG, ADFI or F/G (Averette et al., 1999). Average daily gain was increased by 4% supplemental fat and efficiency of gain was also increased with the 4% supplemental fat diets (Table 3). In the same study, pork belly thickness was increased with increasing saturation of supplemental fat (Averette et al., 1999).

Another solution which has shown significant improvements in belly firmness resulted from supplementation of diets with conjugated linoleic acid (CLA) (Thiel et al., 1998; Eggert et al., 1999a, b, c) without negatively impacting ADG or feed conversion. Similarly, no effects of CLA supplementation were detected on performance traits in this study. In fact, improvements in feed efficiency with CLA addition (Dugan et al., 1997; Thiel et al., 1998) have been measured. Conjugated linoleic acid is a term used to describe a mixture of positional and geometric isomers of linoleic acid. CLA is naturally found in ruminant food products such as beef, milk and cheeses. It is produced primarily by biohydrogenation by the ruminant bacteria *Butyrivibrio*

fibrisolvens (Kelly and Bauman, 1996). CLA has been reported to reduce tumor incidence, reduce body fat, and increase body protein (Ip et al., 1994; Park et al., 1997). Due to the potential effects of CLA on human health, many researchers have recently evaluated CLA as a swine feed additive.

Both supplemental fat and CLA have potential to affect pork quality. Only one paper has been published examining the effects of CLA on pork quality and the focus was on the impact of CLA on longissimus thoracis quality and palatability (Dugan et al., 1999). Four percent supplemental fat increased the water holding capacity of longissimus chops. This may result in improved shelf-life and consumer acceptability of pork products. Water holding capacity is related to muscle pH (Briskey et al., 1960) and may be reduced as muscle pH drops. Muscle pH at 45 min post-mortem was greater in animals consuming tallow ($P < 0.04$) but the increases detected were not due to 4% supplemental fat overall. However, it is known that the lipid fraction of muscle can affect membrane integrity (Bosi, 1999) so it is possible that supplemental fat could influence water holding capacity. Further, these differences were no longer detected 24 h later when ultimate pH of longissimus chops was measured. Engel et al. (2001) did not detect any differences in 24 h pH of longissimus muscle from gilts fed diets containing 2 to 6 % choice white grease or poultry fat.

Effects of fat supplementation on color score and Minolta L*, a*, or b* were not detected. Seerley et al. (1978) also saw no differences in color score with supplementation of animal or poultry fat at 2.5 or 5% of the diet. Pigs were fed the experimental diets from 18 kg to 90 kg over an average of 101 d. Marbling score of the longissimus chops was increased 18.8% in pigs fed CLA (Table 4). Others have shown similar results with increases of 11.3% with CLA supplementation (Dugan et al., 1997). Related to the increase in marbling score was a 2.77 g increase in intramuscular fat, partially resulting in an 18.0 g increase in lean (per kg wet wt of loin) (Dugan and Aalhus, 1999). In another study by the same group, longissimus muscle chops from CLA-fed pigs had an increased marbling score and a 22% increase in intramuscular fat compared to those consuming the control diet (Dugan et al., 1999).

Backfat depth in this study was not altered by CLA or supplemental fat and averaged only

14 mm at slaughter. Backfat depth has been reduced by CLA in other studies (Cook et al., 1998; Thiel et al, 1998; Sparks et al., 1999). Backfat thickness in carcasses from pigs fed 4.8 or 9.5g/kg CLA was reduced 24% compared to pigs receiving no CLA. However, backfat depths in these experiments were much greater (16 to 28 mm) than in our study. Perhaps the animals in our study were approaching a minimum backfat depth required for normal tissue structure and function and this may have resulted in increased resistance to further changes. Wood (1973) posed two possible explanations: there may be a difference in the mechanism of fat deposition in genetically fat vs. genetically lean pigs or the proportion of de novo fatty acid synthesis (usually more saturated) is reduced in lean pigs along with an overall lower fat deposition at the same level of feed intake.

Both supplemental fat and CLA addition to the diets resulted in changes to the fatty acid composition of belly fat and subcutaneous fat removed from the 10th rib of the longissimus muscle. Conjugated linoleic acid supplementation resulted in increases in C14:0, C18:0 and C18:1*trans* and decreases in C18:1cis and C20:1*cis* in belly fat. In addition, the amount of MUFA were reduced and the MUFA/PUFA ratio was increased by CLA feeding. Most other studies that have determined fatty acid composition after supplementing 1 to 2% CLA have measured similar changes. Eggert et al. (1999a) also saw an average 20% increase in the saturated fatty acids and an 11.8% reduction in unsaturated fatty acids of belly fat from gilts fed diets containing 1% CLA. In addition to measuring an increase in stearic acid, we noted a significant decrease in oleic acid in fat samples from CLA supplemented animals (Figure 2). Ramsay et al. (2001) has shown similar results with apparent increases in relative percentages of stearic acid and a reduction in oleic acid. They and others have noted that 1 to 2% dietary CLA may result in inhibited delta-9 desaturase activity in both skeletal muscle and adipose tissue of several species (Kouba and Mourot, 1998; Lee et al., 1998). The delta-9 desaturase enzyme catalyzes the synthesis of oleic acid (C18:1) from stearic acid (C18:0) and therefore, is an important factor in determination of the levels of these fatty acids in porcine adipose tissue. CLA has been also been shown to reduce fat deposition and increase lipolytic enzyme activity in mice (Park et al., 1997; Park et al., 1999).

Increases in the 9*c*, 11*t* and the 10*t*, 12*c* CLA isomers from belly fat of pigs in this study have also been seen in other studies (Thiel-Cooper et al., 1998; Eggert et al., 1999a). When CLA concentration was linearly increased in diets from 0 to 1%, a linear increase in the CLA content in both subcutaneous pork adipose tissue and lean tissue was found ($P < 0.0001$) (Thiel-Cooper et al., 1998). Further, both saturated fat and CLA have been shown to increase belly firmness (Thiel-Cooper et al., 1998; Averette et al., 1999; Eggert et al., 1999a,b,c) supporting the reduced iodine values and increased belly weights of pigs fed 1% CLA in this study. Eggert et al. (1999c) measured belly firmness on a scale from 1 (very soft) to 3 (very firm) in pigs fed 1% CLA from 90 to 115 kg. Firmness was increased by 0.54 units in the CLA-fed pigs when compared to pigs consuming diets with 1% sunflower oil.

Only one other study has evaluated the combined effects of supplemental fat combined with CLA feeding (Eggert et al., 1999c) and they did not report any measurements of fatty acid composition. Because CLA has the potential to alter gene expression of key lipogenic enzymes and supplemental fat can be directly deposited in swine adipose tissue, their combination may result in additive effects on pork fat quality. Indeed, we noted that supplementation of 1% CLA and 4% tallow resulted in an additive reduction of belly fat iodine value (Figure 1). Prior to this study, we and others have noted increased saturated fatty acid composition due to tallow supplementation (Viljoen and Ras, 1991; Leszczynski et al., 1992; See et al., 1997). Pigs fed either 6.1% tallow or 6.1% sunflower oil from 8 wk of age until 85 kg had 13 or 36.3% linoleic acid, respectively in backfat samples from the last rib (Viljoen and Ras, 1991). Similar results were obtained when pigs were fed diets containing extruded full-fat soybeans (FFS) (10 or 20%) or 4% tallow. After 6 wk, there was a 39.9% reduction in linoleic acid of bacon samples in pigs consuming the 4% tallow diet compared to those consuming the 20% FFS diet (Leszczynski et al, 1992).

The 12.5% increase in linoleic acid from belly fat of pigs consuming 4% yellow grease is not surprising. Seerley et al. (1978) fed poultry fat at 2.5 and 5% of the diet and saw increases in linoleic acid content of longissimus intramuscular fat. Boyd (1997) compared the relationships between the fatty acid profile of the diet and the resulting profile and IV of backfat. He

determined that there was a linear relationship between dietary linoleic acid content and the IV of backfat. These same relationships can be seen in this study. The yellow grease had a greater C18:2 content than the tallow and tallow supplementation resulted in a reduced C18:2 content in both the subcutaneous adipose tissue and the longissimus muscle intramuscular fat. Other data collected in our lab has shown a linear decrease ($P < 0.05$) in C18:2 content and IV of carcass fat as dietary tallow level increased (Averette et al., 1999).

It is expected that changes in carcass composition and/or fatty acid composition may lead to differences in palatability and acceptance of pork products. One example is the increased opportunity for rancidity in products containing greater amounts of unsaturated fatty acids (Melton, 1990). Cameron and Enser (1991) compared eating quality traits with intramuscular fatty acid composition. In general, greater concentrations of monounsaturated fatty acids and saturated fatty acids were associated with higher panel scores for overall acceptability as well as tenderness, juiciness, and flavor. Lower scores for these traits resulted from pork with higher concentrations of polyunsaturated fatty acids. Further, Miller (1990) determined that canola oil supplementation led to increases in linoleic acid and off-flavors which were due to oxidation. In the present study, supplementation of CLA and tallow led to lower concentrations of C18:2. However, there were minimal differences in taste panel acceptability of longissimus muscle chops. Larick et al. (1992) determined the content of volatile compounds in pork after feeding several combinations of safflower oil and tallow. They noted significant increases in the linoleic acid content of pork from pigs fed diets high in C18:2 and increased concentrations of several volatiles associated with increased oxidation activity. However, these changes had minimal impact on the flavor of cooked, fresh lean tissue.

Because bacon contains a greater amount of fat than other pork products, it may be more susceptible to development of rancidity (Rogers and Etzler, 2000). Processing, packaging, and storage conditions may also have effects on the shelf-life. Rogers and Etzler (2000) Determined that overall panel ratings were acceptable for vacuum-packaged products and totally unacceptable for sliced-slab (not vacuum-packaged), frozen products, regardless of supplemental dietary fat source or inclusion level. In that same study, the fatty acid composition was changed

due to various dietary fat sources. In addition several differences were noted, including attributes of saltiness and flavor intensity, but were small differences and were not considered to be of practical importance by the authors. Recently, Dugan et al., (1999) evaluated the effects of CLA feeding on pork quality and palatability characteristics. Longissimus chops were evaluated by a six-member panel for tenderness, flavor, and juiciness. The panel did not detect differences in these characteristics in samples from pigs fed CLA or a sunflower oil control diet. We are unaware of any studies that have evaluated the combined effects of CLA and supplemental fat on sensory attributes of bacon. The descriptive analysis developed by the panel, of both bacon and longissimus chop samples, is more in-depth than many other published studies that have looked at only a few descriptors or evaluated samples with difference testing. The differences the panel detected in salty flavor intensity or intensity of salty aftertaste of bacon from pigs fed corn oil or corn oil combined with yellow grease, respectively, may have been due to the differences in fatty acid composition or overall fat composition. If the total amount of fat in the bacon or its fatty acid composition altered the retention of brine ingredients, such as salt or nitrates, it would have the potential to affect flavor. The increased intensity of fat flavor and reduced lean flavor due to CLA feeding may have occurred for similar reasons. The increase in the aftertaste associated with lipid oxidation in longissimus samples from pigs fed 4% yellow grease is likely due to changes in fatty acid composition discussed previously. Overall, the numerical differences detected by the panel were minimal. These minimal differences indicate that consumer acceptance of bacon and pork products from pigs fed supplemental fat and CLA would not differ from commodity pork products.

Implications:

These data show that tallow and conjugated linoleic acid will significantly reduce the iodine value (IV) of belly fat and have an additive effect when combined. Negative effects of tallow or CLA supplementation on growth, feed intake, feed efficiency or carcass quality were not detected. Fatty acid composition of belly fat was altered by both tallow and CLA addition. Individually, tallow and CLA resulted in increased saturation of belly fat and when supplemented together resulted in a reduction of belly fat iodine value to 62. However, supplementation of

yellow grease led to increased linoleic acid in belly fat samples and could result in increased opportunity for lipid oxidation in pork products. Further, our taste panel evaluation determined that flavor attributes of bacon and pork products from pigs fed CLA would be accepted by consumers and would not differ from commodity pork products

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Table 1. Diet Composition

Ingredient, %	0% Supplemental Fat	4% Supplemental Fat
Corn	80.86	73.4
SBM	15.43	19.0
Corn Oil or CLA-60	1.0	1.0
Tallow / Yellow Grease	—	4.0
Dicalcium Phosphate	0.90	0.88
Limestone	0.84	0.83
Salt	0.50	0.50
L-Lysine, 98%	0.16	0.10
V/TM Premix	0.25	0.25
Antibiotic (CTC)	0.05	0.05
Calculated Composition		
Linoleic Acid	2.25	2.63
ME, kcal/kg	3,378	3,553
Lysine, %	0.80	0.84

Table 2. Fatty acid composition of supplemental fats

Fatty Acid, wt. %	Corn Oil	CLA-60	Yellow Grease	Tallow
14:0	nd	0.24	1.68	4.98
16:0	10.25	4.57	20.16	25.90
16:1 cis	0.07	nd	5.12	4.66
18:0	1.40	1.77	6.20	14.08
18:1 trans	nd	nd	5.60	2.96
18:1 cis	25.38	18.36	33.63	34.58
18:2	60.29	6.86	21.12	4.26
18:2 (9c, 11t)	nd	23.44	nd	nd
18:2 (10t, 12c)	nd	29.63	nd	nd
18:3	1.06	nd	1.54	0.40
SFA, %[a]	11.91	7.29	28.32	45.19
UFA, %[b]	86.89	78.49	67.34	48.09
U/SFA ratio	7.30	10.79	2.34	1.06
Iodine Value[c]	134.35	125.24	82.78	47.18

[a]sum of C14:0, C16:0, C18:0, and C:20:0
[b]sum of C16:1, C18:1, C18:2, and C18:3
[c]Calculated : C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723) (AOCS, 1998b)

Table 3. Average daily gain, feed intake and feed efficiency of pigs consuming 0% or 4% supplemental fat combined with linoleic acid (LA) or conjugated linoleic acid (CLA)

	0% Supplemental Fat		4% Yellow Grease		4% Tallow		
Item	LA	CLA	LA	CLA	LA	CLA	pSEM
ADG, kg[a]	0.86	0.83	0.86	0.89	0.90	0.88	0.03
ADFI, kg	2.32	2.28	2.20	2.18	2.31	2.26	0.07
G/F[b]	0.37	0.37	0.39	0.41	0.39	0.39	0.01

[a]Fat level 0 vs 4% ($P < 0.09$)
[b]Fat level 0 vs 4% ($P < 0.01$)

Table 4. Pork quality traits of pigs consuming 0% or 4% supplemental fat combined with linoleic acid (LA) or conjugated linoleic acid (CLA)

	0% Supplemental Fat		4% Yellow Grease		4% Tallow		
Item	LA	CLA	LA	CLA	LA	CLA	pSEM
Backfat, mm	13.89	13.57	15.29	15.03	14.34	13.80	0.79
Longissimus muscle area, cm^2	40.05	39.60	41.60	41.22	42.31	39.54	1.10
Water holding capacity, mg[a]	107.15	111.39	96.41	82.75	89.23	91.84	11.61
45 min pH[b]	6.03	6.08	5.94	6.14	6.19	6.22	0.08
Ultimate pH	5.25	5.27	5.29	5.29	5.26	5.30	0.02
Minolta Color							
L*	55.75	56.42	55.45	54.76	54.77	54.41	0.92
a*	7.54	7.39	8.54	7.96	7.72	8.18	0.55
b*	7.34	7.18	7.71	7.31	6.97	7.34	0.50
Color Score	3.55	3.29	3.54	3.46	3.64	3.57	0.16
Marbling Score[c]	1.61	1.85	1.73	2.34	1.77	1.88	0.16

[a]Fat level 0% vs 4% ($P < 0.06$)
[b]Fat source YG vs T ($P < 0.04$)
[c]Linoleic acid main effect ($P < 0.01$)

Table 5. Fatty acid profile of belly fat samples from pigs consuming 0% or 4% supplemental fat combined with linoleic acid (LA) or conjugated linoleic acid (CLA).

	0% Supplemental Fat		4% Yellow Grease		4% Tallow		
Item, wt%	LA[a]	CLA	LA	CLA	LA	CLA	pSEM
C14:0[b,c,d]	1.10	1.50	1.08	1.41	1.14	1.64	0.06
C16:0[e,f]	20.37	22.81	20.03	20.52	19.43	21.72	0.43
C16:1 cis	1.86	1.94	1.82	1.87	1.78	1.91	0.10
C18:0[c]	11.58	14.03	11.81	13.30	11.43	14.43	0.55
C18:1 trans[b,c,f,g]	0.57	0.95	1.25	1.82	0.96	1.43	0.05
C18:1 cis[c]	41.77	37.35	40.05	35.75	41.01	36.52	0.75
C18:2[d,g,h]	16.02	14.88	17.08	17.56	16.04	14.72	0.48
C18:2 (9c, 11t)[f,i]	0.14	0.59	0.30	0.96	0.30	1.05	0.04
C18:2 (10t, 12c)[f,i]	0.01	0.38	0.10	0.74	0.02	0.76	0.04
C20:1 cis[c]	0.77	0.65	0.70	0.59	0.72	0.63	0.03
C18:3[h,f,g]	0.59	0.58	0.67	0.70	0.61	0.58	0.02
Other[j]	5.22	4.34	5.11	6.29	6.56	4.61	
Monounsaturates, %[c]	45.0	40.9	43.9	40.1	44.5	40.5	0.8
Polyunsaturates, %[f,g,h]	16.7	16.4	18.1	20.0	17.0	17.1	0.5
MUFA/PUFA ratio[c,f,g,h]	2.7	2.5	2.4	2.0	2.6	2.4	0.1
Iodine Value[b,c,g]	68.1	62.6	69.2	66.9	67.7	62.0	1.2

[a]LA = linoleic acid and CLA = conjugated linoleic acid

Table 5, contd.

[b]Main effect of fat source ($P < 0.05$)
[c]Main effect of linoleic acid ($P < 0.001$)
[d]Fat level effect (0 vs. 4%) ($P < 0.05$)
[e]Fat source x linoleic acid interaction ($P < 0.05$)
[f]Fat level effect (0 vs. 4%) ($P < 0.01$)
[g]Fat source effect (YG vs. T) ($P < 0.01$)
[h]Main effect of fat source ($P < 0.001$)
[i]Fat source x linoleic acid interaction ($P < 0.001$)
[j]Sum of fatty acids that are < 1% (C12:0, C15:0, C20:0, C22:0, C22:1).

Table 6. Fatty acid composition of loin samples from pigs consuming 0% or 4% supplemental fat combined with linoleic acid (LA) or conjugated linoleic acid (CLA)

	0% Supplemental Fat		4% Yellow Grease		4% Tallow		
Item, wt%	LA[a]	CLA	LA	CLA	LA	CLA	pSEM
C14:0[b,c,d]	1.03	1.26	0.97	1.21	1.10	1.44	0.06
C16:0	19.70	21.53	20.15	19.30	19.24	20.99	0.74
C16:1 cis	1.73	1.81	1.74	1.65	1.82	1.78	0.08
C18:0[c]	11.64	13.74	12.38	14.07	11.37	14.74	0.78
C18:1 trans[d,e,f]	0.66	0.96	1.34	1.95	1.04	1.58	0.05
C18:1 cis[b,c,g,h]	41.16	36.39	38.34	34.35	41.00	35.71	0.81
C18:2[b,c,d]	17.73	16.06	18.83	17.87	17.60	15.63	0.53
C18:2 (9c, 11t)[e,f,g]	0.14	0.58	0.23	0.98	0.30	1.06	0.04
C18:2 (10t, 12c)[e,f]	0.00	0.38	0.01	0.75	0.02	0.73	0.05
C20:1 cis[c]	0.78	0.67	0.73	0.63	0.74	0.59	0.03
C18:3[b,d,i]	0.65	0.62	0.73	0.70	0.66	0.58	0.03
Other	4.78	6.00	4.55	6.54	5.11	5.17	
Monounsaturates, %[c]	44.36	39.86	42.20	38.63	44.64	39.66	0.87
Polyunsaturates, %[c,d,h]	18.52	17.63	19.79	20.30	18.57	17.99	0.56
MUFA/PUFA ratio[b,c,d,f]	2.41	2.27	2.14	1.91	2.41	2.21	0.05
Iodine Value[c]	70.64	63.81	70.89	66.09	70.69	62.78	1.56

[a]LA = linoleic acid and CLA = conjugated linoleic acid

Table 6, contd.

[b]Main effect of fat source ($P < 0.01$)
[c]Main effect of linoleic acid ($P < 0.01$)
[d]Fat source effect (YG vs. T) ($P < 0.01$)
[e]Fat x linoleic acid interaction ($P < 0.01$)
[f]Fat level effect (0 vs. 4%) ($P < 0.01$)
[g]Fat source effect (YG vs. T) ($P < 0.05$)
[h]Fat level effect (0 vs. 4%) ($P < 0.05$)
[i]Main effect of linoleic acid ($P < 0.05$)

Table 7. Conjugated linoleic acid (CLA) increased belly weights during bacon processing

	0% Supplemental Fat		4% Yellow Grease		4% Tallow		
Item	LA	CLA	LA	CLA	LA	CLA	pSEM
Green wt, kg[a]	2.44	2.65	2.57	2.68	2.59	2.81	0.09
Pump wt, kg[a]	2.97	3.21	3.14	3.28	3.16	3.42	0.11
Smoke wt, kg[b]	2.20	2.41	2.36	2.42	2.40	2.58	0.10
Yield, %	90.0	90.5	91.7	90.2	92.4	91.9	1.2

[a]Linoleic acid main effect ($P < 0.02$)
[b]Linoleic acid main effect ($P < 0.08$)

Table 8. Flavor and aftertaste of bacon from pigs consuming 0% or 4% supplemental fat combined with linoleic acid (LA) or conjugated linoleic acid (CLA) as rated by the taste panel

	0% Supplemental Fat		4% Yellow Grease		4% Tallow		
Descriptor	LA[a]	CLA	LA	CLA	LA	CLA	pSEM
Flavor	5.65	5.66	6.04	5.59	5.71	5.66	0.14
Sweet[b]	3.98	3.81	4.13	4.08	3.96	4.10	0.09
Salty[c]	5.88	5.94	6.38	5.90	6.29	5.76	0.17
Smoked	5.65	5.66	6.04	5.59	5.71	5.66	0.14
Fat[d]	5.33	5.81	5.77	5.83	5.63	5.59	0.12
Lean[e]	5.06	4.89	4.98	4.91	4.90	4.74	0.10
Brown sugar	2.17	2.32	2.29	2.10	2.15	2.22	0.09
Molasses	1.67	1.34	1.23	1.27	1.31	1.23	0.07
Burnt[d,f]	1.13	1.36	1.08	1.24	1.21	1.16	0.07
Aftertaste							
Sweet	3.17	3.13	3.25	3.05	3.08	3.21	0.09
Salty[g]	4.85	5.02	5.21	5.03	5.44	4.79	0.14
Smoked[h]	4.83	5.03	5.17	4.80	4.94	4.93	0.11
Meaty	3.69	3.73	3.83	3.75	3.77	3.67	0.09

[a]LA = linoleic acid, CLA = conjugated linoleic acid
[b]Main effect of fat ($P < 0.08$)
[c]Main effect of linoleic acid ($P < 0.02$)
[d]Fat by linoleic acid interaction ($P < 0.09$)
[e]Main effect of linoleic acid ($P < 0.10$)

Table 8, contd.

[f]Main effect of linoliec acid ($P < 0.04$)
[g]Fat by linoleic acid interaction ($P < 0.02$)
[h]Fat by linoleic acid interaction ($P < 0.04$)

Table 9. Aroma, flavor, and aftertaste of longissimus chop samples from pigs consuming 0% or 4% supplemental fat combined with linoleic acid (LA) or conjugated linoleic acid (CLA) as rated by the taste panel

	0% Supplemental Fat		4% Yellow Grease		4% Tallow		
Descriptor	LA[a]	CLA	LA	CLA	LA	CLA	pSEM
Aroma							
Oxidized	2.26	2.33	2.63	2.20	2.19	2.24	0.15
Cooked pork	6.21	5.80	5.77	5.82	5.98	5.96	3.01
Fat[b]	3.09	3.01	3.04	3.13	3.06	3.24	0.09
Metallic	2.83	2.75	2.79	2.81	2.77	2.85	0.11
Briny	1.84	1.92	1.91	1.84	1.86	1.77	0.07
Piggy[c,d]	1.69	1.96	1.64	1.53	1.78	1.80	0.12
Flavor	5.65	5.66	6.04	5.59	5.71	5.66	0.14
Oxidized	2.10	1.97	2.12	2.05	1.99	1.94	0.14
Cooked pork	6.22	6.30	6.21	6.25	6.14	6.19	0.13
Metallic	3.92	3.89	4.00	3.78	3.90	3.79	0.11
Astringent	3.22	3.16	3.08	3.15	3.16	2.93	0.09
Sweet	1.89	2.08	1.99	2.01	2.00	2.02	0.08
Sour[b,e]	1.85	1.72	1.64	1.55	1.70	1.52	0.10
Salty	1.69	1.68	1.81	1.68	1.68	1.69	0.07
Piggy	1.70	1.71	1.56	1.51	1.56	1.60	0.11

Table 9 contd.

Aftertaste							
Oxidized[f]	3.26	3.10	3.22	3.23	3.05	3.01	0.11
Fat	4.07	3.98	3.88	3.93	3.94	3.95	0.19
Metallic	2.96	2.92	2.85	2.97	2.98	2.96	0.09
Astringent[c,g]	1.75	1.51	1.63	1.70	1.38	1.45	0.12

[a]LA = linoleic acid, CLA = conjugated linoleic acid
[b]Main effect of linoleic acid ($P < 0.09$)
[c]Main effect of fat level ($P < 0.09$)
[d]Fat source effect (YG vs T) ($P < 0.08$)
[e]Fat level effect (0 vs 4%) ($P < 0.03$)
[f]Fat source effect (YG vs T) ($P < 0.10$)
[g]Fat source effect (YG vs T) ($P < 0.05$)

Figure 1. Additive effects of tallow and CLA result in a 7.5 unit IV drop in belly fat samples

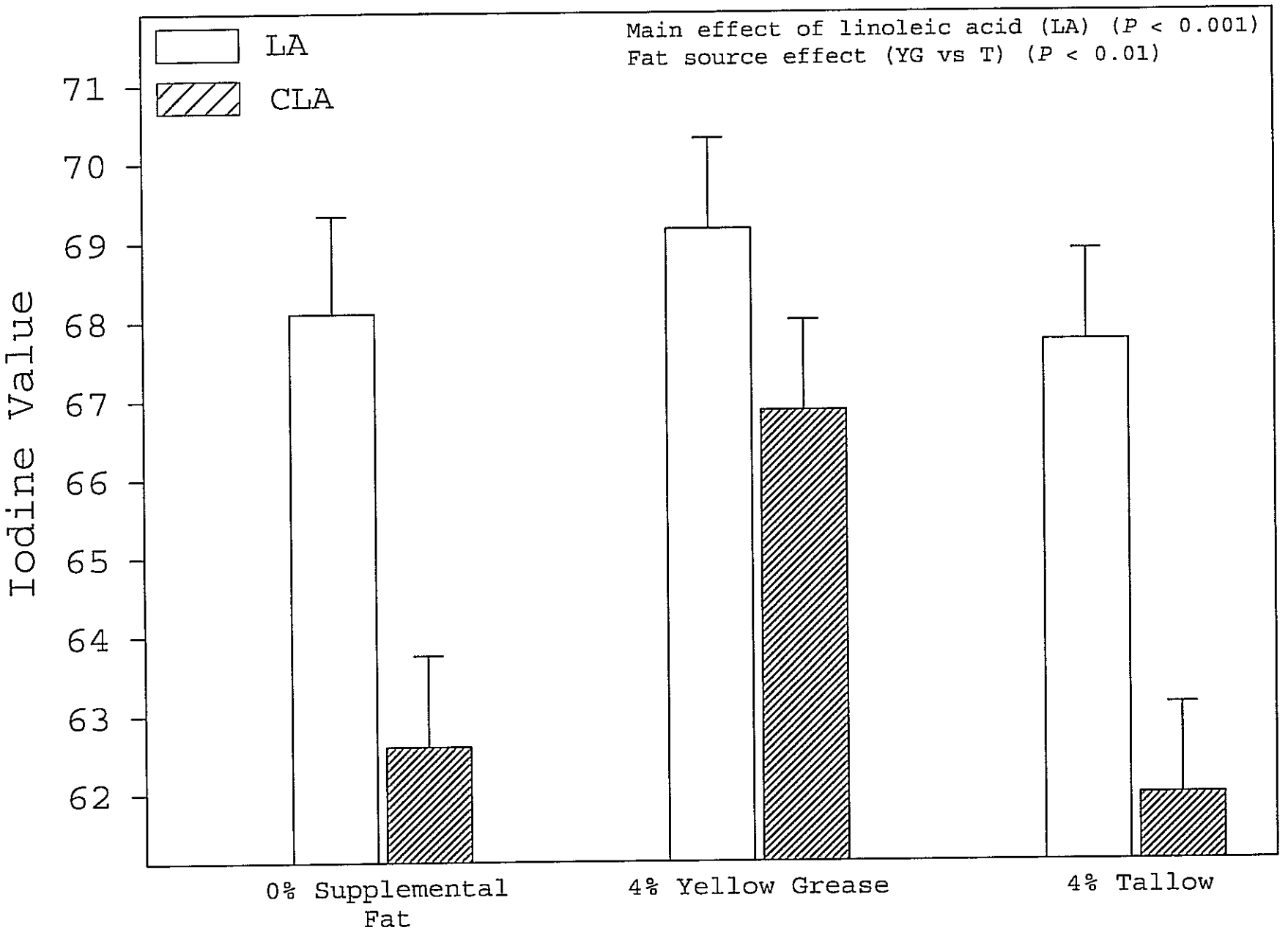

Figure 2. CLA appears to alter activity of Stearoyl-CoA Desaturase