EFFECT OF LEVEL AND DURATION OF FEEDING CONJUGATED LINOLEIC ACID IN DIFFERENT DIETARY PROGRAMS ON THE GROWTH PERFORMANCE OF GROWING-FINISHING PIGS AND ON LONGISSIUMUS MUSCLE QUALITY, BELLY CHARACTERISTICS, AND FAT QUALITY MEASURED POST MORTEM.

BY

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THESIS

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Abstract

The effect of level and duration of feeding conjugated linoleic acid in different dietary programs on the growth performance of growing-finishing pigs and on *Longissiumus* muscle quality, belly characteristics, and fat quality measured post mortem was evaluated in a study carried out on a commercial wean-to-finish facility. A randomized complete block design with 15 treatments consisting of different combinations of Dietary Program (i.e., 0% DDGS, 30% DDGS, and DDGS withdrawal [30% DDGS from week 0 to approximately 104 kg and 0% DDGS from approximately 104 kg to end of study]), CLA Inclusion Level (i.e., 0, 0.5, and 1.0%), and CLA Feeding Duration (i.e., 0, 14, and 28 days prior to harvest). The treatments (Trt.) were defined by the combination of Dietary Program, CLA Inclusion level, and CLA Feeding Duration and were as follows: Trt. 1 (0%, 0%, and 0 days), Trt. 2 (30%, 0%, and 0 days), Trt. 3 (Withdrawal, 0%, and 0 days), Trt. 4 (0%, 0.5%, 14 days), Trt. 5 (30%, 0.5%, 14 days), Trt. 6 (Withdrawal, 0.5%, 14 days), Trt. 7 (0%, 0.5%, 28 days), Trt. 8 (30%, 0.5%, 28 days), Trt. 9 (Withdrawal, 0.5%, 28 days), Trt. 10 (0%, 1.0%, 14 days), Trt. 11 (30%, 1.0%, 14 days), Trt. 12 (Withdrawal, 1.0%, 14 days), Trt. 13 (0%, 1.0%, 28 days), Trt. 14 (30%, 1.0%, 28 days), Trt. 15 (Withdrawal, 1.0%, 28 days). Pen was the experimental unit. The study used a total of 3,300 pigs housed in pens of 20 with 11 pens per treatment. This study was carried out from an initial live weight of 92.2 ± 1.20 kg for a fixed-time feeding period of 70 days (to Week 10 of the study), with CLA being fed for the last 14 or 28 days prior to harvest according to treatment. All pigs were individually weighed at the start of the study. Group pen weights were collected on all replicates at the start of study, week 3, 6, 8, and 10 of the study period. At the end of Week 10 of study, all pens in a replicate were taken off test, and sent for harvest on the same day. Carcass, *Longissiumus* muscle, belly, and fat quality measures were collected after harvest. At approximately 24 h post mortem, a fat sample was taken and near-infrared spectroscopy (NIR) was performed on the sample, to measure iodine value. Including 30% DDGS in the diet reduced ($P < 0.05$) growth performance (i.e., ADG and G:F), carcass characteristics (i.e., carcass yield and 10th rib backfat depth), belly firmness (i.e., belly flop distance and subjective firmness score), and increased ($P < 0.05$) iodine value by on average 7.46 g/100g (68.88 to 76.34 g/100g), when compared to pigs fed 0% DDGS. Withdrawing DDGS from the diet for the last 4 wk before harvest increased ($P < 0.05$) growth performance, carcass yield, belly firmness (i.e., belly flop distance and subjective firmness score), and reduced ($P < 0.05$) iodine value by on average 3.61 units (76.34 to 72.73 g/100g), when compared to pigs fed 30% DDGS. The level and duration of feeding CLA had no effect ($P > 0.05$) on growth performance; however, feeding diets with 1% CLA for 28 days increased ($P < 0.05$) flop distance and subjective firmness score indicating an improvement in belly firmness. In addition, including CLA at either 0.5 or 1.0% reduced ($P < 0.05$) iodine value by on average 1.4 and 1.7 g/100g, respectively, and including CLA in the diet for either 14 or 28 days reduced iodine value ($P < 0.05$) by 1.1 and 2.0 g/100g, respectively, compared to controls (0 % CLA and 0 days). The results of this study suggest that feeding DDGS leads to a reduction in growth performance and carcass and fat quality; however, withdrawing DDGS from the diet 4 wk before harvest and/or feeding CLA can improve some of these measures, particularly, fat quality.

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CHAPTER 1: LITERATURE REVIEW

Introduction

Conjugated linoleic acid (CLA) consists of a group of positional and geometric (cis or trans) isomers of linoleic acid. Conjugated linoleic acid was first discovered when extracted from the lipid fraction of cooked ground beef and was found to have anticarcinogenic activity (Ha et al., 1987). This discovery sparked interest in the compound and subsequent research suggested that CLA possessed several other properties when included in mammalian diets. One of the biological effects of CLA related to fat accretion and nutrient partitioning, and when included in diets for growing-finishing pigs, CLA has been shown in some studies to improve growth performance, carcass leanness, belly firmness, and iodine value of fat. However, not all studies have shown all of these positive responses and, in addition, few of these studies have been carried out under commercial conditions.

The following literature review summarizes previous research investigating at the effect of feeding CLA on growth performance, carcass characteristics, and fat composition of growing-finishing pigs.

GROWTH PERFORMANCE

Effect of Feeding CLA on the Growth Performance of Growing-Finishing Pigs

A summary of 17 studies evaluating the effects of CLA inclusion in the diets of growing-finishing pigs on growth performance are presented in Table 1. Of the studies reported in Table 1, CLA inclusion levels in the test diets ranged from 0.2 to 5.0 % with all but one study (Sun et al., 2004) using levels of less than 2 % CLA. It is also important to note that the body weight range over which CLA was fed, similar to CLA inclusion level, also varied between studies with a range from 18.5 to 130 kg.

In general, CLA inclusion in the diet appeared to have little effect on average daily gain, with only 3 of the 17 studies reporting a significant increase or decrease (Thiel-Cooper et al., 2001; Eggert et al., 2001; Sun et al., 2004). Of those 3 studies, 2 studies showed that CLA increased average daily gain on average by 10%; however, it's important to note that diets from both studies contained more than 1.5% CLA (Thiel-Cooper et al., 2001; Sun et al., 2004). Thiel-Cooper et al. (2001) conducted a study with 5 CLA inclusion levels (i.e., 0, 0.20, 0.42, 0.83, and 1.67%) and reported that average daily gain increased linearly as the concentration of CLA in the diet increased; however, the only CLA inclusion level that was significantly different from the control (0% CLA) was the highest inclusion level (1.67%). Sun et al. (2004) also compared multiple CLA levels (i.e., 0, 2.0, and 4.0%) and reported an increase in average daily gain with increasing CLA levels, compared to the control. However, Eggert et al. (2001) reported a significant decrease of 10 % in average daily gain for pigs fed CLA. The authors suggested that this could have been due to the short duration of the CLA feeding period which was over a 43.3 kg body weight range. Overall, the inclusion of CLA in the diets of growing-finishing pigs appears to have little effect on average daily gain.

Sixteen studies (Table 1) reported the effect of CLA inclusion in diets on feed intake. Similar to average daily gain, most studies showed little effect of CLA inclusion on feed intake, with only one study (Sun et al., 2004) reporting a significant increase in feed intake on average by 6% for pigs fed CLA. It's important to note, however, that Sun et al. (2004) used high levels of CLA (greater than 1.6%) in comparison to the other studies reported in Table 1.

Seventeen studies in Table 1 reported on the effect of CLA inclusion on feed efficiency. Thirteen of the 17 studies reported no effect of CLA inclusion on feed efficiency. However, three studies showed an increase in feed efficiency by on average 6% (Thiel-Cooper et al., 2001;

Wiegand et al., 2001; Sun et al., 2004), and one study showed a decrease in feed efficiency of 3 % (Barnes et al., 2012) when CLA was included in diets.

Thiel-Cooper et al. (2001) conducted a study evaluating 5 CLA levels (i.e., 0, 0.20, 0.42, 0.83, and 1.67%) and reported a significant increase in feed efficiency over the control for the 1.67% CLA inclusion level only. Sun et al. (2004) tested CLA inclusion levels of 0, 2.0, and 4.0% and reported that feed efficiency increased linearly with increasing CLA inclusion levels. Wiegand et al. (2001) tested CLA inclusion levels of 0 and 1.25% and reported an increase in feed efficiency with inclusion of CLA in the diet. It was hypothesized by Chin et al. (1994) that the improvement of feed efficiency in rats fed CLA could be because CLA changes the ability of the animal to regulate energy metabolism and nutrient partitioning. The study conducted by Barnes et al. (2012), however, does not support the above hypothesis. Barnes et al. (2012) evaluated CLA inclusion levels of 0 and 1% CLA and the authors reported a reduced feed efficiency with CLA inclusion. These authors suggested that this could have resulted from the short duration of the CLA feeding period (6 weeks). Weber et al. (2006), found that there was an increase in feed efficiency only in the second half of an eight week feeding period. It is also important to note that the 2 studies that reported an effect on CLA feeding on feed efficiency (Wiegand et al., 2001; Barnes et al., 2012) did not report an impact on average daily gain or feed intake, which are known to be associated with changes in feed efficiency.

As demonstrated in the studies above, CLA inclusion level and duration appears to have little impact on growth performance. However, only 4 studies reported in Table 1 evaluated multiple CLA inclusion levels and only one study used diets containing more than 2% CLA. More research is needed to understand the impact of feeding higher levels of CLA on growth performance. In addition, most published studies were carried out on research facilities with limited numbers of animals (16 to 288). It is important to establish the effects of feeding CLA on growth performance and other parameters under commercial conditions involving a larger number of animals.

CARCASS CHARACTERISTICS

Effect of feeding CLA on Carcass Characteristics

A summary of studies evaluating the effects of including CLA in swine diets on carcass characteristics measured following harvest at the end of the growing-finishing period are presented in Table 2. Of the studies reported in Table 2, CLA inclusion levels in the test diets ranged from 0.2 to 4.0 % with all but two studies (Sun et al., 2004; Stanimirovic et el., 2012) using diets with less than 2 % CLA. Feeding CLA had an effect on only 3 of 9 carcass measurements presented in Table 2 (i.e., backfat depth, *Longissiumus* muscle marbling, and belly firmness), therefore, the discussion of the effects of CLA inclusion in diets on carcass characteristics will focus on these 3 variables.

There was some disagreement between studies regarding the effect of feeding CLA on 10th rib backfat depth. Five of the 10 studies presented in Table 2 reported a decrease in backfat depth from feeding CLA, with the average difference between pigs fed CLA and controls being 13 % (Thiel-Cooper et al., 2001; Wiegand et al., 2001; Barnes et al., 2012; Corino et al., 2003; Sun et al., 2004). However, the other 5 studies reported no effect of feeding CLA on backfat depth (Table 2). The 5 studies that reported a decrease in backfat depth are discussed below.

Thiel-Cooper et al. (2001) conducted a study with 5 CLA inclusion levels (i.e., 0, 0.20, 0.42, 0.83, and 1.67%) and reported a quadratic response in backfat depth for pigs fed CLA. Backfat depth was reduced up to an inclusion level of 0.42%; however there was no further reduction in backfat depth at the higher inclusion levels. Interestingly, first rib, last rib and lumbar backfat depth were also measured in the study of Thiel-Cooper et al. (2001), however, there was no effect of CLA level on these measurements. Multiple levels of CLA were also tested in 2 additional studies that reported a decrease in backfat depth. These studies (Corino et al., 2003;

Sun et al., 2004) tested 3 different levels of CLA inclusion. Corino et al. (2003) evaluated 0, 0.25, and 0.50% CLA inclusion levels which were lower levels than those compared in the study of Sun et al. (2004) that evaluated 0, 2.0, and 4.0% CLA. Both studies showed a linear decrease in backfat depth with increasing CLA inclusion. Corino et al. (2003) showed reductions in backfat depth of 0.49 and 0.34 cm from feeding 0.25 and 0.50% CLA, respectively, compared to the control (0% CLA). Sun et al. (2004) also showed a reduction in backfat depth but not to the extent of Corino et al. (2003); backfat was reduced by 0.19 and 0.23 cm from feeding 2.0% and 4.0% CLA, respectively, compared to the control (0% CLA). Wiegand et al. (2001) evaluated CLA inclusion levels of 0 and 1.25% CLA and reported a decrease in backfat depth by 0.50 cm with inclusion of CLA in the diet. Similar to the results of Wiegand et al. (2001), Barnes et al. (2012) also evaluated 2 CLA levels (i.e., 0 and 1% CLA) and reported a decrease of 0.48 cm in backfat depth. Results of studies evaluating the effect of CLA inclusion on backfat depth at the 10th rib appeared to differ with half of the studies showing no effect, however, all of the studies that reported an effect showed a decrease in backfat depth when CLA was included in diets compared to the control.

Five of the 8 studies in Table 2 (Wiegand et al., 2001; Wiegand et al., 2002a; Wiegand et al., 2002b; Sun et al., 2004; Go et al., 2012) reported an increase *Longissiumus* muscle marbling when CLA was included in diets. In contrast, the remaining 3 studies (Eggert et al., 2001; Barnes et al., 2012; Weber et al., 2006) reported no significant effect of feeding CLA on *Longissiumus* muscle marbling.

It is important to note that Wiegand et al. (2001, 2002a, and 2002b) measured *Longissiumus* muscle marbling using the National Pork Producers Council 5-point subjective scale; however, Sun et al. (2004) and Go et al. (2012) measured marbling using 2 different techniques, namely

SMART Trac (CEM, Matthews, NC, USA) which measures the fat throughout the sample using MRI technology and petroleum-ether extraction.

Wiegand et al. (2001), Wiegand et al. (2002a), and Wiegand et al. (2002b) evaluated the effect of feeding 2 CLA levels (i.e., 0 and 1.25%) over 3 different weight ranges (i.e., 40 to 106, 28 to 115, and 87 to 115 kg live weight), however, all three studies reported an increase in marbling of approximately 14%when CLA was included in the diet. Similarly, Go et al. (2012) showed an increase in marbling of 38% from feeding 1% compared to 0% CLA between 80 to 110 kg live weight. The studies discussed above evaluated only one level of CLA compared to the control, however, Sun et al. (2004) tested three CLA inclusion levels of 0, 2.0, and 4.0%, and reported that marbling increased linearly with increasing CLA inclusion levels. Sun et al. (2004) showed that feeding 2.0% and 4% CLA increased marbling by 13% and 29%, respectively, compared to the control. Overall, it appears that CLA inclusion in the diets appeared to increase *Longissiumus* muscle marbling, as illustrated in the studies discussed above.

Only 2 studies in Table 2 reported on the effect of CLA inclusion in diets on belly firmness (Eggert et al., 2001; Weber et al., 2006). Both studies evaluated 2 CLA inclusion levels (i.e., 0 and 1.0%) and reported that belly firmness was increased on average by 18% when feeding CLA. Belly firmness is of increased interest in the pork industry with the increased use of corn distiller dried grain with solubles (DDGS), a corn by-product produced by dry-grind ethanol plants. The addition of DDGS in swine diets has been reported to negatively affect carcass quality through increased deposition of soft fat, which causes problems with slicing of pork bellies for bacon. The two studies above demonstrate that CLA may be able to increase belly firmness which could potentially provide a solution to the soft fat and belly firmness problem.

In summary, dietary CLA inclusion appears to have an impact on backfat depth, *Longissiumus* muscle marbling, and belly firmness. However, the extent of any effect of feeding CLA on these measures differed between studies, and, therefore, more research is necessary to more fully understand how feeding CLA affects these carcass characteristics. Understanding the effect of feeding CLA could help pork producers who aim to produce a lean carcass with increased marbling and belly firmness. In addition, only two studies reported on the effect of feeding CLA on belly firmness, and this measure, in particular, is of increasing interest in the swine industry. Therefore, more research is also necessary to fully understand the beneficial impact of feeding CLA on belly firmness.

FATTY ACID COMPOSITION OF CARCASS FAT

Effect of Feeding CLA on the Fatty Acid Composition of Carcass Fat

Wood et al. (2008) stated that fat quality is driven by the fatty acid composition of the fat and characterized by its consistency, and susceptibility to oxidation, which can affect both the flavor and color of fat. Changing the fatty acid composition of adipose tissue by feeding different oils and fats changes the lipid melting point and fat firmness. Dietary fats that result in an increase in poly-unsaturated fatty acids in the adipose tissue, especially linoleic acid, can produce soft pork fat. Inversely, high levels of palmitic and oleic acids in dietary fat result in firmer pork fat. According to Lee et al. (1998), CLA affects the saturated to unsaturated fatty acid ratio in carcass fat by inhibiting stearoyl-CoA desaturase activity, a key enzyme involved in the synthesis of monounsaturated fatty acids as well as in the regulation of this process, and, consequently, increases the saturated fatty acid content of the fat deposited in the carcass.

A summary of 11 studies evaluating the effects of feeding CLA to swine on aspects of fat composition and quality are presented in Table 3. Across all of these studies, the fatty acid profile, iodine value, and the total saturated (SFA), monounsaturated (MUFA), polyunsaturated (PUFA), and unsaturated (USFA) fatty acids were reported for 3 fat depots (backfat, belly, and intramuscular); however, all 3 fat depots were not measured in every study. Conjugated linoleic acid inclusion levels in the test diets, ranged from 0.2 to 4.0 % with all but 1 study (Tous et al., 2013), using less than 2 % CLA inclusion. The focus of this discussion will be on the effects of CLA inclusion on changes in fatty acid profile and, particularly, the ratio of saturated to unsaturated fatty acids, and iodine value of the 3 fat depots.

Ten of the 11 studies reported increases in the concentration of palmitic acid (C16:0) by on average 12% with feeding CLA; however, one study (Thiel-Cooper et al., 2001) reported that feeding CLA decreased palmitic acid concentration. Thiel-Cooper et al. (2001) evaluated 5 CLA inclusion levels (i.e., 0, 0.20, 0.42, 0.83, and 1.67%) and reported a decrease in palmitic acid, in the backfat depot for the 0.83 and 1.67% CLA inclusion levels, but not for the 0.20 and 0.42% CLA inclusion levels. These authors also reported that linoleic acid content of the backfat increased on average by 19% compared to the control treatment, when 0.42, 0.83, and 1.67% CLA was added in the diet; however, in the intramuscular depot, linoleic acid content was only increased (by 16%) when 0.83% CLA was included in the diet. Nevertheless, this literature review suggests that feeding CLA generally resulted in a reduction in linoleic acid (C18:2) concentration in carcass fat, with 6 of the 11 studies reporting a decrease in linoleic acid by on average 17% across the 3 depots. However, 3 additional studies (Wiegand et al., 2002a; White et al., 2009; Pompeu et al., 2013) reported that linoleic acid was increased by on average 4% in pigs fed diets with 1% CLA inclusion, 1 study reported no significant change, and 1 study (Thiel-Cooper et al., 2001) reported an increase that was dependent on both the level of CLA included in the diet and, also, the depot in question. In summary, the fatty acid profile was changed when feeding CLA, as discussed above; in general most studies reported increases in palmitic acid and decreases in linoleic acid. Changes in the fatty acid profile can change the saturated to unsaturated fatty acid ratio and this will be discussed below.

Nine studies, reported in Table 3, evaluated the total SFA content, and reported that SFA increased by an average of 14% when CLA was included in the diet (Eggert et al., 2001; Barnes et al., 2012; Wiegand et al., 2002a, 2002b; Weber et al., 2006; Martin et al., 2008; Larsen et al., 2008; Tous et al., 2013; Pompeu et al., 2013). The reported increase in SFA would result in firmer fat in all three depots, with, in this respect, belly fat being of upmost importance for the industry as described in previous sections. Only 8 studies (Table 3) evaluated MUFA, but all reported a decrease in MUFA of an average 10% with CLA inclusion (Eggert et al., 2001; Barnes et al., 2012; Wiegand et al., 2002a, 2002b; Weber et al., 2006; Martin et al., 2008; Tous et al., 2013; Pompeu et al., 2013). Only 3 of 11 studies in Table 3 evaluated the effect of CLA inclusion on USFA, however, all studies reported a decrease when CLA was included in diets of 11% (averaged across studies) (Eggert et al., 2001; Barnes et al., 2012; Weber et al., 2006). Seven of the 11 studies evaluated PUFA and reported inconsistent results within and across studies, when CLA was included in the diet. With the change in saturated to unsaturated fatty acid ratio with the addition of CLA, iodine value can be greatly affected. Four studies reported on the effect of CLA inclusion on iodine value (Eggert et al., 2001; Weber et al., 2006; Larsen et al., 2008; White et al., 2009; Pompeu et al., 2013), and across studies there was an average decrease of 5.4 g/100g.

In conclusion, the inclusion of CLA in swine diets generally affected the fatty acid composition similarly across the fat depots evaluated. In general, the feeding of CLA increased palmitic acid concentration (C16:0), and decreased linoleic acid concentration (C18:2) of the carcass fat. These changes in the concentration of fatty acids would increase the saturated to unsaturated fatty acid ratio, leading to firmer pork fat and fewer problems with slicing bellies. The inclusion of CLA in diets also resulted in a decrease in iodine value which can be used as an indicator of fat quality by packers. With the increased use of DDGS and the detrimental effects it can have on fat quality, fat quality will continue to be a topic of concern in the pork industry. Conjugated linoleic acid inclusion in swine diets may be one approach that can be used to combat these negative effects. Given the lack of consistency in the results of historical research studies, further research is needed to understand how the inclusion of CLA in swine diets can affect the ratio of saturated to unsaturated fatty acids, iodine value, and quality of fat depots.

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TABLES

Table 1. Summary of studies evaluating the effects of feeding conjugated linoleic acid on the growth performance of pigs.

				Ingredient	CLA inclusion level, %[1]								
Performance trait reference	# Pigs	BW range, kg	Number of pigs/pen	substituted by CLA	0	0.1 - 0.25	0.26 - 0.5	0.6 - 0.75	0.76 - 1.0	1.1 - 1.5	1.6 - 2.0	2.1 - 5.0	*P*-value
Growth Performance													
Average daily gain, kg													
Dugan et al. (1997) [2]	108	61.5 - 106	3	Sunflower oil	1.01	-	-	-	-	-	1.01	-	0.84
Thiel-Cooper et al. (2001)	32	26 - 116	1	Corn	0.94	0.93	0.95	-	0.97	-	1.02	-	<0.05
Eggert et al. (2001)	30	75.0 - 118.3	1	Sunflower oil	0.98	-	-	-	0.88	-	-	-	<0.05
Ramsay et al. (2001)	48	18.5 - 54.4	7	Corn oil	0.76	0.78	0.74	-	0.75	-	0.74	-	>0.05
Wiegand et al. (2001)	60	40 - 106	2	Soybean oil	0.88	-	-	-	-	0.90	-	-	0.40
Dunshea et al. (2002a)[2]	144	64.8 - 103.5	9	Tallow	0.92	-	0.93	-	-	-	-	-	0.66
Dunshea et al. (2002b)[2]	160	61.6 - 109.5	8	Tallow	0.99	-	0.97	-	-	-	-	-	0.41
Wiegand et al. (2002a)	92	28 - 115	4	Soybean oil	0.92	-	-	-	-	0.93	-	-	>0.05
Wiegand et al. (2002b)	92	87 - 115	4	Soybean oil	0.98	-	-	-	-	0.95	-	-	>0.05
Sun et al. (2004a)	54	63.8 - 98.9	3	Soybean oil	0.78	-	-	-	-	-	0.84	0.89	<0.01
Lauridsen et al. (2005a)	100	40 - 100	1	Soybean oil	1.21	-	1.24	-	-	-	-	-	>0.05
Lauridsen et al. (2005b)	100	40 - 130	1	Soybean oil	1.18	-	1.24	-	-	-	-	-	>0.05
Weber et al. (2006)	228	59.0 - 112.9	3	Soybean oil	0.95	-	-	-	0.97	-	-	-	>0.05
Martin et al. (2008) [2]	288	70 - 107	12	Palm oil	0.71	-	-	-	0.70	-	0.72	-	>0.05
Stanimirovic et al. (2012)	97	66.0 - 103.5	12	Soybean oil	0.84	-	0.86	-	-	-	-	-	>0.05
Go et al. (2012)	16	80 - 110	4	Canola oil	0.78	-	-	-	0.70	-	-	-	0.74
Barnes et al. (2012)	22	52.7 - 102.2	2	Soybean oil	1.26	-	-	-	1.22	-	-	-	0.42
Average daily feed intake, kg													
Dugan et al. (1997) [2]	108	61.5 - 106	3	Sunflower oil	3.08	-	-	-	-	-	2.92	-	0.07
Thiel-Cooper et al. (2001)	32	26 - 116	1	Corn	2.68	2.54	2.56	-	2.63	-	2.63	-	>0.05
Eggert et al. (2001)	30	75.0 - 118.3	1	Sunflower oil	3.67	-	-	-	3.47	-	-	-	>0.05
Ramsay et al. (2001)	48	18.5 - 54.4	7	Corn oil	1.58	1.63	1.60	-	1.62	-	1.56	-	>0.05
Dunshea et al. (2002a)[2]	144	64.8 - 103.5	9	Tallow	2.64	-	2.58	-	-	-	-	-	0.45
Dunshea et al. (2002b)[2]	160	61.6 - 109.5	8	Tallow	3.06	-	3.06	-	-	-	-	-	0.94
Wiegand et al. (2002a)	92	28 - 115	4	Soybean oil	2.79	-	-	-	-	2.74	-	-	>0.05
Wiegand et al. (2002b)	92	87 - 115	4	Soybean oil	3.31	-	-	-	-	3.29	-	-	>0.05
Sun et al. (2004a)	54	63.8 - 98.9	3	Soybean oil	2.51	-	-	-	-	-	2.61	2.70	<0.01
Lauridsen et al. (2005a)	100	40 - 100	1	Soybean oil	3.05	-	2.98	-	-	-	-	-	>0.05
Lauridsen et al. (2005b)	100	40 - 130	1	Soybean oil	3.27	-	3.31	-	-	-	-	-	>0.05
Weber et al. (2006)	228	59.0 - 112.9	3	Soybean oil	2.45	-	-	-	2.42	-	-	-	>0.05
Martin et al. (2008) [2]	288	70 - 107	12	Palm oil	2.37	-	-	-	2.30	-	2.30	-	>0.05
Stanimirovic et al. (2012)	97	66.0 -103.5	12	Soybean oil	2.85	-	2.81	-	-	-	-	-	>0.05
Go et al. (2012)	16	80 - 110	4	Canola oil	2.88	-	-	-	2.95	-	-	-	0.68
Barnes et al. (2012)	22	52.7 - 102.2	2	Soybean oil	3.44	-	-	-	3.51	-	-	-	0.50
Gain:Feed, kg:kg													
Dugan et al. (1997) [2]	108	61.5 - 106	3	Sunflower oil	0.328	-	-	-	-	-	0.346	-	0.06
Thiel-Cooper et al. (2001)	32	26 - 116	1	Corn	0.352	0.367	0.373	-	0.370	-	0.384	-	<0.05
Eggert et al. (2001)	30	75.0 - 118.3	1	Sunflower oil	0.266	-	-	-	0.252	-	-	-	>0.05
Ramsay et al. (2001)	48	18.5 - 54.4	7	Corn oil	0.472	0.469	0.463	-	0.454	-	0.454	-	>0.05
Wiegand et al. (2001)	60	40 - 106	2	Soybean oil	0.33	-	-	-	-	0.35	-	-	<0.05
Dunshea et al. (2002a)[2]	144	64.8 - 103.5	9	Tallow	0.348	-	0.360	-	-	-	-	-	0.10
Dunshea et al. (2002b)[2]	160	61.6 - 109.5	8	Tallow	0.324	-	0.317	-	-	-	-	-	0.87
Wiegand et al. (2002a)	92	28 - 115	4	Soybean oil	0.331	-	-	-	-	0.340	-	-	>0.05
Wiegand et al. (2002b)	92	87 - 115	4	Soybean oil	0.296	-	-	-	-	0.288	-	-	>0.05
Sun et al. (2004a)	54	63.8 - 98.9	3	Soybean oil	0.311	-	-	-	-	-	0.322	0.330	<0.01
Lauridsen et al. (2005a)	100	40-100	1	Soybean oil	0.396	-	0.415	-	-	-	-	-	>0.05
Lauridsen et al. (2005b)	100	40-130	1	Soybean oil	0.361	-	0.374	-	-	-	-	-	>0.05
Weber et al. (2006)	228	59.0 - 112.9	3	Soybean oil	0.386	-	-	-	0.399	-	-	-	>0.05
Martin et al. (2008) [2]	288	70 - 107	12	Palm oil	0.300	-	-	-	0.304	-	0.313	-	>0.05

Table 1 (Cont.)

Stanimirovic et al. (2012)	97	66.0 -103.5	12	Soybean oil	0.294	-	0.304	-	-	-	-	-	>0.05
Barnes et al. (2012)	22	52.7 - 102.2	2	Soybean oil	0.36	-	-	-	0.35	-	-	-	0.05
Go et al. (2012)	16	80 - 110	4	Canola oil	0.271	-	-	-	0.237	-	-	-	0.65

[1] The CLA oil preparation used in the trials contained between 50-68% of conjugated linoleic acid.

[2] Study diets used were based on wheat or barley; other studies used diets based on corn.

Table 2. Summary of studies evaluating the effects of feeding conjugated linoleic acid on the carcass characteristics of pigs.

Performance trait reference	# Pigs	BW range, kg	Number of pigs/pen	Ingredient substituted by CLA	CLA inclusion level, %[1]								*P*-value
					0	0.1 - 0.25	0.26 - 0.5	0.6 - 0.75	0.76 - 1.0	1.1 - 1.5	1.6 - 2.0	2.1 - 5.0	
Carcass Characteristics													
Hot carcass weight, kg													
Wiegand et al. (2001)	60	40 - 106	2	Soybean oil	79	-	-	-	-	77	-	-	0.32
Wiegand et al. (2002a)	92	28 - 115	4	Soybean oil	84.4	-	-	-	-	84.4	-	-	>0.05
Wiegand et al. (2002b)	92	87 - 115	4	Soybean oil	84.4	-	-	-	-	83.5	-	-	>0.05
Corino et al. (2003)	36	97.2 - 172	6	Lard	138.1	140.1	140.9	-	-	-	-	-	>0.05
Sun et al. (2004a)	54	63.8 - 98.9	3	Soybean oil	78.6	-	-	-	-	-	78.3	79.1	0.23
Lauridsen et al. (2005a)	100	40 - 100	1	Soybean oil	79.08	-	79.33	-	-	-	-	-	>0.05
Lauridsen et al. (2005b)	100	40 - 130	1	Soybean oil	98.86	-	101.99	-	-	-	-	-	>0.05
Weber et al. (2006)	228	59.0 - 112.9	3	Soybean oil	80.84	-	-	-	80.92	-	-	-	0.92
Stanimirovic et al. (2012)	97	66.0 -103.5	12	Soybean oil	80.35	-	80.39	-	-	-	-	-	>0.05
Go et al. (2012)	16	80 - 110	4	Canola oil	85.0	-	-	-	80.0	-	-	-	0.78
Barnes et al. (2012)	22	52.7 - 102.2	2	Soybean oil	80.86	-	-	-	82.09	-	-	-	0.42
Tous et al. (2013)	16	73 - 117	1	Sunflower oil	93.5	-	-	-	-	-	-	92.2	0.54
Carcass yield, %													
Eggert et al. (2001)	30	75.0 - 118.3	1	Sunflower oil	73.82	-	-	-	73.71	-	-	-	>0.05
Dunshea et al. (2002a)[2]	144	64.8 - 103.5	9	Tallow	77.70	-	77.85	-	-	-	-	-	0.54
Dunshea et al. (2002b)[2]	160	61.6 - 109.5	8	Tallow	67.40	-	67.85	-	-	-	-	-	0.14
Corino et al. (2003)	36	97.2 - 172	6	Lard	81.4	81.4	81.3	-	-	-	-	-	>0.05
Weber et al. (2006)	228	59.0 - 112.9	3	Soybean oil	71.92	-	-	-	71.49	-	-	-	0.22
Martin et al. (2008) [2]	288	70 - 107	12	Palm oil	80.6	-	-	-	80.2	-	80.4	-	0.78
Tous et al. (2013)	16	73 - 117	1	Sunflower oil	80.9	-	-	-	-	-	-	80.4	0.30
Go et al. (2012)	16	80 - 110	4	Canola oil	76.8	-	-	-	76.0	-	-	-	0.65
Backfat depth, cm (at the 10th rib) carcass													
Thiel-Cooper et al. (2001)	32	26 - 116	1	Corn	2.86	2.34	2.34	-	2.61	-	2.57	-	<0.05
Eggert et al. (2001)	30	75.0 - 118.3	1	Sunflower oil	2.08	-	-	-	1.91	-	-	-	>0.05
Wiegand et al. (2001)	60	40 - 106	2	Soybean oil	2.84	-	-	-	-	2.34	-	-	<0.05
Wiegand et al. (2002a)	92	28 - 115	4	Soybean oil	2.62	-	-	-	-	2.24	-	-	>0.05
Wiegand et al. (2002b)	92	87 - 115	4	Soybean oil	2.62	-	-	-	-	2.08	-	-	>0.05
Corino et al. (2003)	36	97.2 - 172	6	Lard	3.84	3.35	3.50	-	-	-	-	-	<0.05
Sun et al. (2004a)	54	63.8 - 98.9	3	Soybean oil	2.21	-	-	-	-	-	2.02	1.98	0.03
Weber et al. (2006)	228	59.0 - 112.9	3	Soybean oil	1.80	-	-	-	1.68	-	-	-	0.06
Go et al. (2012)	16	80 - 110	4	Canola oil	2.49	-	-	-	2.50	-	-	-	0.83
Barnes et al. (2012)	22	52.7 - 102.2	2	Soybean oil	3.02	-	-	-	2.54	-	-	-	0.02
Longissiumus muscle measurements													
Ultimate pH													
Eggert et al. (2001)	30	75.0 - 118.3	1	Sunflower oil	5.41	-	-	-	5.47	-	-	-	>0.05
Dunshea et al. (2002b)[2]	160	61.6 - 109.5	8	Tallow	5.40	-	5.43	-	-	-	-	-	0.06
Wiegand et al. (2002b)	92	87 - 115	4	Soybean oil	5.7	-	-	-	-	5.7	-	-	>0.05
Corino et al. (2003)	36	97.2 - 172	6	Lard	5.80	5.82	5.69	-	-	-	-	-	>0.05
Lauridsen et al. (2005a)	100	40 - 100	1	Soybean oil	5.55	-	5.59	-	-	-	-	-	>0.05
Lauridsen et al. (2005b)	100	40 - 130	1	Soybean oil	5.46	-	5.53	-	-	-	-	-	>0.05
Weber et al. (2006)	228	59.0 - 112.9	3	Soybean oil	5.63	-	-	-	5.62	-	-	-	0.74
Martin et al. (2008) [2]	288	70 - 107	12	Palm oil	5.4	-	-	-	5.5	-	5.5	-	>0.05
Go et al. (2012)	16	80 - 110	4	Canola oil	5.65	-	-	-	5.64	-	-	-	0.20
Tous et al. (2013)	16	73 - 117	1	Sunflower oil	5.57	-	-	-	-	-	-	5.58	0.80
Subjective color													
Eggert et al. (2001)	30	75.0 - 118.3	1	Sunflower oil	2.54	-	-	-	2.55	-	-	-	>0.05
Wiegand et al. (2001)	60	40 - 106	2	Soybean oil	2.33	-	-	-	-	2.34	-	-	0.98
Wiegand et al. (2002a)	92	28 - 115	4	Soybean oil	2.43	-	-	-	-	2.31	-	-	>0.05

Table 2 (Cont.)

Wiegand et al. (2002b)	92	87 - 115	4	Soybean oil	2.43	-	-	-	-	2.38	-	-	>0.05
Weber et al. (2006)	228	59.0 - 112.9	3	Soybean oil	2.72	-	-	-	2.78	-	-	-	0.37
Barnes et al. (2012)	22	52.7 - 102.2	2	Soybean oil	2.68	-	-	-	2.70	-	-	-	0.50
Subjective marbling													
Eggert et al. (2001)	30	75.0 - 118.3	1	Sunflower oil	1.38	-	-	-	1.40	-	-	-	>0.05
Wiegand et al. (2001)	60	40 - 106	2	Soybean oil	1.51	-	-	-	-	1.86	-	-	<0.05
Wiegand et al. (2002a)	92	28 - 115	4	Soybean oil	2.04	-	-	-	-	2.18	-	-	<0.05
Wiegand et al. (2002b)	92	87 - 115	4	Soybean oil	2.04	-	-	-	-	2.31	-	-	<0.05
Sun et al. (2004a)	54	63.8 - 98.9	3	Soybean oil	2.4	-	-	-	-	-	2.7	3.1	0.01
Weber et al. (2006)	228	59.0 - 112.9	3	Soybean oil	1.01	-	-	-	1.05	-	-	-	0.10
Go et al. (2012)	16	80 - 110	4	Canola oil	2.30	-	-	-	3.17	-	-	-	0.01
Barnes et al. (2012)	22	52.7 - 102.2	2	Soybean oil	2.43	-	-	-	3.10	-	-	-	0.07
Subjective firmness													
Eggert et al. (2001)	30	75.0 - 118.3	1	Sunflower oil	2.33	-	-	-	2.36	-	-	-	>0.05
Wiegand et al. (2001)	60	40 - 106	2	Soybean oil	1.96	-	-	-	-	2.29	-	-	0.06
Wiegand et al. (2002a)	92	28 - 115	4	Soybean oil	2.36	-	-	-	-	2.27	-	-	>0.05
Wiegand et al. (2002b)	92	87 - 115	4	Soybean oil	2.36	-	-	-	-	2.49	-	-	>0.05
Weber et al. (2006)	228	59.0 - 112.9	3	Soybean oil	2.68	-	-	-	2.71	-	-	-	0.74
Drip loss, %													
Eggert et al. (2001)	30	75.0 - 118.3	1	Sunflower oil	5.46	-	-	-	5.07	-	-	-	>0.05
Dunshea et al. (2002b)[2]	160	61.6 - 109.5	8	Tallow	5.91	-	5.86	-	-	-	-	-	0.91
Sun et al. (2004a)	54	63.8 - 98.9	3	Soybean oil	5.2	-	-	-	-	-	4.9	4.9	0.30
Lauridsen et al. (2005a)	100	40-100	1	Soybean oil	6.51	-	5.85	-	-	-	-	-	>0.05
Lauridsen et al. (2005b)	100	40-130	1	Soybean oil	6.50	-	7.24	-	-	-	-	-	>0.05
Weber et al. (2006)	228	59.0 - 112.9	3	Soybean oil	2.91	-	-	-	2.71	-	-	-	0.38
Go et al. (2012)	16	80 - 110	4	Canola oil	5.71	-	-	-	5.12	-	-	-	0.87
Tous et al. (2013)	16	73 - 117	1	Sunflower oil	2.30	-	-	-	-	-	-	1.61	0.30
Belly measurements													
Belly Firmness													
Eggert et al. (2001)	30	75.0 - 118.3	1	Sunflower oil	2.43	-	-	-	2.91	-	-	-	<0.01
Weber et al. (2006)	228	59.0 - 112.9	3	Soybean oil	2.67	-	-	-	3.11	-	-	-	0.01

[1] The CLA oil preparation used in the trials contained between 50-68% of conjugated linoleic acid.

[2] Study diets used were based on wheat or barley; other studies used diets based on corn.

Table 3. Summary of studies evaluating the effects of feeding conjugated linoleic acid on fatty acid composition and iodine value of various fat depots.[1]

Fat depot	# Pigs	BW range, kg	Number of pigs/pen	Ingredient substituted by CLA	Fatty Acid, %								Total SFA^{2}	Total MUFA^{3}	Total PUFA^{4}	Total USFA^{5}	Iodine Value^{6} (g/100g)
					C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:4					
Backfat																	
Thiel-Cooper et al. (2001)	32	26 - 116	1	Corn													
0%					1.76^{b}	30.63^{a}	1.93^{c}	12.87	25.80^{d}	16.71^{b}	-	0.15	-	-	-	-	-
0.20%					1.84^{a}	27.12^{ab}	2.32^{ab}	13.86	27.44^{c}	17.47^{b}	-	0.17	-	-	-	-	-
0.42%					1.79^{b}	31.63^{a}	2.50^{a}	12.29	29.42^{b}	19.42^{a}	-	0.14	-	-	-	-	-
0.83%					1.90^{a}	24.77^{b}	2.33^{ab}	13.73	30.97^{a}	20.24^{a}	-	0.15	-	-	-	-	-
1.67%					2.12^{a}	20.41^{b}	1.96^{bc}	12.34	31.51^{a}	20.24^{a}	-	0.16	-	-	-	-	-
Wiegand et al. (2002a)^{7}	92	28 - 115	4	Soybean oil													
0%					1.67	27.84	-	13.98	39.17	15.55	0.93	0.37	43.49	16.84	-	-	-
1.25%					2.29	31.35	-	15.56	31.81	15.12	0.79	0.63	49.19	16.54	-	-	-
Wiegand et al. (2002b)^{7}	92	87 - 115	4	Soybean oil													
0%					1.67	27.84	-	13.98	39.17	15.55	0.93	0.37	43.49	16.84	-	-	-
1.25%					3.00	32.51	-	17.82	27.53	14.74	0.53	0.26	53.33	15.52	-	-	-
Weber et al. (2006)	228	59.0 - 112.9	3	Soybean oil													
0%					1.38^{b}	24.33^{b}	1.58	15.77	42.00^{a}	14.19^{a}	0.93^{a}	0.24^{a}	41.51	44.71^{a}	16.04	60.54^{a}	67.56^{a}
1.00%					2.40^{a}	26.36^{a}	1.57	16.11	34.84^{b}	12.70^{b}	0.64^{b}	0.19^{b}	44.60	35.05^{b}	16.93	51.68^{b}	62.54^{b}
White et al. (2009)^{7}	36	88 - 109	1	CWG^{8}													
0%					1.30	21.36	2.33	9.98	39.13	18.10	0.55	0.28	-	-	-	-	71.11
1.00%					1.43	22.15	2.16	10.84	37.24	17.50	0.56	0.23	-	-	-	-	68.31
Tous et al. (2013)	16	73 - 117	1	Sunflower oil													
0%					1.52^{b}	21.20^{b}	1.52	13.00^{b}	36.00^{a}	19.50^{a}	0.72	0.44	36.50^{b}	40.70^{a}	22.70^{a}	-	-
4.00%					2.75^{a}	25.10^{a}	1.34	17.10^{a}	28.00^{b}	10.90^{b}	0.75	0.35	46.10^{a}	33.50^{b}	20.05^{b}	-	-
Belly																	
Eggert et al. (2001)	30	75.0 - 118.3	1	Sunflower oil													
0%					1.43^{b}	24.55^{b}	2.60^{b}	11.52^{b}	41.33^{a}	13.62^{a}	0.50	0.33^{a}	37.50^{b}	47.49^{a}	14.49^{a}	61.75^{a}	66.37^{a}
1.00%					2.16^{a}	27.73^{a}	2.95^{a}	14.56^{a}	37.35^{b}	9.01^{b}	0.38	0.20^{b}	44.45^{a}	43.63^{b}	11.15^{b}	54.78^{b}	57.69^{b}
Weber et al. (2006)	228	59.0 - 112.9	3	Soybean oil													
0%					1.45^{b}	24.49^{b}	2.58	13.12^{b}	41.64^{a}	11.12^{a}	0.67^{a}	0.29	39.06^{b}	48.27^{a}	12.66	60.92^{a}	63.03^{a}
1.00%					2.07^{a}	27.29^{a}	2.57	17.03^{a}	34.01^{b}	9.70^{b}	0.44^{b}	0.30	46.39^{a}	40.14^{b}	12.74	52.88^{b}	56.12^{b}
Larsen et al. (2009)	48	55 - 113	1	Soybean oil													
0%					-	25.27^{b}	2.76^{b}	13.23^{b}	39.63^{a}	13.46^{a}	2.84	1.39^{a}	38.49^{b}	-	60.09^{a}	-	67.44^{a}
1.25%					-	29.63^{a}	3.12^{a}	16.39^{a}	31.77^{b}	11.19^{b}	2.90	1.14^{b}	46.01^{a}	-	50.11^{b}	-	57.25^{b}
White et al. (2009)^{2}	36	88 - 109	1	CWG^{8}													
0%					1.31	21.75	2.40	10.85	39.45	16.00	0.46	0.30	-	-	-	-	67.70
1.00%					1.56	22.50	2.28	11.56	36.78	16.30	0.49	0.30	-	-	-	-	65.66
Pompeu et al. (2013)	1102	100.4 - 123.7	23	CWG^{8}													
0%					-	-	2.03	-	41.10^{a}	17.13^{b}	-	-	33.38^{b}	47.59	19.03^{b}	-	69.02^{a}
0.60%					-	-	1.91	-	38.78^{b}	17.65^{a}	-	-	35.34^{a}	44.48	19.83^{a}	-	67.85^{b}
Intramuscular fat																	
Thiel-Cooper et al. (2001)	32	26 - 116	1	Corn													
0%					1.00^{d}	21.81^{d}	2.72^{c}	12.40	35.85^{ac}	11.99^{b}	-	1.45^{c}	-	-	-	-	-
0.20%					1.04^{dc}	22.75^{dc}	3.10^{bc}	11.69	37.17^{a}	12.03^{b}	-	1.51^{c}	-	-	-	-	-
0.42%					1.16^{bc}	24.10^{bc}	3.31^{b}	11.15	35.67^{ac}	12.88^{ab}	-	1.29^{bc}	-	-	-	-	-
0.83%					1.19^{b}	24.94^{b}	3.34^{b}	11.89	33.96^{ab}	13.87^{a}	-	1.06^{a}	-	-	-	-	-
1.67%					1.34^{a}	25.61^{a}	4.43^{a}	11.44	32.11^{b}	13.01^{ab}	-	1.10^{bc}	-	-	-	-	-
Eggert et al. (2001)	30	75.0 - 118.3	1	Sunflower oil													
0%					1.13	24.50^{b}	3.49^{b}	10.41	44.21	8.53	0.16	1.86	36.04^{b}	53.27	10.69	63.96^{a}	61.55^{a}
1.00%					1.31	26.35^{a}	4.34^{a}	12.11	41.77	6.38	0.18	1.44	39.77^{a}	51.62	8.60	60.23^{b}	57.31^{b}
Wiegand et al. (2002a)^{7}	92	28 - 115	4	Soybean oil													
0%					1.53	30.39	-	13.67	44.88	8.22	0.27	1.03	45.60	9.53	-	-	-
1.25%					1.88	33.18		14.70	40.27	8.74	0.23	0.41	49.76	9.39	-	-	-
Barnes et al. (2012)	22	52.7 - 102.2	2	Soybean oil													
0%					1.25^{b}	25.3^{b}	3.21^{b}	12.23^{b}	45.64^{a}	7.25^{a}	0.57	1.22	39.25^{b}	49.84^{a}	10.92	60.8^{a}	-

Table 3 (Cont.)

1.00%					1.66^{a}	28.68^{a}	4.63^{a}	13.29^{a}	39.86^{b}	5.88^{b}	0.63	0.90	44.4^{a}	45.54^{b}	10.06	55.6^{b}	-
Wiegand et al. (2002b)[7]	92	87 - 115	4	Soybean oil													
0%					1.53	30.39	-	13.67	44.88	8.22	0.27	1.03	45.60	9.53	-	-	-
1.25%					2.03	36.70	-	14.27	38.99	6.52	0.12	0.66	53.00	7.30	-	-	-
Weber et al. (2006)	228	59.0 - 112.9	3	Soybean oil													
0%					0.98^{b}	22.84^{b}	2.63^{b}	14.61^{b}	34.67^{a}	13.71^{a}	0.44	3.86^{a}	38.42^{b}	42.68	18.91^{a}	61.59^{a}	65.18^{a}
1.00%					1.42^{a}	27.07^{a}	3.51^{a}	16.14^{a}	34.10^{b}	9.94^{b}	0.68	2.12^{b}	44.63^{a}	40.56	14.54^{b}	55.1^{b}	57.9^{b}
Martin et al. (2008)	288	70 - 107	12	Palm oil													
0%					0.72^{b}	20.56^{b}	2.36	13.70^{b}	36.74^{a}	13.75	0.58	3.21^{a}	36.03^{b}	43.96^{a}	19.40^{a}	-	-
1.00%					0.97^{a}	22.77^{a}	2.25	15.96^{a}	34.92^{ab}	12.52	0.57	1.86^{b}	40.61^{a}	41.34^{b}	16.33^{b}	-	-
2.00%					0.96^{a}	22.65^{a}	2.50	15.38^{a}	33.33^{b}	13.17	0.58	2.25^{b}	39.94^{a}	40.06^{b}	17.79^{ab}	-	-
Tous et al. (2013)	16	73 - 117	1	Sunflower oil													
0%					1.24^{b}	21.7^{b}	2.76^{b}	11.20	33.8^{a}	16.30	0.29^{b}	3.63	34.9^{b}	42.8^{a}	22.30	-	-
4.00%					1.87^{a}	23.6^{a}	3.91^{a}	11.20	26.4^{b}	15.50	0.49^{a}	4.00	37.4^{a}	37.2^{b}	25.30	-	-

[a,b,c,d] Values with different superscripts within a column category indicate treatment effects ($P < 0.05$).

[1] The CLA oil preparation used in the trials contained between 50-68% of conjugated linoleic acid.

[2] Total SFA – Total saturated fatty acids

[3] Total MUFA – Total monounsaturated fatty acids

[4] Total PUFA – Total polyunsaturated fatty acids

[5] Total USFA – Total unsaturated fatty acids

[6] Iodine Value = [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, 1998)

[7] Superscripts were not give in paper

[8] CWG = Choice white grease

CHAPTER 2: EFFECT OF LEVEL AND DURATION OF FEEDING CONJUGATED LINOLEIC ACID IN DIFFERENT DIETARY PROGRAMS ON THE GROWTH PERFORMANCE OF GROWING-FINISHING PIGS AND ON *LONGISSIUMUS* MUSCLE QUALITY, BELLY CHARACTERISTICS, AND FAT QUALITY MEASURED POST MORTEM.

INTRODUCTION

The practice of feeding high levels of Distillers Dried Grains with Solubles (DDGS), which can reduce the costs of diets and, therefore, of producing pigs, can increase the incidence of soft fat problems in pigs. The objective of the proposed study was to evaluate the feeding of conjugated linoleic acid (CLA), which consists of a group of positional and geometric (cis or trans) isomers of linoleic acid, in dietary programs with and without DDGS inclusion and in combination with a DDGS withdrawal period at the end of the finishing phase. Because CLA is relatively expensive, the effects of CLA inclusion level and feeding period were evaluated. The effect of dietary CLA supplementation in different dietary programs can be applied in order to minimize production costs while ensuring that fat quality is maintained. However, there is very little research evaluating the effect of CLA and DDGS inclusion in swine diets on growing-finishing pigs.

Therefore, the objective of this study is to determine the effects of level and duration of feeding CLA (Lutalin, BASF, Lampertheim, Germany) in different dietary programs on the growth performance of growing-finishing pigs and on *Longissiumus* muscle quality, belly characteristics, and fat quality measured post mortem.

MATERIALS AND METHODS

This study was conducted at The Bible Grove Technology Center of The Maschhoffs located near Bible Grove, IL and the experimental protocol was approved by the University of Illinois Institutional Animal Care and Use Committee.

Experimental Design and Treatments. This study was conducted as a randomized complete block design (blocking factor was day of start on test) with 15 treatments consisting of different combinations of Dietary Program (i.e., 0% DDGS, 30% DDGS, and DDGS withdrawal [30% DDGS from week 0 to approximately 104 kg and 0% DDGS from approximately 104 kg to end of study]), CLA Inclusion Level (i.e., 0, 0.5, and 1.0%), and CLA Feeding Duration (i.e., 0, 14, and 28 days prior to harvest). The treatments (Trt.) were defined by the combination of Dietary Program, CLA Inclusion level, and CLA Feeding Duration and were as follows: Trt. 1 (0%, 0%, and 0 days), Trt. 2 (30%, 0%, and 0 days), Trt. 3 (Withdrawal, 0%, and 0 days), Trt. 4 (0%, 0.5%, 14 days), Trt. 5 (30%, 0.5%, 14 days), Trt. 6 (Withdrawal, 0.5%, 14 days), Trt. 7 (0%, 0.5%, 28 days), Trt. 8 (30%, 0.5%, 28 days), Trt. 9 (Withdrawal, 0.5%, 28 days), Trt. 10 (0%, 1.0%, 14 days), Trt. 11 (30%, 1.0%, 14 days), Trt. 12 (Withdrawal, 1.0%, 14 days), Trt. 13 (0%, 1.0%, 28 days), Trt. 14 (30%, 1.0%, 28 days), Trt. 15 (Withdrawal, 1.0%, 28 days).

The study was carried out over a fixed-time period of 10 weeks, with CLA being fed for the last 4 or 2 weeks of the study period, depending on dietary treatment. All pens in a replicate were taken off test, and sent for harvest on the same day.

Animals and Allotment. A total of 3,300 animals, which were the progeny of PIC 359 sires mated to PIC C29 dams (PIC, Hendersonville, KY), were used in the study. An initial allotment was carried out when the pigs arrived at the site at 12 weeks post-weaning and approximately 41 kg live weight. The initial allotment was carried out using all pigs within a block (i.e., delivered to the site on the same day) with the objective of forming pens with the same pen mean live weight and within-pen coefficient of variation in live weight. On the day of arrival at the site, 10 barrows and 10 gilts were randomly selected, placed into a pen, and individually weighed. This process was repeated until all of the pigs in a block had been placed in pens. Within a block, pigs were moved between pens to achieve similar pen mean live weight and within-pen coefficient of variation across all pens. Pigs were allowed a 2-week acclimation period prior to the start of the study.

A second allotment was carried out after the acclimation period prior to the start of the study when pigs were approximately 60 kg live weight. Within a block, pen weights were taken and replicates were formed which consisted of 15 pens of similar pen mean live weight. Pens within a replicate were randomly allotted to treatment and were moved to the same area of the barn and started on test.

Diets and Housing. Diets were formulated to meet or exceed NRC (2012) recommendations for nutrients requirements of growing-finishing pigs across the weight range used in the study (approximately 41 to 130 kg). Feed and water were available ad libitum throughout the study period. The analyzed composition of the major ingredients (corn, DDGS, soybean meal, and CLA) is presented in Table 4 and the composition of the experimental diets is presented in Tables 5 to 7. The CLA product used, Lutalin CLA (BASF, Lampertheim, Germany), contained 56% CLA isomers (cis-9,trans-11 and trans-10,cis-12).

From arrival at the site to approximately 60 kg body weight, all pigs were fed the same diet (Treatment 1; 0%, 0%, 0 days). Pigs were fed treatment diets starting at approximately 60 kg body weight in the following phases and amounts/phase: Grow-finish phase 3; 43.5 kg/pig, Grow-finish phase 4; 65.8 kg/pig, Grow-finish phase 5; 83.9 kg/pig (Tables 5 to 7). At week 6 of the study, CLA was included in the Grow-finish phase 5 diet, at the expense of corn, and DDGS was withdrawn from the diet, according to dietary treatment (Table 7).

Pigs were housed in groups of 20 in two rooms of a tunnel ventilated wean-to-finish building that had fully slatted concrete flooring. Pen divisions and gates were of horizontal steel rods, with adjustment gates located in the back of the pen which were moved if pigs were removed during the study to maintain the same floor space per pig (0.67 m^2 per pig). Pens were equipped with a Feed Ease 2-hole wet-dry box feeder (A.J. O’Mara Group, McCook Lake, SD) mounted in the fence line that provided a trough space of 3.56 cm/pig and l WEC-1 Water Ease cup (A.J. O’Mara Group, McCook Lake, SD).

The thermostat inside the two rooms was set at 18.3ºC throughout the study period and the room temperature was maintained with thermostatically-controlled heaters and fan ventilation. Water sprinklers, located on the ceiling in the back of the each pen, were activated when the temperature of the rooms reached 29.4 ºC.

Growth Measurements. All pigs were individually weighed at the time of initial allotment. Group pen weights were collected on all replicates at the start of study, week 3, 6, 8, and 10 of the study period. Pigs from 6 of the 11 replicates (i.e., 1, 3, 6, 7, 8, and 9) were also individually weighed at week 6, 8, and 10 of the study period. These pigs were also ultrasonically scanned at the start (approximately 104 kg) and end of the CLA feeding period. A transverse ultrasound scan was taken at the 10th rib using an Aloka model 500V B-mode scanner with an Aloka 5011 probe (Corometrics Medical Systems, Wallingford, CT) and backfat depth (over the middle of the *Longissimus* muscle) and *Longissimus* muscle depth were measured on the scan using the Biotronics system (Biotronics, Inc., Ames, IA), which captures images from the ultrasound scanner and automatically measures backfat depth and *Longissimus* muscle depth.

Feed delivered to each feeder was measured using a feed delivery system (Big Dutchman, Holland, MI). Also, the feed remaining in the feeder was measured every time pig weights were collected to calculate feed intake and feed efficiency. Pigs that experienced health problems or injuries were weighed and removed from study and these weights were used in the calculation of growth rate and feed efficiency.

Harvest and Carcass Measurements. All pigs that completed the growth study were sent for harvest to a commercial plant on the day after final weights were collected. Hot carcass weight was collected on the slaughter line.

Longissiumus Muscle Quality and Belly Characteristics Measurements. For 3 replicates (i.e., replicate 1, 5, and 11), 10 pigs were randomly selected from each pen for detailed *Longissiumus* muscle quality and belly characteristics measurements. At 24h post mortem, whole boneless loins (IMPS Item No. 412B) were collected from each carcass. All additional loin measurements were taken on the cut surface of the *Longissimus* muscle. Ultimate pH was measured using a Hanna Instruments HI98160 pH meter. Objective color measurements were taken using a CR-410 Minolta Chromameter with settings of illuminant D65 and 0° viewing angle (Minolta Camera Company, Tokyo, Japan). Subjective scores were also collected for color (1 = extremely pale to 6 = extremely dark; NPPC 1999), firmness (1 = extremely soft to 5 = extremely firm; NPPC 1991), and marbling (1 = 1% intramuscular fat to 10 = 10% intramuscular fat; NPPC 1999). Drip loss was measured using a 2.5 cm diameter core sample (taken from a 1.9 cm thick chop) which was weighed before and after being held in a chiller (1.1°C) for 5 days.

The belly was removed and belly weight, length (measured from cranial to caudal end), width (measured from dorsal to ventral edge), thickness, subjective firmness score, and flop distance were measured. Belly thickness was measured by laying the belly flat on a table and measuring thickness at 3 locations in the center of the belly (25%, 50%, and 75% from cranial end). Belly flop distance was measured by draping the belly over a stainless-steel rod with the lean side up and measuring the distance between the skin surfaces.

Fatty acid composition of carcass fat was measured using a 3.2 cm diameter core fat sample that was taken from the clear plate (at the dorsal posterior edge) on the right side of every carcass. The core was cut in half vertically and near-infrared spectroscopy (NIR; Model Bruker MPA; Bruker Optics, Billerica, MA) was performed on the exposed surface of the split core, to measure iodine value.

Statistical Analysis. All data were tested for normality using PROC UNIVARIATE procedure of SAS (SAS Inst. Inc., Cary, NC). Morbidity and mortality were not normally distributed and were analyzed using the PROC FREQ procedure of SAS. Data meeting the criteria for normality were analyzed using the PROC MIXED procedure of SAS. Data were analyzed as a randomized complete block design with the model accounting for the fixed effects of treatment, the three-way interaction, and the random effects of block and replicate. Pen was used as the experimental unit for the growth and iodine measurements. Individual pig was used as the experimental unit for the *Longissiumus* muscle quality and belly characteristics measurements. Least-squares means were compared using the PDIFF option of SAS.

RESULTS AND DISCUSSION

INGREDIENT AND DIET COMPOSITION

The analyzed composition of the major ingredients used to formulate the diets used in the study [i.e., distillers dried grains with solubles (DDGS), corn, soybean meal (SBM), soy hulls, and conjugated linoleic acid (CLA)] are presented in Table 4. The origin of the CLA product (Lutalin CLA) used in this study was from BASF and the composition of the CLA was analyzed by this company, at Lampertheim, Germany using Gas Chromatography (GC) and High-Performance Liquid Chromatography (HPLC). The CLA analysis reported that the CLA product contained 60.60% CLA isomers, which was 4.6 percentage units more than expected (56% CLA isomers). The specific isomers in this product were *cis*-9, *trans*-11 and *trans*-10, *cis*-12 isomers; however the levels of these isomers were not reported in the analysis.

Diet formulation and calculated and analyzed nutrient levels for growing-finishing phases 3 to 5 are presented in Tables 5 to 7, respectively. Diets were formulated to be isocaloric and to the same standard ileal digestible lysine level. In growing-finishing phase 5, as CLA level increased, the level of corn decreased to maintain the same energy level across diets. As expected, analyzed values for nutrients were very similar to calculated values. The analyzed CLA product inclusion levels were on average within 76 to 77% (i.e., 0.38 and 0.77%) of the expected levels, for 0.5 and 1.0% CLA, respectively (Tables 5 to 7). However, this lower level of CLA could have resulted from oxidation during pelleting or storage of the diet. According to Roach et al. (2002), it is essential to protect CLA from oxidation before the sample is used and to avoid mechanical grinders that may cause thermal lipolysis.

GENERAL

Two statistical analyses were carried out on the data. Firstly, Treatments 4 to 15 were analyzed as a 3 × 2 × 2 factorial arrangement of Dietary Program × CLA Inclusion Level × CLA Feeding Duration treatments. There was only one statically significant treatment interaction which was a Dietary Program by CLA Inclusion Level interaction for ultrasound 10th rib backfat depth ($P < 0.05$). However, differences between treatment interaction means for 10th rib backfat were small and of little or no biological or practical significance (data not reported).

Subsequently, the data were analyzed as a 15 treatment study with contrast statement being used to test for differences between treatment levels within main effects. The main effect of DDGS inclusion level were evaluated by comparing those treatments that had diets with 0% DDGS inclusion (i.e., Treatments 1, 4, 7, 10, and 13), with those that had either 30% DDGS inclusion (i.e., Treatments 2, 5, 8, 11, and 14), or DDGS Withdrawal (i.e., Treatments 3, 6, 9, 12, and 15). Similarly, the main effect of CLA inclusion level was evaluated by comparing those treatments that had diets with 0% (i.e., Treatments 1, 2, and 3), with those that had either 0.5% (i.e., Treatments 4, 5, 6, 7, 8, and 9), or 1.0% (i.e., Treatments 10, 11, 12, 13, 14, and 15) CLA inclusion. In addition, the main effect of CLA feeding duration was evaluated by comparing those treatments that fed diets without CLA which was equivalent to feeding duration of 0 days; (i.e., Treatments 1, 2, and 3), with those that fed CLA for either 14 days (i.e., Treatments 4, 5, 6, 10, 11, and 12), or 28 days (i.e., Treatments 7, 8, 9, 13, 14, and 15). The *P*-value of contrast treatments, described above, are presented in Table 12. The results of these analyses will be presented and discussed in the remainder of this section of the thesis.

GROWTH PERFORMANCE

Effect of dietary program. Least-squares means for the effect of dietary program on growth performance are summarized in Table 8. There was no effect ($P > 0.05$) of including DDGS in the diet on ADFI, however, feeding diets with 30% DDGS reduced ADG and G:F by approximately 4% relative to the control (0% DDGS). These results are in agreement with the study of Whitney et al. (2006) that reported that pigs fed 30% DDGS had reduced ADG and G:F, (by approximately 6%) but similar ADFI compared to the control (0% DDGS). However, other studies have shown no effect of feeding diets with 30% DDGS on growth performance (Xu et al., 2010a). It is not clear why ADG and G:F were reduced by feeding diets with 30% DDGS in the present study, however, given that ADFI was not affected, the reduced growth could have resulted from lower nutrient digestibility, a deficiency of a limiting nutrient, or overestimation of the energy value of DDGS. The variability in DDGS quality (color, particle size, fat stability, etc.) from different sources, as shown in the study by Xu et al. (2010a), could also contribute to differences in performance of pigs fed diets with DDGS.

Withdrawing DDGS from the diet at the end of the finishing phase had no effect ($P > 0.05$) on ADFI, however, ADG and G:F decreased by on average 2% when compared to the control (0% DDGS). Compared to the 30% DDGS inclusion treatment, withdrawing DDGS had no effect ($P > 0.05$) on ADFI, but ADG increased by on average 2% and G:F increased by on average 3%. These results are not in agreement with the study of Xu et al. (2010b) which evaluated 30% DDGS inclusion in the diet and 4 different times of DDGS withdrawal (i.e., 0, 3, 6, and 9 weeks prior to harvest) and showed no effect of DDGS withdrawal on growth performance. Nevertheless, there is little research that has evaluated withdrawing DDGS before harvest, thus, further research is necessary to clarify any effect on growth performance.

Effect of CLA inclusion level. Least-squares means for the effects of CLA inclusion level on growth performance are presented in Table 8. There was no effect ($P > 0.05$) of including CLA at either 0.5 or 1.0%, on growth performance. The results of the present study are in agreement with Weber et al. (2006) and Stanimirovic et al. (2012). Stanimirovic et al. (2012) evaluated the effect of including 0.5% CLA in the diet and Weber et al. (2006) evaluated a CLA inclusion level of 1%, and both studies showed no effect on growth performance. As demonstrated in the current study and in 12 of the 17 studies evaluated in the literature review (Table 1), CLA inclusion in the diet at the levels evaluated appears to have little impact on growth performance.

Effect of CLA feeding duration. Least-squares means for the effects of CLA feeding duration on growth performance are presented in Table 8. There was no effect ($P > 0.05$) of including CLA in the diet for either 14 or 28 days, on growth performance. Only 2 studies discussed in the literature review (Table 1) have evaluated the effect of CLA feeding duration (Dunshea et al., 2002a; b). Both of these studies evaluated 2 CLA inclusion levels (i.e., 0 and 0.4%) with 2 feeding durations (i.e., 42 and 49 days) and showed that feeding duration had no effect on growth performance. The feeding durations used in the current study were shorter than those used by Dunshea et al. (2002a;b); however, there was still no effect on growth performance with the increased CLA feeding duration. Longer CLA feeding durations may or may not lead to an effect on growth performance, and need to be further evaluated.

CARCASS CHARACTERISTICS

Effect of dietary program. Least-squares means for the effects of dietary program on carcass characteristics which were measured in the live animal using ultrasound and on the carcass post mortem, are presented in Table 9. Compared to the control (0% DDGS), including 30% DDGS in the diet decreased ($P = 0.03$) 10th rib backfat depth (live animal ultrasound) by on average 0.1 cm (1.8 to 1.7 cm) and carcass yield by approximately 0.6 percentage units. A study conducted by Whitney et al. (2006) also reported a decrease, by on average 1.5%, in carcass yield when feeding 30% DDGS compared to the control. Including DDGS in corn-soybean meal based diets increases the fiber content of diets which generally leads to an increase in gut fill and intestinal mass. Increased intestinal mass would lead to a decrease in carcass yield, which could be a reason for the decrease in carcass yield observed in the present study. However, there are a number of studies that have reported that including DDGS in the diet had no effect on carcass yield (Cromwell et al., 2011; Xu et al., 2010b). Nevertheless, a decrease in carcass yield, as seen in the current study, would result in lost revenue for producers. The amount of backfat pigs have can also impact the premium producers receive; however, the published literature would suggest that DDGS inclusion has a variable effect on backfat depth. Whitney et al. (2006), White et al. (2009), and Pompeu et al. (2013) evaluated DDGS inclusion of 0 to 40 % and found that backfat depth was not affected; however, Cromwell et al. (2011) and Salyer et al. (2012) reported a decrease in backfat depth from feeding diets with 0 to 45 % DDGS, which is in agreement with the current study.

Withdrawing DDGS from the diet at the end of the finishing phase had no effect ($P > 0.05$) on 10th rib backfat depth; however, carcass yield was increased ($P = 0.002$) by approximately 0.5 percentage units, when compared to those fed 30% DDGS. Xu et al. (2010b) evaluated feeding with 30% DDGS inclusion in the diet and 4 different times of DDGS withdrawal (i.e., 0, 3, 6, and 9 weeks) and showed no effect of withdrawal time on carcass yield or backfat depth. This disagrees with the findings of the current study for carcass yield but is in agreement with the backfat depth results. The increase in carcass yield following withdrawal of DDGS from the diet in the present study could have resulted from decreased gut fill and intestinal mass. Overall, the current study suggested that feeding diets with an inclusion of 30% DDGS can decrease backfat depth and carcass yield; however, if DDGS are withdrawn at the end of the finishing phase, carcass yield can be improved.

Effect of CLA inclusion level. Least-squares means for the effects of CLA inclusion level on carcass characteristics are presented in Table 9. There was no effect ($P > 0.05$) of including CLA in the diet at 0.5% compared to 0% on carcass characteristics. However, including CLA in the diet at 1% decreased backfat depth ($P = 0.03$) by on average 0.09 cm (1.79 to 1.70 cm), but had no effect ($P > 0.05$) on carcass yield, compared to the control (0% CLA). All 8 studies that evaluated carcass yield that were reported in Table 2 of the literature review, support the current study findings that carcass yield was not affected by CLA inclusion. In addition, the decrease in backfat depth in pigs fed 1% CLA is in agreement with 5 of the 10 studies in the literature review that evaluated backfat depth (Table 2; Eggert et al., 2001; Wiegand et al., 2002a;b; Weber et al., 2006; Go et al., 2012). However, the other 5 studies that evaluated backfat depth, showed that CLA did not effect backfat depth (Thiel-Cooper et al., 2001; Wiegand et al., 2001; Barnes et al., 2012; Corino et al., 2003; Sun et al., 2004). Based on the findings of the current study, including 1% CLA can result in decreased backfat which would allow producers to market leaner, therefore more valuable, pigs.

Effect of CLA feeding duration Least-squares means for the effects of CLA feeding duration on carcass characteristics are presented in Table 9. There was no effect ($P > 0.05$) of including CLA in the diet for 14 days on carcass characteristics, compared to those not fed CLA. However, including CLA in the diet for 28 days decreased backfat depth ($P = 0.03$) by on average 0.10 cm (1.79 to 1.69 cm), and had no effect ($P > 0.05$) on carcass yield, compared to the control (0 days of CLA feeding). As stated previously, in the current study the CLA feeding period was carried out over a fixed-time period of either 14 or 28 days. Other studies evaluated in the literature review (Table 2) were carried out over a fixed weight range (on average 55.8 ± 22.8 kg). A number of studies have shown that increasing the range in weight over which CLA is fed, which would result in an increase in feeding duration, did not lead to a change in backfat depth or carcass yield (i.e., Thiel-Cooper et al., 2001; Eggert et al., 2001; Wiegand et al., 2001; Barnes et al., 2012; Wiegand et al., 2002a;b; Dunshea et al., 2002a;b; Corino et al., 2003; Sun et al., 2004a; Weber et al., 2006; Martin et al., 2008; Tous et al., 2013; Go et al., 2012). In addition, only two studies evaluated the effect of CLA feeding durations (i.e., 42 and 49 days) (Dunshea et al., 2002a; b) and these studies reported that CLA feeding duration had no effect on carcass yield. However, they also reported that backfat depth was significantly decreased when CLA was fed for 42 days but not 49 days. Overall, there has been limited research carried out into the effect of duration of feeding of CLA on carcass measures and also, there is some inconsistency in the results of studies.

LONGISSIUMUS MUSCLE QUALITY AND BELLY CHARACTERISTICS

Longissiumus muscle quality and belly characteristics evaluation was carried out on a subsample of 10 pigs from each pen from 3 replicates (i.e., replicates 1, 5, and 11). There was an unplanned difference ($P < 0.05$) in harvest live weight of 10.2 kg between the highest and lowest treatment (Table 10). Due to this large difference in harvest live weight between treatments, means (except harvest live weight) were corrected to a common harvest live weight of 129.8 kg using co-variance analysis and the results of this analysis will be discussed below.

Effect of dietary program. The effect of dietary program on *Longissiumus* muscle quality and belly characteristics are summarized in Table 10. Including 30% DDGS in the diet had no effect ($P > 0.05$) on the weight, subjective color score, drip loss, or Minolta L* of the *Longissiumus* muscle; however, *Longissiumus* muscle pH was 0.024 units higher ($P = 0.02$), and subjective marbling and firmness scores (i.e., 0.2 and 0.3 points lower, respectively) and Minolta a* and b* (i.e., 0.6 and 0.4 units, respectively) were lower ($P < 0.05$) for pigs fed diets with 30% compared to 0% DDGS. However, the differences between these 2 treatments were small and are unlikely to be practically important.

Belly measurements were also taken and, with the exception of the width and length of the belly, all differences between the 2 treatments (i.e., 0% DDGS and 30% DDGS) were statistically significant ($P < 0.05$). Including 30% DDGS in the diet decreased belly weight and depth ($P < 0.05$) by on average 0.2 kg and 0.3 cm, respectively. In addition, subjective firmness score was decreased by 1 point (based on a scale from 1 = soft to 5 = very firm), which indicates that belly firmness was decreased and flop distance, which was measured by draping the belly over a stationary stainless-steel rod with the lean side up and measuring the distance between the skin surfaces, decreased by on average 5.2 cm, when 30% DDGS was included in the diet. As the fat in bellies becomes more unsaturated and softer, the distance between the skin surfaces in the flop test decreases, as seen in the current study.

Withdrawing DDGS from the diet for 4 wk at the end of the finishing phase had no effect ($P > 0.05$) on *Longissiumus* muscle weight, color, marbling, drip loss, Minolta L*, or b* compared to the 30% DDGS treatment. However, *Longissiumus* muscle pH was 0.024 units lower ($P = 0.01$), firmness 0.2 points higher ($P = 0.01$), and Minolta a* was 0.3 units higher ($P = 0.01$) when DDGS was withdrawn from the diet, compared to pigs fed 30% DDGS. However, the differences between these 2 treatments were small and of limited practical significance. In addition, withdrawal of DDGS increased belly weight and depth ($P < 0.05$), by on average 0.3 kg and 0.2 cm, respectively, and flop distance and subjective firmness score ($P < 0.05$) by on average 2.2 cm and 0.5 points, respectively, compared to pigs fed 30% DDGS. The increase in flop distance and subjective firmness score indicates an improvement in belly firmness when withdrawing DDGS from the diet for the last 4 wk before harvest. These results are in agreement with the study of Xu et al. (2010b) which evaluated 30% DDGS inclusion in the diet and 4 different times of DDGS withdrawal (i.e., 0, 3, 6, and 9 weeks) and showed that removing DDGS during the final 3, 6, or 9 weeks before harvest can increase belly firmness.

In conclusion, the addition of 30% DDGS and the DDGS withdrawal treatment had little effect on *Longissiumus* muscle measurements; however, belly firmness, measured by the flop distance and subjective firmness score, was impacted.

Effect of CLA inclusion level. Least-squares means for the effects of CLA inclusion level on *Longissiumus* muscle quality and belly characteristics are summarized in Table 10. Including CLA in the diet at 0.5% decreased belly weight (*P* = 0.01) by on average 0.2 kg, compared to controls (0% CLA), but had no effect (*P* > 0.05) on any other *Longissiumus* muscle quality or belly characteristic. Including CLA at 1.0% in the diet increased belly length (*P* = 0.01) by 0.3 cm, compared to controls (0% CLA). Nevertheless, the decrease in belly weight and increase in belly length were relatively small and unlikely to be of practical importance in many situations. In addition, including CLA at 1.0% increased flop distance (*P* = 0.02) by 1.1 cm, and subjective firmness score (*P* = 0.004) by 0.2 points, indicating an improvement in belly firmness. This would be in agreement with the two studies (Eggert et al., 2001; Weber et al., 2006) that were summarized in the literature review (Table 2) that reported on the effect of CLA inclusion on belly firmness. Both studies evaluated 2 CLA inclusion levels (i.e., 0 and 1.0%) and reported that measures of belly firmness were increased on average by 18% when feeding CLA. The current study and the 2 studies discussed have demonstrated that CLA can increase belly firmness which could potentially provide a solution to the carcass fat and belly firmness problem that packers sometimes see when DDGS is included in the diet. However, improvements in measures of belly firmness in the current study were relatively small and may not be large enough to overcome the negative effects of including DDGS in the diet. Overall, the inclusion of CLA at either 0.5 or 1.0% had no effect on the *Longissiumus* muscle measurements and a relatively small effect on belly firmness measurements.

Effect of CLA feeding duration. Least-squares means for the effects of CLA feeding duration on *Longissiumus* muscle quality and belly characteristics are summarized in Table 10. Including CLA in the diet for 14 days had no effect (*P* > 0.05) on any of the *Longissiumus* muscle quality and belly characteristics that were measured, when compared to the control (0 days of feeding CLA). In addition, including CLA in the diet for 28 days had no effect ($P > 0.05$) on *Longissiumus* muscle measurements; however, belly measurements were affected. Including CLA in the diet for 28 days reduced belly weight and width ($P < 0.05$) by on average 0.3 kg and 0.6 cm, respectively, when compared to the control (0 days of feeding CLA). Furthermore, flop distance and subjective firmness score were increased ($P < 0.05$) by on average 2.0 cm and 0.4 points, respectively, when feeding CLA for 28 days and indicates that belly firmness was increased. Therefore, increasing the time for which CLA is fed can increase belly firmness; however, the increase may not be large enough to overcome the negative effects that are seen when large amounts of unsaturated dietary fat are included in the diet.

IODINE VALUE

Effect of dietary program. Least-squares means for the effects of dietary program on iodine value measured using near infrared spectroscopy (NIR) are presented in Table 11. The iodine value of fat was increased ($P < 0.05$) by 7.46 g/100 g (averaged across treatments), for pigs fed 30% DDGS compared to controls (0% DDGS; average iodine value of 68.88 g/100 g). However, withdrawing 30% DDGS from the diet at the end of the finishing phase for the last 4 weeks of growth reduced ($P < 0.05$) iodine value by on average 3.61 units, compared to pigs fed 30% DDGS (76.34 to 72.73 g/100 g, respectively). A number of studies (Whitney et al., 2006; Xu et al., 2010b; Benz et. al., 2010) have shown that feeding DDGS can increase iodine value and according to Xu et al. (2010b), withdrawing DDGS prior to harvest reduces iodine value by approximately 1 g/100g per week of withdrawal. In the current study, DDGS was withdrawn from the diet at 4 weeks prior to harvest and the reduction in iodine value was on average 3.61 units (76.34 to 72.73 g/100g) or 0.90 units per week of withdrawal, which is in agreement with Xu et al. (2010b). Based on the current study, a DDGS withdrawal program could allow producers to feed DDGS earlier in the growth period, which would reduce feed cost, and reduce the iodine value of fat depending on when DDGS was withdrawn from the diet.

Effect of CLA inclusion level. Least-squares means for the effects of CLA inclusion level on iodine value measured using near infrared spectroscopy (NIR) are presented in Table 11. Including CLA at either 0.5 or 1.0% reduced iodine value ($P < 0.05$) by on average 1.4 and 1.7 g/100 g, respectively, when compared to pigs fed 0% CLA. The current study is in agreement with all 4 studies that were summarized in the literature review (Table 3) that reported on the effect of CLA inclusion on iodine value (Eggert et al., 2001; Weber et al., 2006; Larsen et al., 2009; White et al., 2009; Pompeu et al., 2013). The average reduction in iodine value from the addition of CLA to the diets in these 4 studies was 5.37 units; however, the decrease in iodine value ranged from 1.17 (Pompeu et al., 2013) to 10.19 (White et al., 2009). Pompeu et al. (2013) and White et al. (2009) evaluated 2 different CLA inclusion levels (i.e., 0.6 and 1.0%), and both reported a decrease in iodine value of 1.2 and 2.0 g/100 g, respectively. Both studies are in agreement with the results of the current study; however, not all studies summarized in the literature review (Table 2) showed small decreases in iodine value. Eggert et al. (2001) evaluated the inclusion of 1.0% CLA in the diet and reported a decrease of 8.68 g/100 g in iodine value, compared to pigs fed 0% CLA. The inconsistency in response in iodine value when feeding CLA in the studies summarized in the literature review and in the current study does not appear to depend on CLA inclusion level, which ranged between 0.6 to 1.25% across studies or on fat depots sampled (belly, backfat, and intramuscular). A number of studies have shown fat iodine value varies between fat depots within the carcass (Xu et al., 2010b; Benz et al., 2011a), and the relative differences between fat depots is not consistent (Wiegand et al., 2011). This inconsistency in response in iodine value to feeding CLA needs to be further evaluated.

Effect of CLA feeding duration Least-squares means for the effects of CLA feeding duration on iodine value measured using near infrared spectroscopy (NIR) are presented in Table 11. Including CLA in the diet for either 14 or 28 days reduced iodine value ($P < 0.05$) by 1.1 and 2.0 g/100 g, respectively, when compared to the control (0 days of feeding CLA). Thus, increasing the duration of feeding of CLA by 2 weeks decreased iodine value by approximately 1.0 g/100 g. According to Pork Composition and Quality Assessment Procedures (National Pork Producers Council, 2000), acceptable pork fat quality has an iodine value of less than 70 g/100 g and despite the decrease in iodine value when including CLA in the diet for either 14 or 28 days, the iodine value was on average 72.4 g/100 g. Nevertheless, it is not clear if a further reduction in iodine value would be achieved if CLA duration was increased beyond 4 weeks.

Use of CLA in the swine industry. The practice of feeding high levels of DDGS can increase the incidence of soft fat problems in pigs. In the current study, iodine value increased ($P < 0.05$) by on average 7.46 g/100 g when 30% DDGS was included in the diet. An increase in iodine value is an indication of soft and unsaturated fat. In order to combat the problem of soft fat, CLA has been included in diets to reduce the iodine value of fat. However, the current study reported that including CLA in the diet at 0.5 or 1.0% for either 14 or 28 days, only reduced iodine value ($P < 0.05$) by on average 1.6 g/100 g. This relatively small reduction in iodine value is unlikely to be of practical importance in many situations.

CONCLUSIONS

The objective of this study was to determine the effects of level and duration of feeding CLA in different dietary programs on the growth performance of growing-finishing pigs and on *Longissiumus* muscle quality, belly characteristics, and fat quality measured post mortem.

The results of this study suggest that including 30% DDGS in the diet was associated with reductions in growth performance (i.e., ADG and G:F), carcass characteristics (i.e., carcass yield and 10th rib backfat depth), and belly firmness (i.e., belly flop distance and subjective firmness score), and increases in iodine value. Some of these negative effects were reduced when DDGS was withdrawn from the diet for 4 weeks prior to harvest. Withdrawing DDGS increased growth performance, carcass yield, belly firmness (i.e., belly flop distance and subjective firmness score), and decreased iodine value. Based on the current study, a DDGS withdrawal program could allow producers to feed DDGS earlier in the growth period, which would reduce feed cost, and improve carcass and fat quality depending on when DDGS was withdrawn from the diet.

In addition to the different dietary program, the supplementation of diets with CLA was also evaluated. Conjugated linoleic acid is relatively expensive, therefore, the current study evaluated the effects of both CLA level and feeding duration to identify the minimum level of feeding and feeding duration to obtain improvements. The results of this study, suggest that CLA level and feeding duration had no effect on growth performance and relatively small effect on carcass, *Longissiumus* muscle quality, belly characteristics, and iodine value. With such a small effect, use of CLA may not be economically justified.

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TABLES

Table 4. Analyzed composition of distillers dried grains with solubles (DDGS), corn, soybean meal (SBM), soy hulls, and conjugated linoleic acid (CLA).

Item	DDGS[1]	Corn	SBM[2]	Soy Hulls	CLA[3]
Proximate analysis, % as-fed basis[4]					
DM	90.52	85.62	88.77	89.36	-
CP	30.37	8.43	47.75	10.65	-
Crude Fat	6.76	3.28	0.92	1.32	-
Crude Fiber	6.85	1.79	2.89	36.50	-
ADF	15.03	2.83	6.03	45.80	-
NDF	27.35	6.80	9.00	10.65	-
Phosphorus	0.86	0.28	0.65	0.12	-
Calcium	0.04	0.00	0.36	0.62	-
Sodium	0.13	-	-	0.01	-
Ash	4.19	0.95	5.72	4.50	-
Chloride	0.18	-	-	-	-
Amino acid analysis (total), % as-fed basis[5]					
Lysine	0.85	-	2.84	-	-
Threonine	1.10	-	1.83	-	-
Methionine	0.63	-	0.65	-	-
Cysteine	0.54	-	0.67	-	-
Methionine + Cysteine	1.17	-	1.32	-	-
Arginine	1.36	-	3.33	-	-
Isoleucine	1.09	-	2.15	-	-
Leucine	3.26	-	3.48	-	-
Valine	1.39	-	2.19	-	-
Histidine	0.75	-	1.19	-	-
Alanine	2.11	-	2.01	-	-
Glutamic acid	4.95	-	8.28	-	-
Glycine	1.18	-	1.96	-	-
Aspartic acid	1.89	-	5.29	-	-
Phenylalanine	1.41	-	2.35	-	-
Proline	2.23	-	2.49	-	-
Serine	1.43	-	2.37	-	-
Tyrosine	0.88	-	1.26	-	-
Tryptophan	0.23	-	0.64	-	-
ME, kcal/kg	3154.38	3320.64	3367.93	1883.71	-
Conjugated linoleic acid analysis (total), % as-fed basis[6]					
CLA isomers	-	-	-	-	60.60

[1] DDGS origin: Center Ethanol, Sauget, IL.

[2] SBM origin: ADM Quincy, IL.

[3] CLA origin: BASF, Lampertheim, Germany.

[4] Proximate analysis was performed at Midwest Laboratories, Omaha, NE using wet chemistry.

[5] Amino acid analysis was performed at Ajinomoto Heartland, Inc. laboratory using High-Performance Liquid Chromatography (HPLC).

[6] Conjugated linoleic acid analysis was performed at BASF, Lampertheim, Germany using Gas Chromatography (GC) and High-Performance Liquid Chromatography (HPLC)

Table 5. Diet formulation and calculated and analyzed composition (Grow-Finish 3).[1]

	DDGS inclusion level, %			
	0		30	
Ingredient, %				
Corn	78.11		56.96	
Soybean meal	17.13		9.96	
DDGS	0.00		30.00	
Limestone	0.93		1.23	
Yellow grease	0.00		0.90	
Salt	0.46		0.40	
Mono-cal 21%	0.47		0.03	
Alimet	0.09		0.00	
Threonine (98%)	0.08		0.01	
Lysine, dry (98%)	0.30		0.39	
Trace minerals	0.09		0.09	
Vitamins	0.03		0.03	
Optiphos PF 1000	0.02		0.00	
Total	100.00		100.00	
Composition	Calculated	Analyzed[2,3]	Calculated	Analyzed[2,3]
ME, kcal/kg	3244.44	-	3244.44	-
CP, %	14.24	17.10	17.94	17.90
Crude fat, %	2.63	3.37	4.67	3.31
Crude fiber, %	2.44	2.29	2.97	1.33
ADF, %	3.69	5.10	5.73	6.00
NDF, %	8.13	10.20	12.28	10.30
Calcium, %	0.55	0.64	0.55	0.66
Phosphorus, %	0.42	0.49	0.49	0.48
Phosphorus, available, %	0.24	-	0.24	-
Calcium:Phosphorus ratio	1.30	1.31	1.12	1.38
Sodium, %	0.20	0.19	0.20	0.20
Salt, %	0.53	0.58	0.54	0.69
Total Lysine, %	0.91	0.99	0.98	0.97
Digestible Lysine, %	0.81	-	0.81	-
Total Cysteine, %	0.33	0.30	0.32	0.32
Total Isoleucine, %	0.55	0.63	0.66	0.67
Total Leucine, %	1.22	1.64	1.74	1.75
Total Methionine, %	0.30	0.30	0.33	0.33
Total Methionine + Cysteine, %	0.53	0.60	0.64	0.64
Total Threonine, %	0.60	0.67	0.66	0.68
Total Tryptophan, %	0.16	0.17	0.16	0.17
Total Valine, %	0.62	0.75	0.81	0.81
Met + Cys:Lysine ratio (Dig.)	0.57	-	0.64	-
Tryptophan:Lysine ratio (Dig.)	0.17	-	0.16	-
Threonine:Lysine ratio (Dig.)	0.62	-	0.62	-
Isoleucine:Lysine ratio (Dig.)	0.58	-	0.66	-
Valine:Lysine ratio (Dig.)	0.65	-	0.79	-
Digestible Lysine:ME ratio	2.51	-	2.51	-

[1] Diets manufactured at the Maschhoff's Carlyle Feed Mill.

[2] Amino acid analysis was performed at Ajinomoto Heartland, Inc. laboratory using High-Performance Liquid Chromatography (HPLC).

[3] Proximate analysis was performed at Midwest Laboratories, Omaha, NE using wet chemistry.

Table 6. Diet formulation and calculated and analyzed composition (Grow-Finish 4).[1]

	DDGS inclusion level, %	
	0	30
Ingredient, %		
Corn	80.17	58.57
Soybean meal	14.89	8.78
Soy hulls	3.09	0.00
DDGS	0.00	30.00
Limestone	0.83	1.07
Yellow grease	0.00	0.80
Salt	0.46	0.40
Mono-cal 21%	0.15	0.00
Alimet	0.03	0.00
Threonine (98%)	0.04	0.00
Lysine, dry (98%)	0.21	0.27
Trace minerals	0.08	0.08
Vitamins	0.03	0.03
Optiphos PF 1000	0.03	0.00
Total	100	100

Composition	Calculated	Analyzed[2,3]	Calculated	Analyzed[2,3]
ME, kcal/kg	3244.44	-	3244.44	-
CP, %	13.29	14.60	17.38	18.20
Crude fat, %	2.69	1.76	4.61	4.21
Crude fiber, %	2.69	1.36	2.97	1.40
ADF, %	3.99	4.10	5.72	6.30
NDF, %	8.60	8.70	12.32	13.00
Calcium, %	0.45	0.50	0.48	0.52
Phosphorus, %	0.35	0.40	0.48	0.51
Phosphorus, available, %	0.20	-	0.24	-
Calcium:Phosphorus ratio	1.30	1.25	1.00	1.02
Sodium, %	0.20	0.18	0.20	0.22
Salt, %	0.53	0.58	0.54	0.64
Total Lysine, %	0.79	0.84	0.85	0.87
Digestible Lysine, %	0.69	-	0.69	-
Total Cysteine, %	0.22	0.27	0.31	0.34
Total Isoleucine, %	0.51	0.60	0.64	0.70
Total Leucine, %	1.17	1.42	1.72	1.94
Total Methionine, %	0.24	0.26	0.33	0.36
Total Methionine + Cysteine, %	0.46	0.53	0.63	0.70
Total Threonine, %	0.52	0.59	0.63	0.69
Total Tryptophan, %	0.14	0.16	0.16	0.17
Total Valine, %	0.59	0.70	0.79	0.87
Met + Cys:Lysine ratio (Dig.)	0.57	-	0.74	-
Tryptophan:Lysine ratio (Dig.)	0.18	-	0.18	-
Threonine:Lysine ratio (Dig.)	0.63	-	0.69	-
Isoleucine:Lysine ratio (Dig.)	0.64	-	0.75	-
Valine:Lysine ratio (Dig.)	0.72	-	0.91	-
Digestible Lysine:ME ratio	2.13	-	2.13	-

[1] Diets manufactured at the Maschhoff's Carlyle Feed Mill.

[2] Amino acid analysis was performed at Ajinomoto Heartland, Inc. laboratory using High-Performance Liquid Chromatography (HPLC).

[3] Proximate analysis was performed at Midwest Laboratories, Omaha, NE using wet chemistry.

Table 7. Diet formulation and calculated and analyzed composition (Grow-Finish 5).[1]

	Treatment											
DDGS inclusion level, %	0		30		0		30		0		30	
CLA inclusion level, %	0		0		0.5		0.5		1		1	
Ingredient, %												
Corn	82.65		61.04		82.10		60.50		81.55		59.96	
Soybean meal	12.52		6.40		12.56		6.45		12.61		6.49	
Soy hulls	3.04		0.00		3.04		0.00		3.04		0.00	
DDGS	0.00		30.00		0.00		30.00		0.00		30.00	
Lutalin CLA	0.00		0.00		0.50		0.50		1.00		1.00	
Limestone	0.83		1.07		0.83		1.06		0.82		1.06	
Salt	0.41		0.35		0.41		0.35		0.41		0.35	
Mono-cal 21%	0.20		0.00		0.20		0.00		0.21		0.00	
Alimet	0.01		0.00		0.01		0.00		0.01		0.00	
Yellow grease	0.00		0.79		0.00		0.78		0.00		0.78	
Threonine (98%)	0.04		0.00		0.04		0.00		0.04		0.00	
Lysine, dry (98%)	0.20		0.26		0.20		0.26		0.19		0.26	
Trace minerals	0.08		0.08		0.08		0.08		0.08		0.08	
Vitamins	0.03		0.03		0.03		0.03		0.03		0.03	
Optiphos PF 1000	0.02		0.00		0.02		0.00		0.02		0.00	
Total	100		100		100		100		100		100	
Composition	Calculated	Analyzed[2,3]	Calculated	Analyzed[2,3]	Calculated	Analyzed[2,3,4]	Calculated	Analyzed[2,3,4]	Calculated	Analyzed[2,3,4]	Calculated	Analyzed[2,3,4]
ME, kcal/kg	3244.44	-	3244.44	-	3244.44	-	3244.44	-	3244.44	-	3244.44	-
CP, %	12.32	12.20	16.41	18.10	12.30	14.10	16.39	17.30	12.28	13.30	16.37	16.90
Crude fat, %	2.75	2.72	4.66	5.06	2.73	3.02	4.64	5.47	2.71	3.74	4.61	5.02
Crude fiber, %	2.65	2.28	2.94	2.20	2.65	2.38	2.94	1.92	2.64	2.29	2.93	2.52
ADF, %	3.91	4.20	5.67	6.40	3.90	4.10	5.66	6.10	3.89	3.20	5.65	5.40
NDF, %	8.59	7.60	12.34	10.80	8.56	8.40	12.30	9.50	8.52	8.20	12.26	11.00
Calcium, %	0.45	0.47	0.47	0.48	0.45	0.47	0.47	0.53	0.45	0.53	0.47	0.48
Phosphorus, %	0.35	0.43	0.47	0.51	0.35	0.37	0.47	0.49	0.35	0.44	0.47	0.45
Phosphorus, available, %	0.18	-	0.23	-	0.18	-	0.23	-	0.18	-	0.23	-
Calcium:Phosphorus ratio	1.30	1.09	1.00	0.94	1.30	1.27	1.00	1.08	1.30	1.20	1.00	1.07
Sodium, %	0.18	0.22	0.18	0.20	0.18	0.16	0.18	0.19	0.18	0.23	0.18	0.17
Salt, %	0.48	0.63	0.49	0.58	0.48	0.56	0.49	0.56	0.48	0.69	0.49	0.58
Total Lysine, %	0.71	0.71	0.78	0.83	0.71	0.79	0.78	0.78	0.71	0.80	0.78	0.82
Digestible Lysine, %	0.62	-	0.62	-	0.62	-	0.62	-	0.62	-	0.62	-
Total Cysteine, %	0.21	0.25	0.30	0.32	0.21	0.25	0.30	0.32	0.21	0.26	0.30	0.32
Total Isoleucine, %	0.47	0.44	0.60	0.61	0.47	0.56	0.60	0.65	0.46	0.54	0.59	0.56
Total Leucine, %	1.11	1.19	1.66	1.83	1.11	1.31	1.66	1.79	1.10	1.32	1.65	1.72
Total Methionine, %	0.21	0.24	0.32	0.35	0.22	0.25	0.32	0.36	0.22	0.25	0.32	0.34
Total Methionine + Cysteine, %	0.42	0.48	0.61	0.67	0.42	0.51	0.61	0.65	0.42	0.51	0.61	0.66
Total Threonine, %	0.48	0.51	0.59	0.66	0.48	0.57	0.59	0.63	0.48	0.56	0.59	0.64
Total Tryptophan, %	0.13	0.13	0.14	0.17	0.13	0.15	0.14	0.16	0.13	0.15	0.14	0.16
Total Valine, %	0.55	0.57	0.75	0.81	0.55	0.64	0.75	0.81	0.55	0.63	0.74	0.77
Met + Cys:Lysine ratio (Dig.)	0.57	-	0.79	-	0.57	-	0.79	-	0.57	-	0.79	-
Tryptophan:Lysine ratio (Dig.)	0.18	-	0.18	-	0.18	-	0.18	-	0.18	-	0.18	-
Threonine:Lysine ratio (Dig.)	0.64	-	0.72	-	0.64	-	0.72	-	0.64	-	0.72	-
Isoleucine:Lysine ratio (Dig.)	0.64	-	0.77	-	0.64	-	0.77	-	0.64	-	0.77	-
Valine:Lysine ratio (Dig.)	0.74	-	0.95	-	0.74	-	0.95	-	0.73	-	0.94	-
Digestible Lysine:ME ratio	1.92	-	1.92	-	1.92	-	1.92	-	1.92	-	1.92	-
CLA Product, %	-	-	-	-	0.50	0.36	0.50	0.39	1.00	0.73	1.00	0.80

[1] Diets manufactured at the Maschhoff's Carlyle Feed Mill.

[2] Amino acid analysis was performed at Ajinomoto Heartland, Inc. laboratory using High-Performance Liquid Chromatography (HPLC).

[3] Proximate analysis was performed at Midwest Laboratories, Omaha, NE using wet chemistry.

[4] Conjugated linoleic acid analysis (Lutalin CLA: 56%) was performed at BASF, Lampertheim, Germany using Gas Chromatography (GC) and High-Performance Liquid Chromatography (HPLC)

Table 8. Effect of dietary treatment on growth performance.

	Dietary treatment																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
Dietary program[1]	0	30	30WD	0	30	30WD	0	30	30WD	0	30	30WD	0	30	30WD		
CLA inclusion level, %	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	1	1		
Item CLA feeding duration, d	0	0	0	14	14	14	28	28	28	14	14	14	28	28	28	SEM	*P*-value
Number of pens[2]	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	-	-
Body weight, kg																	
Start of study	60.7	61.1	60.9	60.9	60.7	60.8	61.0	60.4	60.8	60.9	61.0	60.8	61.0	61.1	60.9	1.31	0.70
End of study	132.9^{a}	130.1^{cd}	130.9^{abc}	132.3^{ab}	129.3^{cd}	130.5^{bcd}	132.5^{ab}	128.5^{d}	129.8^{cd}	131.2^{abc}	130.0^{cd}	130.0^{cd}	132.6^{a}	128.8^{d}	131.2^{abc}	1.94	<0.001
Average daily gain, kg[3,4,5]	1.01^{ab}	0.96^{ef}	0.97^{def}	1.00^{abcd}	0.96^{ef}	0.98^{cdef}	1.01^{a}	0.95^{ef}	0.97^{def}	0.98^{bcde}	0.97^{def}	0.98^{cdef}	1.00^{abc}	0.95^{f}	0.98^{cde}	0.028	<0.001
Average daily feed intake, kg	2.77	2.77	2.73	2.78	2.79	2.73	2.76	2.74	2.72	2.71	2.76	2.76	2.76	2.69	2.76	0.074	0.59
Gain:feed, kg:kg[3,4,5]	0.366^{ab}	0.346^{gh}	0.357^{cdef}	0.359^{bcde}	0.344^{h}	0.357^{cdef}	0.366^{a}	0.346^{gh}	0.357^{def}	0.362^{abcd}	0.351^{fgh}	0.355^{efg}	0.364^{abc}	0.351^{fgh}	0.355^{def}	0.003	<0.001
Morbidity and mortality, %	2.78	2.73	1.84	4.09	2.29	0.91	2.74	3.20	1.37	4.55	3.64	3.69	3.20	1.37	2.73	-	0.56

[a,b,c,d,e,f,g,h,i,j,k] Means within a row or interaction subclass with different superscripts differ ($P \leq 0.05$).

[1] 0 = 0% DDGS; 30 = 30% DDGS dietary inclusion; 30WD = DDGS withdrawal (30% DDGS from week 0 to approximately 104 kg and 0% DDGS from approximately 104 kg to end of study).

[2] Analysis was carried out on all replicates of the study.

[3] Dietary program 0 vs. 30% DDGS $P \leq 0.05$

[4] Dietary program 0 vs. 30WD $P \leq 0.05$

[5] Dietary program 30% DDGS vs. 30WD $P \leq 0.05$

Table 9. Effect of dietary treatment on carcass characteristics.

	Dietary treatment																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
Dietary program[1]	0	30	30WD	0	30	30WD	0	30	30WD	0	30	30WD	0	30	30WD		
CLA inclusion level, %	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	1	1		
Item CLA feeding duration, d	0	0	0	14	14	14	28	28	28	14	14	14	28	28	28	SEM	*P*-value
Number of pens	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	-	-
Ultrasound measurements[2]																	
Backfat depth, cm																	
Week 6	1.5^{abc}	1.45^{abcd}	1.37^{cde}	1.55^{a}	1.40^{bcde}	1.37^{cde}	1.52^{ab}	1.35^{de}	1.37^{cde}	1.52^{ab}	1.42^{abcde}	1.32^{e}	1.52^{ab}	1.37^{cde}	1.37^{cde}	0.025	0.01
End of study (week 10)[4,6,7]	1.83	1.80	1.73	1.83	1.68	1.75	1.78	1.55	1.75	1.73	1.70	1.68	1.65	1.68	1.75	0.031	0.08
Carcass characteristics[3]																	
Harvest live weight, kg	132.9^{a}	130^{def}	130.2^{cdef}	132.5^{abc}	130^{def}	130.5^{bcdef}	132.5^{abc}	128.6^{ef}	129.6^{def}	130.7^{abcde}	129.8^{def}	129.6^{def}	132.7^{ab}	128.3^{f}	131.1^{abcd}	2.13	<0.001
Hot carcass weight, kg	98.3^{a}	95.7^{cdef}	95.8^{cdef}	97.8^{ab}	94.7^{def}	96.1^{cd}	97.7^{ab}	94.2^{f}	96.0^{cde}	96.6^{bc}	95.0^{cdef}	96.0^{cde}	98.0^{ab}	94.4^{ef}	96.4^{bc}	1.56	<0.001
Carcass yield, %[4,5]	73.9^{a}	73.7^{abcde}	73.5^{abcde}	73.8^{abcd}	73.3^{bcde}	73.6^{abcde}	73.8^{abcd}	73.2^{de}	74.1^{a}	73.9^{ab}	73.2^{cde}	74.1^{a}	73.9^{abc}	73.1^{e}	73.5^{abcde}	0.26	0.05

[a,b,c,d,e,f,g,h,i,j,k] Means within a row or interaction subclass with different superscripts differ ($P \leq 0.05$).

[1] 0 = 0% DDGS; 30 = 30% DDGS dietary inclusion; 30WD = DDGS withdrawal (30% DDGS from week 0 to approximately 104 kg and 0% DDGS from approximately 104 kg to end of study).

[2] Ultrasound measurements were taken at the 10th rib on a subsample of 6 replicates.

[3] All carcass data from 1 replicate was excluded from the analysis due to issues during the transportation of pigs to the plant.

[4] Dietary program 0 vs. 30% DDGS $P \leq 0.05$

[5] Dietary program 0 vs. 30WD $P \leq 0.05$

[6] CLA inclusion level 0% vs. 1% $P \leq 0.05$

[7] CLA feeding duration 0 vs. 28 days $P \leq 0.05$

Table 10. Effect of dietary treatment on *Longissiumus* muscle quality and belly characteristics.[1,2]

		Dietary treatment																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
	Dietary program[3]	0	30	30WD	0	30	30WD	0	30	30WD	0	30	30WD	0	30	30WD		
	CLA inclusion level, %	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	1	1		
Item	CLA feeding duration, d	0	0	0	14	14	14	28	28	28	14	14	14	28	28	28	SEM	*P*-value
Number of pens		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	-	-
Number of pigs		30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	-	-
Slaughter line measurements																		
Harvest live weight, kg		135.4^{a}	130.0^{abcd}	126.1^{d}	132.4^{abc}	127.6^{cd}	133.7^{ab}	133.8^{ab}	127.6^{cd}	130.0^{abcd}	129.0^{bcd}	127.6^{cd}	125.2^{d}	129.2^{bcd}	125.8^{d}	133.6^{abc}	5.34	0.01
Hot carcass weight, kg		96.9^{abc}	96.0^{cde}	97.3^{ab}	97.3^{ab}	96.9^{abc}	96.1^{cde}	97.2^{ab}	95.8^{de}	97.2^{ab}	97.2^{ab}	95.7^{e}	97.9^{a}	96.7^{bcd}	96.8^{bc}	96.3^{bcde}	0.88	<0.001
Carcass yield, %		74.7^{abcd}	74.0^{de}	75.0^{ab}	75.0^{ab}	74.7^{abcd}	74.0^{de}	74.8^{abc}	73.7^{e}	74.9^{abc}	75.2^{ab}	73.7^{e}	75.4^{a}	74.5^{bcd}	74.6^{bcd}	74.2^{cde}	0.31	<0.001
Longissiumus muscle measurements[4]																		
Weight, kg		3.90	3.80	3.90	3.90	3.80	3.80	3.80	3.90	3.90	3.90	3.80	3.90	4.00	3.80	3.90	0.159	0.61
Ultimate pH[13,15]		5.51	5.55	5.48	5.47	5.53	5.52	5.49	5.52	5.50	5.54	5.53	5.52	5.51	5.51	5.50	0.022	0.09
Subjective color[5]		3.35	3.47	3.41	3.35	3.34	3.42	3.34	3.35	3.35	3.48	3.31	3.33	3.42	3.31	3.46	0.194	0.66
Subjective marbling[6,13,20]		2.65	2.52	2.38	2.45	2.46	2.40	2.71	2.72	2.60	2.66	2.25	2.39	2.68	2.40	2.67	0.227	0.17
Subjective firmness[7,13,15]		2.94	2.73	2.81	2.92	2.73	2.87	3.06	2.63	2.88	2.84	2.59	2.83	3.15	2.68	2.99	0.150	0.07
Drip loss, %		4.96	5.77	5.30	5.18	5.40	5.37	5.80	4.79	5.68	5.20	5.71	5.61	5.48	4.97	5.85	0.412	0.68
Objective color scores[8]																		
Minolta L*		51.19	50.86	51.73	51.78	51.57	50.92	52.90	50.87	51.52	51.91	51.60	51.42	51.34	52.19	51.47	0.543	0.10
Minolta a*[13,14,15]		20.15^{abcde}	19.78^{def}	19.92^{bcdef}	20.65^{a}	19.66^{ef}	20.09^{bcde}	20.27^{abc}	20.14^{bcde}	19.85^{cdef}	20.33^{ab}	19.59^{f}	20.19^{abcd}	20.36^{ab}	19.56^{f}	20.12^{bcde}	0.267	<0.001
Minolta b*[13,14]		2.90	2.73	2.81	3.20	2.90	2.80	3.23	2.67	2.61	3.05	2.57	2.89	3.31	2.86	2.98	0.258	0.30
Belly measurements																		
Weight, kg[13,15,16,19,20]		7.82^{ab}	7.66^{bcd}	8.01^{a}	7.60^{bcde}	7.60^{bcde}	7.75^{abc}	7.44^{cde}	7.32^{e}	7.87^{ab}	7.91^{ab}	7.68^{bcd}	7.76^{abc}	7.75^{abc}	7.40^{de}	7.65^{bcd}	0.377	<0.001
Width, cm[19]		35.23	35.56	36.02	35.41	35.38	35.20	35.10	35.41	35.61	35.64	35.56	35.20	34.72	34.49	34.95	0.181	0.47
Depth, cm																		
D25[9,13,14]		3.25^{abc}	2.95^{de}	3.18^{abcd}	3.28^{ab}	3.02^{bcde}	2.97^{cde}	3.20^{abcd}	2.90^{e}	2.97^{cde}	3.43^{a}	2.90^{e}	3.15^{abcde}	3.12^{bcde}	3.00^{cde}	3.12^{bcde}	0.117	0.007
D50[10,13,15]		2.31	2.24	2.44	2.31	2.24	2.29	2.34	2.18	2.34	2.39	2.16	2.36	2.34	2.18	2.44	0.036	0.09
D75[11,13,15]		2.49^{a}	2.18^{de}	2.41^{abc}	2.26^{bcde}	2.36^{abcd}	2.34^{abcde}	2.34^{abcde}	2.13^{e}	2.46^{ab}	2.34^{abcde}	2.24^{cde}	2.44^{ab}	2.39^{abcd}	2.13^{e}	2.34^{abcde}	0.058	0.02
Average[13,15]		2.69^{a}	2.44^{bcd}	2.67^{a}	2.62^{abc}	2.54^{abcd}	2.54^{abcd}	2.62^{ab}	2.39^{d}	2.59^{abcd}	2.72^{a}	2.41^{cd}	2.64^{a}	2.62^{ab}	2.44^{bcd}	2.62^{ab}	0.065	0.02
Length, cm[17,18]		69.42^{e}	70.79^{abcde}	71.55^{abcde}	70.33^{bcde}	70.36^{bde}	71.35^{abde}	71.07^{abde}	69.65^{de}	72.52^{a}	71.73^{abd}	72.44^{ab}	72.82^{a}	72.44^{ac}	71.83^{ab}	71.53^{abde}	0.312	0.05
Flop distance, cm[13,14,15,17,19,20]		17.07^{ab}	11.91^{d}	14.76^{bc}	18.24^{a}	14.50^{c}	13.46^{cd}	18.95^{a}	13.34^{cd}	15.60^{bc}	18.87^{a}	11.28^{d}	14.66^{bc}	18.59^{a}	14.53^{c}	18.21^{a}	0.342	<0.001
Subjective firmness score[12, 13,14,15,17,19,20]		3.26^{ab}	2.21^{e}	2.76^{cd}	3.31^{ab}	2.51^{de}	2.68^{cd}	3.51^{a}	2.53^{de}	2.96^{bc}	3.38^{a}	2.21^{e}	2.96^{bc}	3.57^{a}	2.78^{cd}	3.44^{a}	0.150	<0.001

^{a,b,c,d,e,f}Means within a row or interaction subclass with different superscripts differ ($P \leq 0.05$).

[1] A random sample of 10 pigs was taken from each pen within 3 replicates (i.e., replicate 1, 5, and 11).

[2] Means(except harvest live weight) were corrected to a common harvest live weight of 129.8 kg.

[3] 0 = 0% DDGS; 30 = 30% DDGS dietary inclusion; 30WD = DDGS withdrawal (30% DDGS from week 0 to approximately 104 kg and 0% DDGS from approximately 104 kg to end of study).

[4] Measurements were taken on the boneless *Longissimus* muscle.

[5] Subjective color scores were recorded using the following 5 point scale: 1 = extremely pale to 6 = extremely dark (NPPC, 1999).

[6] Subjective marbling scores were recorded using the following 10 point scale: 1= 1% intramuscular fat to 10 = 10% intramuscular fat (NPPC, 1999).

[7] Subjective firmness scores were recorded using the following 5 point scale: 1= soft to 5= very firm (NPPC, 1999).

[8] Objective color scores were taken on the surface of the *Longissimus* muscle using a CR-410 Minolta Chromameter with settings of illuminant D65.

[9] D25 – 25% of the distance from cranial end, in the center of the belly.

[10] D50 – 50% of the distance from cranial end, in the center of the belly.

[11] D75 – 75% of the distance from cranial end, in the center of the belly.

[12] Subjective firmness score was recorded using the following 5 point scale: 1= soft to 5= very firm.

[13] Dietary program 0 vs. 30% DDGS $P \leq 0.05$

[14] Dietary program 0 vs. 30WD $P \leq 0.05$

[15] Dietary program 30% DDGS vs. 30WD $P \leq 0.05$

[16] CLA inclusion level 0% vs. 0.5% $P \leq 0.05$

[17] CLA inclusion level 0% vs. 1% $P \leq 0.05$

[18] CLA inclusion level 0.5% vs. 1% $P \leq 0.05$

[19] CLA feeding duration 0 vs. 28 days $P \leq 0.05$

[20] CLA feeding duration 14 vs. 28 days $P \leq 0.05$

Table 11. Effect of dietary treatment on iodine value.

		Dietary treatment																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
	Dietary program[1]	0	30	30WD	0	30	30WD	0	30	30WD	0	30	30WD	0	30	30WD		
	CLA inclusion level, %	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	1.0	1.0	1.0	1.0	1.0	1.0		
Item	CLA feeding duration, d	0	0	0	14	14	14	28	28	28	14	14	14	28	28	28	SEM	*P*-value
Number of pens		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	-	-
Iodine value, g/100 g[2,3,4,5,6,7,8,9,10]		70.43^{h}	77.26^{a}	73.97^{d}	68.62^{ij}	76.66^{ab}	73.35^{de}	68.22^{jk}	75.96^{bc}	72.13^{fg}	69.29^{i}	76.20^{bc}	72.62^{ef}	67.85^{k}	75.64^{c}	71.60^{g}	0.311	<0.001

[a,b,c,d,e,f,g,h,i,j,k] Means within a row or interaction subclass with different superscripts differ ($P \leq 0.05$).

[1] 0 = 0% DDGS; 30 = 30% DDGS dietary inclusion; 30WD = DDGS withdrawal (30% DDGS from week 0 to approximately 104 kg and 0% DDGS from approximately 104 kg to end of study).

[2] All carcass data from 1 replicate was excluded from the analysis due to issues during the transportation of pigs to the plant.

[3] Dietary program 0 vs. 30% DDGS $P \leq 0.05$

[4] Dietary program 0 vs. 30WD $P \leq 0.05$

[5] Dietary program 30% DDGS vs. 30WD $P \leq 0.05$

[6] CLA inclusion level 0% vs. 0.5% $P \leq 0.05$

[7] CLA inclusion level 0% vs. 1% $P \leq 0.05$

[8] CLA feeding duration 0 vs. 14 days $P \leq 0.05$

[9] CLA feeding duration 0 vs. 28 days $P \leq 0.05$

[10] CLA feeding duration 14 vs. 28 days $P \leq 0.05$

Table 12. *P*-value of contrast treatments.

	Dietary program[1]			CLA inclusion level, %			CLA feeding duration, d		
Item	0 vs. 30	0 vs. 30WD	30 vs. 30WD	0 vs. 0.5	0 vs. 1	0.5 vs. 1	0 vs. 14	0 vs. 28	14 vs. 28
Growth Performance									
Average daily gain, kg	< 0.001	< 0.001	0.02	0.69	0.49	0.73	0.55	0.63	0.89
Average daily feed intake, kg	0.83	0.35	0.48	0.90	0.49	0.49	0.98	0.40	0.29
Gain:feed, kg:kg	< 0.001	< 0.001	< 0.001	0.67	0.93	0.67	0.37	0.70	0.11
Carcass Characteristics									
Backfat depth, cm[2]	0.03	0.41	0.20	0.13	0.03	0.41	0.14	0.03	0.36
Carcass yield, %	< 0.001	0.54	0.002	0.64	0.54	0.86	0.70	0.48	0.71
Longissiumus muscle quality and belly characteristics [3]									
Longissiumus muscle measurements[4]									
Weight, kg	0.06	0.89	0.07	0.67	0.60	0.90	0.89	0.42	0.40
Ultimate pH	0.02	0.88	0.01	0.59	0.77	0.30	0.65	0.48	0.14
Subjective color[5]	0.43	0.94	0.38	0.31	0.65	0.48	0.46	0.46	0.99
Subjective marbling[6]	0.05	0.08	0.84	0.67	0.94	0.53	0.38	0.22	0.01
Subjective firmness[7]	< 0.001	0.17	0.01	0.81	0.84	0.95	0.72	0.42	0.15
Drip loss, %	0.99	0.32	0.32	0.93	0.64	0.64	0.81	0.76	0.94
Objective color scores[8]									
Minolta L*	0.14	0.13	0.98	0.29	0.20	0.80	0.38	0.14	0.46
Minolta a*	< 0.001	0.01	0.01	0.21	0.54	0.41	0.28	0.42	0.73
Minolta b*	0.004	0.02	0.59	0.57	0.40	0.73	0.57	0.40	0.72
Belly quality measurements									
Weight, kg	0.02	0.16	< 0.001	0.01	0.11	0.17	0.19	0.003	0.03
Width, cm	0.83	0.49	0.63	0.38	0.07	0.24	0.47	0.05	0.12
Depth, cm									
D25[9]	< 0.001	0.01	0.06	0.37	0.90	0.34	0.99	0.31	0.20
D50[10]	0.002	0.54	< 0.001	0.37	0.74	0.48	0.46	0.63	0.75
D75[11]	0.005	0.39	< 0.001	0.45	0.39	0.89	0.61	0.27	0.45
Average	< 0.001	0.42	< 0.001	0.33	0.64	0.53	0.67	0.30	0.45
Length, cm	0.97	0.06	0.06	0.61	0.01	0.01	0.11	0.10	0.99
Flop distance, cm	< 0.001	< 0.001	< 0.001	0.08	0.02	0.49	0.35	0.002	0.01
Subjective firmness score[12]	< 0.001	< 0.001	< 0.001	0.11	0.004	0.11	0.37	< 0.001	< 0.001
Fat Quality[13]									
Iodine value, g/100 g	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.08	< 0.001	< 0.001	< 0.001

[1] 0 = 0% DDGS; 30 = 30% DDGS dietary inclusion; 30WD = DDGS withdrawal (30% DDGS from week 0 to approximately 104 kg and 0% DDGS from approximately 104 kg to end of study).

[2] Ultrasound measurements were taken at the 10th rib on a subsample of 6 replicates.

[3] A random sample of 10 pigs was taken from each pen within 3 replicates (i.e., replicate 1, 5, and 11).

[4] Measurements were taken on the boneless *Longissimus* muscle.

[5] Subjective color scores were recorded using the following 5 point scale: 1 = extremely pale to 6 = extremely dark (NPPC, 1999).

[6] Subjective marbling scores were recorded using the following 10 point scale: 1= 1% intramuscular fat to 10 = 10% intramuscular fat (NPPC, 1999).

[7] Subjective firmness scores were recorded using the following 5 point scale: 1= soft to 5= very firm (NPPC, 1999).

[8] Objective color scores were taken on the surface of the *Longissimus* muscle using a CR-410 Minolta Chromameter with settings of illuminant D65.

[9] D25 – 25% of the distance from cranial end, in the center of the belly.

[10] D50 – 50% of the distance from cranial end, in the center of the belly.

[11] D75 – 75% of the distance from cranial end, in the center of the belly.

[12] Subjective firmness score was recorded using the following 5 point scale: 1= soft to 5= very firm.

[13] All carcass data from 1 replicate was excluded from the analysis due to issues during the transportation of pigs to the plant.