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Effects of Amino Acid Supplementation of Reduced Crude Protein (RCP) Diets on the Performance and Carcass Quality of Growing-Finishing Swine

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Effects of Amino Acid Supplementation of Reduced Crude Protein (RCP) Diets on the Performance and Carcass Quality of Growing-Finishing Swine.

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Abstract

Barrows and gilts (215/gender) were used to test the effects of synthetic AA supplementation of reduced CP diets on the growth performance and quality characteristics of the LM and the fatty acid composition of the LM and s.c. jowl fat from growing-finishing swine. Pigs were blocked by BW within gender, and allocated randomly to pens (6 pigs/pen) which were then assigned randomly within each block and gender to either corn-SBM diets 1) that were devoid of synthetic lysine (**Ctrl)**; 2) with reduced CP diets where lysine was added to all diets (**RCP1**); 3) with reduced CP where lysine, threonine, and tryptophan were added to all diets (**RCP2**); 4) with where lysine, threonine, and tryptophan were added to all diets (**RCP3)**; or 5) with reduced CP diets where lysine, threonine, tryptophan, and isoleucine was added to all diets (**RCP4**). During finisher phase 3, 10 mg/kg of ractopamine was included in all diets. A subsample of whole pork loins was processed into chops for data collection. Another subsample from the whole pork loin and the s.c. fat from each jowl was freeze dried for fatty acid determination. Gilts had a greater ($P = 0.02$) (lightness) L* value and drip loss than barrows, but the ultimate pH, marbling, and intramuscular fat (IMF) of the LM were greater ($P \leq 0.04$) for barrows than gilts. Color measurements were not affected ($P \geq 0.06$) by the RCP diets, with the exception of redness (a*) which increased ($P = 0.01$) with decreasing CP levels. There were greater ($P < 0.001$) proportions of SFA in the LM of barrows than the LM from gilts. However, gilts had an increase in PUFA content with decreasing levels of CP in the diet and barrows had a decrease in PUFA content of the LM ($P = 0.056$). Barrows had greater ($P = 0.008$) SFA and less ($P < 0.001$) PUFA content in the jowl fat than gilts. The results point toward the reduced CP diets improving fresh pork quality, especially IMF. Also, pork lean and jowl fat were altered in their fatty acid composition by the reducing dietary CP.

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The completion of my project could not have been accomplished without the support and assistance of fellow graduate students. Also, thank you so much to my entire family for supporting me through my Master's experience, even though it took a lot longer than I anticipated.

Dedication

I dedicate this book to my parents, especially my father. They have supported me in every way possible for my entire college career, even if it took 13 years. My father was not able to see me complete this chapter of my life, but I know that he would be extremely proud of me.

Table of Contents

List of abbreviations

All abbreviations in this thesis, unless defined within the text, are in accordance with the requirements and format of *Journal of Animal Science.* The following abbreviations represent a compilation of both those approved by the journal and those that are used specifically for this document.

SID, RCP, Lys, IMF, L*, a*, b*, Met, Trp, Thr

Chapter 1

Review of Literature

Introduction

Swine are classified as monogastric animals because they have a single stomach. They rely on their diet providing them with the energy, protein, and AA that they need. Unlike ruminants, who derive a considerable amount of their AA from the microbes in their rumen, swine must derive the AA that they need for growth and function from the diet. Early on, domesticated swine were able to root around on forage, acorns, and whatever else was available. Now, in the United States, domesticated pigs have been moved indoors to total confinement and are fed fortified grain-based diets. The majority of these diets consist of corn and soybean meal (SBM), with the most popular ingredient in swine diets being corn. Corn is deficient in lysine (Lys) and tryptophan (Trp), which is what pigs need, in addition to other specific AA, for optimal growth. Corn and SBM complement each other well (Damron, 2013) because SBM has higher levels of Lys and Trp. These two feedstuffs also complement each other well because SBM is deficient in methionine (Met) and cysteine (Cys), which is what corn, has higher concentrations of.

The goal of modern swine producing operations is to feed these animals to an acceptable market weight in the least number of days possible before they go to market. This goal has been reached by feeding the swine a grain based diet and by-product feeds (Damron, 2013). Grains are typically sufficient in energy to meet those requirements for growing pigs, but grains are lower in protein than required for adequate growth in pigs (NRC, 2000). Protein requirements for nursery pigs start at 26% CP and reduce to 20% as pigs move to the grower phase. During the grower

phase, pigs will transition from 18 to 15% CP before moving to finisher diets around 13% CP. Therefore, swine diets change as they progress from the nursery phase to the finishing period according to their changing nutrient requirements.

From the 1980's until now, the environmental impact of swine production has been a concern (Carpenter et al., 2004). Producers are concerned with feed costs which have resulted in least cost formulations. The AA requirement of pigs ultimately determines the dietary protein requirement. With the increase in abundance of co-product feedstuffs with greater protein content such as dried distillers grains (DDG's), an abundance of protein and AA may be included in the diet (Gatel and Grosjean, 1992). Several experiments have verified that when the CP was increased from inadequate levels to above requirements ADG improved (Hansen and Lewis 1993; Chen et al., 1995). A further concern with least-cost formulation is the excessive amount of protein that is excreted as nitrogen in the feces and urine resulting from inclusion of higher levels of lower-cost by-products in the diet. A portion of this nitrogen in then oxidized to nitrous oxide (N_2O) into the atmosphere contributing to greenhouse gases. Reducing excessive dietary CP can help reduce such problems as decreased performance and excess nitrogen excretion.

The swine industry has introduced a way to combat these environmental issues by reducing the amount of dietary CP and supplementing with crystalline AA. Kerr and Easter (1995) proposed that reducing the dietary CP by 1 percentage unit would reduce the amount of nitrogen excreted in the manure by 8%. It is possible to avoid compromising ADG or G:F while reducing the protein in the diet if the diet is supplemented properly with specific AA (Cromwell et al., 1996; Tuitoek et al., 1997b). However, impacts of such dietary changes on growth performance and carcass characteristics may be quite inconsistent. If the dietary supply of one or more essential AA is less than what is required for the animal, there will be an AA deficiency.

Feeding excess protein of more than 25% could lead to environmental pollution, decreased feed efficiency, wastefulness, and a decline in weight gain.

Swine diets are conventionally calculated based on CP requirements. The CP requirement is based on the weight of the swine. Ultimately, maintenance of protein deposition in the body requires certain amounts of essential AA. The requirement of the AA in the diet decreases as the weight of the pigs increases. Because the first limiting AA in swine is Lys, producers like to use a 70/30% corn-SBM diet, respectively. This supplies the animal with an adequate amount of Lys for growth. Lowering dietary CP concentrations to levels below current CP requirements in order to reduce nitrogen excretion reduced ADG in growing and finishing pigs (Cromwell et al., 1993; Kerr et al., 1995; Kerr and Easter, 1995). However, feeding diets with CP concentrations in excess of 20% showed no performance benefits as well (Chen et al., 1999; Carpenter et al., 2004). This is likely due to the metabolic cost of extra nitrogen excretion when excessive amounts of dietary CP are included in the diet (Chen et al., 1999).

A possible replacement for corn in the diet is grain sorghum because has the energy value similar to corn, but lower levels of Lys and protein than corn. Barley could replace all of the corn in the diet, and as an added benefit, it has a higher Lys and protein content than corn. Dried distiller's grains with is comparable to corn in that the composition of the AA is poor. Swine can have from 20 to 30% DDGS in their diet without any decline on growth performance. This is why there is an interest again in supplementing diets with synthetic AA. Farmers with insufficient land area to handle all of the waste excreted from these animals are willing to spend extra on the synthetic AA. The synthetic AA will help reduce nitrogen excretion and a reduction in manure nitrogen may be very helpful for these farmers.

Swine that are fed reduced CP diets supplemented with AA had decreased plasma urea nitrogen levels (Lopez et al., 1994; Kerr and Easter, 1995; Miller et al., 1996). This suggests that the deamination of excess AA is reduced (Knowles et al., 1998). Also, their pancreas weights were reduced, which could be the result of lower pancreatic activity and lower energy requirements for pigs offered these diets. Greater fat deposition could be the result of the greater amount of energy available with the low CP-AA supplemented diet (Knowles et al., 1998).

Effect of CP reduction on pig performance

An alternative approach to feeding greater CP concentrations in the diet would be to supplement with specific essential AA while maintaining lower total CP concentrations. In some instances, ADG was not affected by feeding such lower CP-AA supplemented diets (Cisneros et al., 1996; Kerr et al., 2003; Tous et al., 2014). Kerr et al. (2003) hypothesized that feeding grower-finisher pigs a reduced CP-AA supplemented diet in a heat stressed environment should have a negative effect on growth performance; however, it was concluded that a reduction of 3 percentage units in CP and supplementing with AA in a heat stressed environment did not have any adverse effects on growth performance. Others reported reduced ADG when AA were supplemented for natural ingredients in the diet (Lee et al., 2001; Figueroa et al., 2002; Gómez et al., 2002), even considering that Lys, Met, Thr, and Trp were the AA added in each of these studies. These reductions in ADG were attributed to insufficient levels of the first four limiting AA (Gómez et al., 2002) or to the deficiency of some nonessential AA necessary for optimal growth (Lee et al., 2001) in the reduced CP-AA supplemented diets.

Average daily feed intake (ADFI) by growing and finishing pigs was reduced (Cromwell et al., 1993; Kerr et al., 1995; Kerr and Easter., 1995) when CP levels were reduced below the current requirements. However, feed intake was also reduced when the CP levels exceeded 20%

in the diet (Chen et al., 1999; Xu et al., 2010). In some instances, when AA were added to a reduced CP diet, the ADFI was not affected (Tuitoek et al., 1997; Kerr et al., 2003; Tous et al., 2014), thus demonstrating the inconsistent effects of supplemental essential AA. Some researchers have reported that supplementing reduced CP diets with specific AA could improve animal gains (Xu et al., 2010). However, the gain to feed ratio was not affected in some experiments (Tuitoek et al., 1997; Kerr et al., 2003; Tous et al., 2014).

The gain to feed ratio in growing and finishing pigs is more efficient when the CP is lowered below the current CP requirement (Cromwell et al., 1993; Kerr et al., 1995). The gain to feed ratio in growing and finishing pigs is reduced when CP levels exceed 20% (Chen et al., 1999; Carpenter et al., 2004). Chen et al (1999) concluded that the decrease in G:F when the CP is increased in the diet could be due to the higher maintenance energy needs for the animal because of the increase in certain organ weights. Gilts are more susceptible to this decrease than barrows. Increasing the CP in the diet much higher than the requirement increased the weights of the liver, pancreas, and kidneys, thus, increasing the maintenance required for whole body growth (Chen et al., 1999). Plasma urea nitrogen concentrations and urea-cycle enzymes also increased with the increased dietary CP (Chen et al., 1999). Gilts were less able to adjust to the increase in CP than barrows resulting in greater reductions in growth rates in gilts than barrows when fed high CP diets.

Effect of CP reduction on pork carcass composition

Dressing percentage in growing and finishing pigs was reduced when feeding diets containing levels of CP that exceeded 20% (Xu et al., 2010). However, others did not observe differences in dressing percentage when dietary CP exceeded 20% (Chen et al., 1999; Carpenter et al., 2004). Supplementing lower CP diets with synthetic AA did not affect dressing percentage

in certain instances (Tous et al., 2014; Hinson et al., 2009; Kerr et al., 2013). However, in other studies, dressing percentage was reduced when AA were supplemented in the diet (Lee et al., 2001), even when the AA were Lys, Met, Thr, and Trp.

Reducing the CP levels below the recommended concentration increased the 10^{th} rib fat depth (Cromwell et al., 1993). In some instances, backfat depth decreased (Xu et al., 2010) when adding up to 20% CP in the diet, but backfat depth increased linearly when CP was decreased from 20 to 12% in another study (Carpenter et al., 2004). Chen et al (1999) found that increasing the CP in the diet from 20 to 25% in the diet decreased 10^{th} rib, average, and last rib backfat. Also, gilts in that trial had a greater decrease in last rib backfat than barrows when the CP was increased from 20 to 25% in the diet. Adding supplemental AA did not affect the backfat depth in some studies (Cisneros et al., 1996; Tuitoek et al., 1997; Kerr et al., 2003). Specifically, adding supplemental Lys, Met, Thr, and Trp to the diet did not affect the 10^{th} rib backfat thickness (Lee et al., 2001).

As the CP was reduced in the diet, the LM area decreased in gilts (Cromwell et al., 1993; Kerr et al., 1995), but decreasing dietary CP did not affect LM area from barrows (Cromwell et al., 1993). This reduction in muscling in gilts may be happening because the gilts were deficient in one or more specific AA. This deficiency could could have been corrected by supplementing the diets with AA but data from such studies were not available.

Effect of CP reduction on pork quality

There are a number of factors that affect pork quality as defined by consumer preference traits. Tenderness, juiciness, and flavor are the three main factors that affect the eating quality of meat according to consumers (Brewer et al., 2001; Fortin et al., 2004). Higher intramuscular fat

(IMF) has been known to positively influence meat quality according to Barton et al., 1985; Bejerholm et al., 1986; Fernandez et al., 1999b; and Fortin et al., 2004.

Reducing the dietary CP to below the NRC (2000) requirement with no supplemental AA increased marbling in swine (Cromwell et al., 2004). However, marbling decreased when the diet was greater than 20% CP (Xu et al., 2010). Reducing the dietary CP concentrations and supplementing those reduced CP diets with synthetic AA did not alter marbling in finishing swine (Cisneros et al., 1996).

The eating quality of pork has also been related to the fatty acid composition of the muscle. The fatty acids that positively influence pork flavor are SFA's and MUFA's (Cameron and Enser, 1991). Polyunsaturated fatty acids have a negative effect on pork flavor (Cameron and Enser, 1991) and this relates back to the amount of IMF because the IMF has a greater amount of phospholipids than neutral lipids (Enser, 1984).

Kerr et al. (1995) found that reducing the CP from 15 to 11% had the same effect on color score as reducing the percentage of CP from 15 to 11% and supplementing with synthetic AA, but the color score was increased in the diet from 14 to 19%. When Tous et al. (2014) only reduced the CP from 13 to 9% and either held the Lys constant or reduced the Lys in the diet the color scores a*, b*, and L* were not affected.

Drip loss from the longissimus thoracis, drip loss was lower when the pigs were fed a low protein diet (13 to 10% Tous et al., 2014). Kerr et al. (1995) reported that pigs fed a high CP diet (19 to 14%) and low CP-AA supplemented diets (15 to 11%) were not different, but a low CP diet with no AA supplementation had a lower drip loss percentage.

Leaner meat from consumer demand has challenged pork producers to look for different options other than diet composition. Goerl et al (1995) researched two different breed types,

Gene Pool and Hampsire, to compare different levels of CP ranging from 10 – 25%. Ham yields were greater ($P < 0.01$) for the Hampsire gilts and both genetic lines' ham yields increased linearly ($P < 0.01$) as the CP in the diet increased (Goerl et al., 1995).

Conclusion

Pigs tend to have improved performance when the CP is not exceeding the dietary requirement and supplemented with synthetic AA. Feeding excessive CP leads to lower ADG, ADFI and excess nitrogen excreted in the feces. These problems can be improved with the supplementation of AA; however there are still some inconsistencies with this feeding plan and further research is needed.

Chapter 2

Introduction

Nitrogen from manure and urine is oxidized by soil and air, with a portion of nitrogen released into the atmosphere as nitrous oxide (N_2O), and the greenhouse effect of N_2O is approximately 300 times that of CO_2. Maximizing synthetic AA use and reducing CP in swine diets can potentially reduce nitrogen excretion into the environment (Kerr and Easter, 1995; Figueroa et al., 2002; Hinson et al., 2009); however, the response to reduced CP diets on growth performance and carcass characteristics of growing-finishing swine can be quite variable (Dourmad et al., 1993; Kerr et al., 1995; Figueroa et al., 2002). A common practice in the swine industry is to feed ractopamine hydrochloride (RAC), but regulations require the feeding of a minimum of 16% CP in the diet for finishing swine, even though research by DeCamp et al. (2001) and Gaines et al. (2004) indicated that RAC could be fed in lower CP diets formulated with the appropriate levels of synthetic AA without compromising live pig performance or carcass composition.

Intramuscular fat (IMF) in the LM increased 14 to 65% when the CP was reduced in the growing-finishing swine diet (Kerr et al., 1995; Nold et al., 1999; Teye et al., 2006). On the other hand, IMF content and marbling scores have been shown to reduce when RAC was added to swine diets; however, the reductions in IMF/marbling associated with feeding RAC are likely a response to dietary lysine levels in excess of 0.8% (Apple et al., 2007). In addition, little is known about the effects of reducing dietary CP on the fatty acid composition of pork. Both Wood et al. (2013) and Tous et al. (2014) reported that reducing CP in swine diets increased SFA and MUFA, at the expense of PUFA, but synthetic AA were not added to the reduced CP diets in these studies. Therefore the objective of this study was to determine the effects of AA supplementation of the reduced CP diets on quality

characteristics of the LM and the fatty acid composition of s.c. fat and muscle from growing-finishing swine.

Materials and methods

Pig allotment and diets

Crossbred barrows and gilts (n = 210/gender, from the mating of C-29 females to line-380 boars (PIC, Inc., Hendersonville, TN), were blocked by weight and randomly allocated to replicated pens (6 pigs/pen). Then, within gender and blocks, pens were assigned to 1 of 5 dietary treatments (Tables 1 through 3) fed in a 5- phase dietary program (transition from Grower-1 to Grower-2, Grower-2 to Finisher-1, Finisher-1 to Finisher-2, and Finisher-2 to Finisher-3 at mean block BW of 41, 59, 82, and 104 kg, respectively): 1) corn-SBM diets with 23.70, 21.53, 18.97, and 17.66% CP that contain no synthetic lysine (**Ctrl**); 2) reduced CP diets with 21.61, 19.46, 17.34, and 16.30% CP and 0.19, 0.18, 0.15, and 0.12% added lysine hydrochloride, in the Grower-1, Grower-2, Finisher-1, and Finisher-2 diets, respectively (no other dispensable AA were added); (**RCP1**); 3) reduced CP diets with 19.58, 17.44, 15.74, and 14.96% CP, and 0.38, 0.36, 0.29, and 0.24% added lysine hydrochloride, in the Grower-1, Grower-2, Finisher-1, and Finisher-2 diets, respectively (L-threonine and L-tryptophan were added at 2.0 percentage units above SID ideal AA ratio); (**RCP2**); 4) reduced CP diets with 17.61, 15.49, 14.16, and 13.64% CP, and 0.56, 0.54, 0.44, and 0.36% added lysine hydrochloride, in the Grower-1, Grower-2, Finisher-1, and Finisher-2 feeding diets, respectively (L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine were added at 2.0 percentage units above SID ideal AA ratio); (**RCP3**); or 5) reduced CP diets, with 15.72, 13.61, 12.68, and 12.37% CP, and 0.75, 0.72, 0.59, and 0.48% added lysine hydrochloride, in the Grower-1, Grower-2, Finisher-1, and Finisher-2 diets, respectively (L-threonine, DL-methionine,

L-tryptophan, L-isoleucine, and L-valine were added at 2.0 percentage units above SID ideal AA ratio); (**RCP4**). During the final 3-week feeding phase (Finisher-3), 10 mg/kg of ractopamine hydrochloride (RAC; Paylean, Elanco Animal Health, Greenfield, IN) was included in all diets, and Ctrl, RCP1, RCP2, RCP3, and RCP4 diets contained 20.24, 18.60, 17.01, 15.44, and 13.93% CP. In addition, 0.15% L-lysine and 0.3% L-threonine were added to RCP1, 0.30% L-lysine, 0.10% L-threonine, 0.2% DL-methionine, and 0.02% L-tryptophan were added to RCP2, 0.45% L-lysine, 0.16% L-threonine, 0.06% DL-methionine, 0.03% L-isoleucine, 0.02% L-valine, and 0.05% L-tryptophan were added to RCP3, and 0.60% L-lysine, 0.23% L-threonine, 0.10% DL-methionine, 0.11% L-isoleucine, 0.10% L-valine, and 0.07% L-tryptophan were added to RCP4 to ensure that these AA were not deficient in the Finisher-3 diets. All diets were calculated to 95% of the average standard ileal digestible (**SID**) lysine requirement for both genders to make sure that the Lys did not exceed NRC (2000) requirements. In addition, all diets were formulated to contain at least 3.37 Mcal/kg of ME and a lysine:ME of 2.67 g/Mcal.

Pigs were housed in a curtain-sided building with slatted floors, and each 1.49 × 3.96-m pen was equipped with a single-opening feeder and wean-to-finish waterers for ad libitum access to both feed and water. During the first 4 feeding phases (Grower-1, Grower-2, Finisher-1, and Finisher-2), individual BW was measured weekly and pen feed disappearance was measured at the end of each feeding period, whereas during the last feeding phase (Finisher-3), individual BW and feed disappearance were measured weekly to calculate ADG, ADFI, and G:F. At the beginning of the study and the end of each feeding phase, 10^{th} rib fat depth and LM area were measured ultrasonically by a trained, certified technician on 3 gilts and 3 barrows selected randomly from each BW block to estimate carcass gain.

Pig slaughter and pork carcass data collection

Pigs were transported approximately 10 h to a commercial pork slaughter/fabrication facility (Cargill Meat Solutions, Ottumwa, IA) when each pen reached an average weight of 127.0 kg. Pigs were slaughtered according to humane procedures after a 6-h lairage. The 10^{th}-rib fat and LM depths were measured and recorded using a Fat-O-Meater (FOM) probe. Hot carcass weight was recorded and the carcasses were subjected to a 24-h rapid chilling system. After approximately 6 h of chilling, a subsample of left-side carcasses were selected at random and identified (3/pen) for collection of whole, bone-in pork loins (IMPS #410) and 3 whole, bone-in hams (IMPS #401). During carcass fabrication, identified loins and hams were collected, vacuum-pack, boxed, and transported under refrigeration to the University of Arkansas Red Meat Research Abattoir for additional evaluation.

Ham fabrication

Upon arrival at the University of Arkansas Red Meat Research Abattoir, pH of each ham was measured in the center of the semimembranosus (SM) with a hand-held, ceramic-tipped, temperature-compensating pH probe (205 pH/Temperature Meter, Testo Inc., Sparta, NJ) calibrated to pH 4.0 and 10.0. Next, each ham was weighed and subsequently knife-dissected into the "flat" (biceps femoris), "pillow" (semimembranosus), "knuckle" (quadriceps complex), semitendinosus, lean muscle trim, fat trim, and bone. Individual muscle weights, along with total lean, fat and bone weights were collected and then divided by the whole ham weight to calculate ham yields.

Loin fabrication

Loins were removed from their packaging material after 7 d of vacuum-aging in the dark at 2°C, and the tenderloin, blade section and sirloin section were removed from each loin. Then,

pH was measured in the center of the LM using a hand-held, ceramic-tipped, temperature-compensating pH probe (Testo Inc., Sparta, NJ). The resulting center-cut pork loins were processed into 6 chops for data collection. Four 2.5-cm-thick chops were collected from the loin, with 1 chop used for visual and instrumental color, firmness, and marbling data collection, 1 chop designated for proximate analysis, and 2 chops were vacuum-packaged and immediately frozen for Warner-Bratzler shear force (WBSF) determination at a later date. In addition, two 3.8-cm-thick LM chops were cut and used for drip loss determinations.

Pork quality data collection

Trained University of Arkansas personnel visually evaluated each LM chop, after 45 min bloom at 2°C, for color based on the American (1 = pale, pinkish gray to 6 = dark, purplish red; NPPC, 1999) and Japanese color standards for pork (Nakai et al., 1975), firmness (1 = soft to 3 = very firm; NPPC, 2000), and marbling (1 = 1% IMF to 10% IMF; NPPC, 1999). After visual appraisal, instrumental color (L*, a*, and b*) was determined from 3 readings on each chop made with a Hunter MiniScan XE (Hunter Associate Laboratory, Reston, VA) using illuminant A and a 25-mm viewing diameter.

Drip loss was measured according to the procedure of Honikel et al. (1986), with modifications by Apple et al. (2000). Briefly, a 3.0-cm-diameter core was removed from each 3.8-cm-thick chop, weighed, and suspended from a fishhook (barb removed) mounted to the lid of a plastic container. Once filled, containers were subsequently stored for 48 h at 4°C. After the 48-h refrigerated storage period, scores were removed from the hooks, blotted dry, and reweighed to calculate drip loss percentage.

Duplicate 5-g samples of the LM were removed from each chop designated for proximate analyses, weighed, placed in 30-mL beakers, and reweighed before being dried for 72 h in a Labcono freeze-dryer (Labcono Corp., Kansas City, MO) according to the procedure outlined by Apple et al. (2001). The difference between the initial and dried beaker weights was divided by the initial LM sample weight to calculate dry matter (DM). Then, dried LM samples were packaged and submitted to the Poultry Science Department's Analytical Laboratory (University of Arkansas Division of Agriculture, Fayetteville) for quantification of total protein, fat, and ash according to AOAC-approved procedures.

Warner-Bratzler shear force (WBSF) determination

Duplicate 2.5-cm-thick chops were thawed, for 16 h at 2°C, removed from vacuum pouches, deboned, and trimmed off any external fat. Each chop was then weighed, and cooked on an electric, counter-top griddle (model 07047; National Presto Industries, Inc., Eau Claire, WI). Chops were turned every 3 min until they reached the internal temperature of 71°C, and temperature was monitored with a hand-held, FoodChecking digital thermometer (Comark Instruments, Inc., Beaverton, OR). After the chops were cooked, they were immediately blotted with paper towels and weighed to calculate cooking loss percentages. Then, chops were allowed to cool for 2 h to room temperature (21°C) before six 1.3-cm-diameter cores were removed parallel to the muscle fibers. Each core was sheared with a WBSF device attached to an Instron Universal Testing Machine (model 4466; Instron Corp., Canton, MA). This machine was equipped with a 55-kg tension-compression load cell and performed at a crosshead speed of 250 mm/min. The average of 6 cores/LM chop was averaged for statistical purposes.

Fatty acid analysis

Subcutaneous fat from jowls were weighed to 5-g, duplicate samples and placed in 30-mL beakers and reweighed. The beakers were then placed on a Labcono freeze-dryer (Model 4.5, Labcono Corp., Kansas City, MO) with a temperature setting of -50°C and a vacuum of less than 10 mm of Hg. Each set of samples were dried for 72 h. After drying, 30-mg samples were taken from the dried LM and s.c. fat samples and subjected to direct transesterification by incubating in 2.0 mL of 0.2 *M* methanolic KOH at 50°C for 45 min, with vortexing 2 to 3 times/ min until dissolved (Murrieta et al., 2003). Tubes were allowed to cool, and then 2 mL of highly purified hexane and 1 mL of saturated NaCl were added followed by the addition of 1 mL of hexane. Hexane was allowed to evaporate under a hood. Then, the tubes were vortexed and centrifuged for 5 min at 1100 × *g* (22°C) to separate the layers.

A 1.0-mm bed of anhydrous sodium sulfate was placed in GLC vials prior to transferring the fatty acid methyl esters (FAME) in the hexane layer. The FAME was separated by using a GLC (Model 5890 Series II GC with automatic sample injector [HP-7673] with HP-3365 software; Hewlett-Packard, Avondale, PA) with 100-m capillary column (0.25-mm i.d.; Model SP2560 Fused Silica Capillary; Supelco Inc., Bellefonte, PA). Helium was the carrier gas (20 cm^3/s) at a split ratio of 60:1. Oven temperature was maintained at 175°C for 35 min, increased to 215°C at a rate of 5°C/min, and then ramped to 235°C at 10°C/min, whereas injector and detector temperatures were maintained at 250°C. Purified standards were obtained from Supelco (37 component mix) and individual acids were obtained from Nu-Check Prep (Elysian, MN) and Martreya (Pleasant Gap, PA).

Statistical analysis

All data were analyzed as a randomized complete block design, with treatments in a 2 × 5 factorial arrangement, blocks based on initial BW, and pen as the experiment unit. The ANOVA was generated using the mixed models procedure of SAS (SAS Inst., Inc., Cary, NC), with the fixed effects of dietary CP treatment, gender, and the gender × dietary CP diet interaction. Because of the unequal distribution among the dietary CP treatments, PROC IML of SAS was used to generate the appropriate coefficients for linear, quadratic, cubic, and quartic polynomial contrasts for dietary CP treatment and the gender × dietary CP diet interaction.

Results and discussion

Growth performance

During the Grower-1 phase, ADG decreased (linear; $P = 0.01$), whereas, during the grower-2 phase, ADG decreased linearly and cubically ($P \leq 0.055$), as the CP in the diets were reduced and supplemented with synthetic AA (Table 5). Gómez et al (2002) reported that low protein (11.95%), AA supplemented diets also reduced ADG during the grower phase when compared to pigs fed a corn-SBM diet formulated to 16.21% CP. However, Lee et al (2001) reported that reducing the CP levels in the diet from 16 to 13% and supplementing with AA did not affect ADG.

During the Finisher-1 (linear, $P = 0.056$) and Finisher-3 phases (quadratic and cubic, $P \leq 0.037$) ADG decreased as CP was reduced in the diets, but there was no effect ($P \geq 0.178$) of dietary CP on ADG during the Finisher-2 feeding phase (Table 5). Growth rate was reduced when a low protein, AA supplemented diet was fed to pigs (Gómez et al., 2002). In addition, both Lee et al (2001) and Figueroa et al (2002) reported that reducing the CP from 14 to 11% and supplementing with lysine (Lys), methionine (Met), threonine (Thr), and tryptophan (Trp)

reduced ADG during the early-finishing phase; however, reducing the CP from 12 to 9% and supplementing with dispensable AA during the late-finishing phase had no appreciable effects on swine ADG (Lee et al., 2001).

Reducing dietary CP and supplementing dispensable AA had no effect ($P \geq 0.085$) on ADFI during the grower phases or across the entire feeding trial (Table 5). However, ADFI decreased during the Finisher-1 (linear, $P = 0.034$) and Finisher-3 (cubic, $P = 0.004$) phases with decreasing dietary CP. Figueroa et al (2002) and Lee et al (2001) reported a decrease in ADFI when CP was reduced from 14 to 12% while supplementing with AA in the finisher-1 phase. However, Figueroa et al (2002) had increased ADFI when reducing the CP from 16 to 14% CP with supplemental AA.

During the Grower-1 and Grower-2 phases, G:F decreased ($P \leq 0.027$) with decreasing dietary CP in the diet (Table 5). Tuitoek et al (1997) reported no effect on G:F during the grower phases when CP was reduced from 16 to 13%; however, Gómez et al (2002) reported that pigs fed a low-protein, AA-supplemented diet had a lower G:F during the grower phase than pigs fed the control corn-SBM diet.

Gain-to feed ratio responded cubically ($P = 0.023$), linearly ($P = 0.019$), and quadratically ($P = 0.002$) to reductions in dietary CP during the Finisher-1, -2, and -3 phases, respectively (Table-5). In addition, overall G:F was decreased (quadratic and cubic, $P < 0.001$) with decreasing dietary CP and dispensable AA supplementation. Tuitoek et al (1997) reported decreased G:F during the finisher phase when reducing the CP in the diet from 12 to 11%, but G:F was not affected when CP was reduced from 14 to 12%. Conversely, Lee et al (2001) found that decreasing dietary CP from 14 to 11% while supplementing with synthetic AA decreased overall G:F.

With the exception of the Finisher-3 phase when RAC was fed, barrows had greater (P = 0.004) ADG than gilts in each feeding phase, as well as across the entire feeding trial (Table 5). In addition, barrows had greater ($P \leq 0.019$) ADFI than gilts, regardless of feeding phase; however, G:F was only greater ($P < 0.001$) in gilts compared to barrows during Finisher-2 and -3 phases, as well as across the entire feeding trial. Xu et al (2010) reported that barrows also grew larger than gilts during the grower phase across all diets with varying protein levels. There was no effect on G:F in gilts when dietary CP was reduced from 16 to 13% during the grower phase (Tuitoek et al., 1997).

Ultrasonic-measured 10th rib fat depth increased with decreasing dietary CP at the end of the Grower-1 (linear, $P < 0.001$) and Finisher-3 (linear, $P = 0.022$) phases, whereas LM area decreased quadratically ($P \leq 0.034$) at the end of both grower phases, as well as at the completion of the Finisher-1 and Finisher-3 phases (Table 5). Furthermore, calculated lean weight responded linearly ($P \leq 0.007$) and quadratically ($P \leq 0.051$) with decreasing dietary CP by the end of the Grower-1, Grower-2, Finisher-1, and Finisher-3 feeding phases. Tous et al (2014) reported no differences in 1st, 3rd, 4th, and last rib fat depth when the CP in the diet was reduced from 13 to 11% and when the CP was reduced from 10 to 9% with supplemented Lys.

Barrows had greater ($P \leq 0.029$) ultrasonic-measured fat depth than gilts at the end of each feeding phase, but LM area was only greater ($P = 0.046$) in barrows than gilts by the end of the Finisher-1 phase (Table 6). Moreover, gilts had a greater ($P = 0.002$) calculated lean weight than barrows at the end of the Grower-1 phase, but calculated lean weight was greater (P = 0.042) than gilts at the completion of the Finisher-3 phase.

Carcass composition

Reducing dietary CP and supplementing dispensable AA did not affect HCW ($P \geq 0.208$), dressing percentage ($P \geq 0.280$), or LM depth ($P \geq 0.381$); however, 10th rib fat depth increased (linear, $P = 0.001$) and calculated fat-free lean yield decreased (linear, $P = 0.018$) with decreasing dietary CP (Table 6). Kerr et al. (1995) reported that decreasing the CP by 4 percentage units from the grower phase to the finisher phase did not affect HCW or dressing percentage in pigs. Barrows had a greater dressing percentage than gilts, and carcasses from barrows were heavier ($P = 0.001$) and fatter ($P < 0.001$) at the 10th rib than gilt carcasses. Even though LM depth was similar ($P = 0.688$) between barrows and gilts, carcasses from gilts had greater ($P < 0.001$) fat-free lean yields than carcasses of barrows. Chen et al (1999) failed to note any differences in carcass weight when barrows and gilts were fed diets containing between 13 and 25% CP.

Ham lean percentage decreased (linear, $P = 0.002$), and ham fat percentage increased (linear, $P = 0.012$) with decreasing dietary CP, but fresh ham weight ($P \geq 0.157$), as well as percentages of specific muscle groups ($P \geq 0.082$), total bone ($P \geq 0.081$), and total skin ($P \geq 0.105$) did not differ among reduced CP dietary treatments (Table 7). Even though fresh ham weights were similar ($P = 0.415$) between barrows and gilts, ham from gilts had greater ($P < 0.001$) total lean percentage, and, in particular, greater ($P \leq 0.033$) proportions of semimembranosus, semitendinosus, and quadriceps complex than hams from barrows. Moreover, total ham fat percentages were less ($P < 0.001$) in gilts than barrows, but neither total bone nor total skin percentages differed ($P \geq 0.113$) between barrows and gilts.

Longissimus muscle quality characteristics

Neither LM pH ($P \geq 0.196$), drip loss ($P \geq 0.191$), moisture content ($P \geq 0.073$), visual color ($P \geq 0.066$), L* values ($P \geq 0.245$), b* values ($P \geq 0.290$), nor firmness ($P \geq 0.060$) were

affected by reducing dietary CP and supplementing dispensable AA (Table 7). Conversely, redness (a*) values and marbling scores responded in a cubic manner ($P \leq 0.021$) with decreasing dietary CP, and IMF increased in the LM from barrows with decreasing dietary CP, but appeared to decrease in the LM from gilts with decreasing dietary CP (linear gender × dietary CP treatment, $P = 0.028$).

In other studies, drip loss was not affected across diets with different CP concentrations up to 17 (Alonso et al., 2010), 20 (Widmer et al., 2008), or 30% (Xu et al., 2010). However, Tous et al (2014) reported that increasing the CP in the diet from 11 to 13% increased ($P < 0.01$) the drip loss percentage.

The LM from barrows had great pH values ($P = 0.006$), visual color scores ($P \leq 0.044$), and marbling scores ($P = 0.021$) than the LM from gilts, whereas the LM of gilt carcasses had greater drip loss percentages ($P = 0.022$), moisture content ($P = 0.016$), and L* values ($P = 0.021$) than that of barrow carcasses (Table 8). However, sex had no effect ($P \geq 0.072$) on firmness scores of redness (a*) and yellowness (b*) values.

Protein content of the LM was similar between genders ($P = 0.168$) and among reduced dietary CP treatments ($P \geq 0.334$), and even though LM ash percentage did not differ ($P = 0.431$) between barrows and gilts, LM ash content decreased (quadratic, $P = 0.037$) with decreasing dietary CP (Table 8). In addition, cooking loss percentages were not affected by gender ($P = 0.059$) or reduced dietary ($P \geq 0.410$), and WBSF values were similar ($P = 0.220$) between barrows and gilts; however, WBSF values responded cubically ($P = 0.037$) with decreasing dietary CP.

Fatty acid composition

Intramuscular fat from the LM decreased linearly ($P = 0.0162$) in palmitic acid as the diet CP decreased. Tous et al (2014) reported an increase in 16:0, 18:0, and total SFA in the longissimus thoracis s.c. fat as the CP in the diet was decreased by 3 percentage units. The IMF of the LM from barrows had greater ($P < 0.0001$) palmitic acid (16:0) and total SFA than gilts.

Intramuscular fat from the LM increased in 16:1c ($P = 0.0058$, linear) and total MUFA ($P = 0.0369$) as the CP in the diet decreased. Tous et al (2014) found an increase in 16:1n7, 18:1n7, 18:1n9 and MUFA in the longissimus thoracis s.c. fat when the protein was reduced in the diet. Barrows had greater 16:1c ($P = 0.0489$) in the IMF of the LM than gilts. There was no difference ($P = 0.427$) between barrows and gilts with respect to total MUFA.

There was a decrease in 18:2n6 ($P = 0.0562$) and 18:3n3 ($P < 0.0001$) in the IMF of the LM as the CP in the diet decreased, but no change ($P = 0.637$) in total PUFA. Tous et al (2014) also reported a decrease ($P < 0.01$) in PUFA, particularly 18:2n6, 18:3n3, and total PUFA as the CP in the diet was decreased by 3 percentage units. Gilts had a greater proportion of PUFA, particularly 18:2n6, 18:3n3, and total PUFA ($P < 0.05$) in the IMF of the LM than barrows.

Saturated fatty acids, 16:0, 18:0, and total SFA in the jowl fat decreased linearly ($P < 0.05$) as the CP in the diet was decreased. Barrows had greater ($P < 0.05$) proportion of SFA such as 16:0, 18:0, and total SFA in their jowl fat than gilts. Monounsaturated fatty acids, particularly 16:1c, 18:1c9, and total MUFA increased linearly ($P < 0.0001$) in the jowl fat as the CP in the diet was decreased. Jowl fat from barrows had greater ($P = 0.0127$) 16:1c than gilts. As the CP in the diet decreased, 18:2n6, 18:3n3, and total PUFA in the jowl fat decreased linearly ($P < 0.05$). Gilts had a greater ($P < 0.0001$) proportion of PUFA such as 18:2n6, 18:3n3, and total PUFA in the jowl fat than barrows.

Conclusion

Dietary crude protein concentrations can be reduced by incorporating synthetic AA into grower and finisher swine diets. Reducing the dietary crude protein resulted in an improvement in fresh pork quality in the present study, but the improvements associated with reduced crude protein appear to be gender specific.

Tables

Table 1. Composition (as-fed basis) of grower diets offered to pigs to assess the impacts of reduced crude protein on growth and carcass composition[1]

	Grower-1 phase (23 to 41 kg)					Grower-2 phase (41 to 59 kg)				
	C	RCP1	RCP2	RCP3	RCP4	C	RCP1	RCP2	RCP3	RCP4
CP, %:	23.70	21.61	19.58	17.61	15.72	21.53	19.46	17.44	15.49	13.61
Ingredient, %										
Corn	47.39	53.06	58.64	63.95	68.62	53.10	58.69	64.21	69.09	73.82
Soybean meal	30.08	24.23	18.38	12.53	6.73	24.55	18.78	13.00	7.25	1.50
DDGS[1]	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Limestone	0.95	0.98	1.01	1.03	1.06	0.99	1.01	1.04	1.06	1.09
Restaurant grease	0.55	0.49	0.43	0.40	0.50	0.50	0.46	0.40	0.50	0.58
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Dicalcium phosphate	0.16	0.20	0.23	0.27	0.31	0.09	0.12	0.16	0.20	0.24
Vitamin premix[2]	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Trace mineral premix[3]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Copper sulfate	0.10	0.10	0.10	0.10	0.10	---	---	---	---	---
Ethoxiquin	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Ronozyme	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Potassium sulfate	0.00	0.00	0.00	0.10	0.50	0.00	0.00	0.00	0.30	0.65
l-lysine	0.00	0.19	0.38	0.56	0.75	0.00	0.18	0.36	0.54	0.72
L-threonine	0.00	0.00	0.05	0.13	0.22	0.00	0.00	0.04	0.12	0.20
DL-methionine	0.00	0.00	0.00	0.05	0.11	0.00	0.00	0.00	0.00	0.07
L-isoleucine	0.00	0.00	0.00	0.04	0.14	0.00	0.00	0.00	0.07	0.16
L-valine	0.00	0.00	0.00	0.01	0.11	0.00	0.00	0.00	0.03	0.12
L-tryptophan	0.00	0.00	0.03	0.06	0.09	0.00	0.00	0.03	0.06	0.09
Calculated composition, %										
Total lysine	1.19	1.17	1.16	1.14	1.13	1.03	1.02	1.00	0.99	0.98
SID lysine	1.01	1.01	1.01	1.01	1.01	0.86	0.86	0.86	0.86	0.86

Table 1. Composition (as-fed basis) of grower diets[1] (Cont.)

Total P	0.51	0.49	0.47	0.45	0.43	0.47	0.45	0.44	0.42	0.40
Available P	0.31	0.31	0.31	0.31	0.31	0.29	0.29	0.29	0.29	0.29
Total Ca	0.55	0.55	0.55	0.55	0.55	0.53	0.53	0.53	0.53	0.53
ME, Mcal/kg	3.37	3.37	3.37	3.37	3.37	3.38	3.38	3.38	3.38	3.38

[1]C = control diet formulated to meet 95% of the SID lysine requirement; RCP1 = reduced CP diet with added L-lysine hydrochloride; RCP2 = reduced CP diet with added L-lysine, L-threonine, and L-tryptophan; RCP3 = low CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine; and RCP4 = lowest CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine.

[2]Dried distillers' grains with solubles

[3]Supplied 5,512 IU vitamin A, 689 IU vitamin D_3 (D-activated animal sterol), 22.05 IU vitamin E, 2.2 mg vitamin K (menadione sodium bisulfite), 13.78 mg pantothenic acid (D-calcium pantothenate), 4.8 mg niacin, 4.13 mg riboflavin, and 19.3 µg vitamin B12 per kg of feed.

[4]Supplied 0.20 mg SE from sodium selenite, 26.4 mg Mn from manganous oxide, 110 mg Zn from zinc oxide, 110 mg Fe from ferrous sulfate, 11 mg Cu from copper sulfate, and 0.20 mg I from calcium iodate per kg of feed.

Table 2. Composition (as-fed basis) of finisher diets offered to pigs to assess the impacts of reduced crude protein on growth and carcass composition[1]

	Finisher-1 (59 to 82 kg)					Finisher-2 (82 to 104 kg)				
	C	RCP1	RCP2	RCP3	RCP4	C	RCP1	RCP2	RCP3	RCP4
CP, %:	18.97	17.34	15.74	14.16	12.68	17.66	16.30	14.96	13.64	12.37
Ingredient, %										
Corn	59.35	63.76	68.03	71.78	75.55	62.97	66.63	69.97	73.08	76.24
Soybean meal	18.40	13.83	9.28	4.75	0.25	15.00	11.20	7.45	3.73	0.00
DDGS[2]	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Limestone	1.16	1.18	1.20	1.22	1.24	0.94	0.95	0.97	0.99	1.00
Restaurant grease	0.31	0.28	0.26	0.42	0.47	0.33	0.30	0.38	0.50	0.58
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Dicalcium phosphate	0.01	0.04	0.07	0.10	0.13	0.00	0.03	0.05	0.08	0.10
Vitamin premix[3]	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Trace mineral premix[4]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Ethoxiquin	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Ronozyme	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Potassium sulfate	0.00	0.00	0.05	0.35	0.60	0.00	0.00	0.15	0.40	0.60
L-lysine	0.00	0.15	0.29	0.44	0.59	0.00	0.12	0.24	0.36	0.48
L-threonine	0.00	0.00	0.03	0.10	0.16	0.00	0.00	0.01	0.06	0.11
DL-methionine	0.00	0.00	0.00	0.00	0.01	---	---	---	---	---
L-isoleucine	0.00	0.00	0.00	0.03	0.10	0.00	0.00	0.00	0.00	0.06
L-valine	0.00	0.00	0.00	0.00	0.05	---	---	---	---	---
L-tryptophan	0.00	0.00	0.02	0.05	0.07	0.00	0.00	0.02	0.04	0.06
Paylean[5]	---	---	---	---	---	---	---	---	---	---
Calculated composition, %										
Total lysine	0.90	0.89	0.88	0.87	0.86	0.81	0.80	0.79	0.78	0.77
SID lysine	0.74	0.74	0.74	0.74	0.74	0.65	0.65	0.65	0.65	0.65
Total P	0.43	0.42	0.41	0.39	0.38	0.42	0.41	0.39	0.38	0.37
Available P	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
Total Ca	0.56	0.56	0.56	0.56	0.56	0.46	0.46	0.46	0.46	0.46
ME, Mcal/kg	3.37	3.37	3.37	3.37	3.37	3.38	3.38	3.38	3.38	3.38

[1]C = control diet formulated to meet 95% of the SID lysine requirement; RCP1 = reduced CP diet with added L-lysine hydrochloride;

RCP2 = reduced CP diet with added L-lysine, L-threonine, and L-tryptophan; RCP3 = low CP diet with added L-lysine, (Cont.) L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine; and RCP4 = lowest CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine.

[2]Dried distillers' grains with solubles

[3]Supplied 5,512 IU vitamin A, 689 IU vitamin D_3 (D-activated animal sterol), 22.05 IU vitamin E, 2.2 mg vitamin K (menadione sodium bisulfite), 13.78 mg pantothenic acid (D-calcium pantothenate), 4.8 mg niacin, 4.13 mg riboglavin, and 19.3 µg vitamin B12 per kg of feed.

[4]Supplied 0.20 mg SE from sodium selenite, 26.4 mg Mn from manganous oxide, 110 mg Zn from zinc oxide, 110 mg Fe from ferrous sulfate, 11 mg Cu from copper sulfate, and 0.20 mg I from calcium iodate per kg of feed.

[5]Paylean (ractopamine hydrochloride; Elanco Animal Health, a Division of Eli Lilly, Co., Greenfield, IN).

Table 2. Composition (as-fed basis) of finisher diets[1] (Cont.)

	Finisher-3 (104 to 127 kg)				
	C	RCP1	RCP2	RCP3	RCP4
CP, %:	20.24	18.60	17.01	15.44	13.93
Ingredient, %					
Corn	69.14	73.76	78.24	82.25	86.23
Soybean meal	28.65	23.85	19.10	14.35	9.60
DDGS[2]	---	---	---	---	---
Limestone	0.60	0.62	0.65	0.67	0.69
Restaurant grease	0.45	0.40	0.36	0.46	0.49
Salt	0.50	0.50	0.50	0.50	0.50
Dicalcium phosphate	0.36	0.40	0.43	0.46	0.49
Vitamin premix[3]	0.13	0.13	0.13	0.13	0.13
Trace mineral premix[4]	0.10	0.10	0.10	0.10	0.10
Ethoxiquin	0.03	0.03	0.03	0.03	0.03
Ronozyme	0.02	0.02	0.02	0.02	0.02
Potassium sulfate	0.00	0.00	0.00	0.25	0.50
L-lysine	0.00	0.15	0.30	0.45	0.60
L-threonine	0.00	0.03	0.10	0.16	0.23
DL-methionine	0.00	0.00	0.02	0.06	0.10
L-isoleucine	0.00	0.00	0.00	0.03	0.11
L-valine	0.00	0.00	0.00	0.02	0.10
L-tryptophan	0.00	0.00	0.02	0.05	0.07
Paylean[5]	0.03	0.03	0.03	0.03	0.03
Calculated composition, %					
Total lysine	1.02	1.01	1.00	0.99	0.98
SID lysine	0.90	0.90	0.90	0.90	0.90
Total P	0.46	0.44	0.43	0.41	0.40
Available P	0.25	0.25	0.25	0.25	0.25
Total Ca	0.45	0.45	0.45	0.45	0.45
ME, Mcal/kg	3.38	3.38	3.38	3.38	3.38

[1]C = control diet formulated to meet 95% of the SID lysine requirement; RCP1 = reduced CP diet with added L-lysine hydrochloride; RCP2 = reduced CP diet with added L-lysine, L-threonine, and L-tryptophan; RCP3 = low CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine; and RCP4 = lowest CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine

[2]Dried distillers' grains with solubles

[3]Supplied 5,512 IU vitamin A, 689 IU vitamin D_3 (D-activated animal sterol), 22.05 IU vitamin E, 2.2 mg vitamin K (menadione sodium bisulfite), 13.78 mg pantothenic acid (D-calcium pantothenate), 4.8 mg niacin, 4.13 mg riboglavin, and 19.3 µg vitamin B12 per kg of feed

[4]Supplied 0.20 mg SE from sodium selenite, 26.4 mg Mn from manganous oxide, 110 mg Zn from zinc oxide, 110 mg Fe from ferrous sulfate, 11 mg Cu from copper sulfate, and 0.20 mg I from calcium iodate per kg of feed

[5]Paylean (ractopamine hydrochloride; Elanco Animal Health, a Division of Eli Lilly, Co., Greenfield, IN)

Table 3. Amino acid composition (as-fed basis) of grower diets[1]

	Grower-1 phase (23 to 41 kg)					Grower-2 phase (41 to 59 kg)				
	C	RCP1	RCP2	RCP3	RCP4	C	RCP1	RCP2	RCP3	RCP4
CP, %:	23.70	21.61	19.58	17.61	15.72	21.53	19.46	17.44	15.49	13.61
Calculated, %										
Lysine	1.19	1.17	1.16	1.14	1.13	1.03	1.02	1.00	0.99	0.98
Methionine	0.39	0.36	0.33	0.35	0.38	0.37	0.34	0.31	0.29	0.32
Methionine + cysteine	0.81	0.75	0.69	0.67	0.66	0.75	0.69	0.63	0.58	0.58
Threonine	0.91	0.81	0.77	0.76	0.75	0.83	0.73	0.68	0.66	0.65
Tryptophan	0.27	0.23	0.22	0.22	0.22	0.23	0.20	0.19	0.19	0.18
Isoleucine	0.98	0.87	0.76	0.69	0.68	0.81	0.71	0.62	0.59	0.58
Valine	1.14	1.03	0.92	0.81	0.80	0.97	0.87	0.77	0.69	0.68
Leucine	2.20	2.05	1.89	1.73	1.56	2.02	1.87	1.71	1.56	1.40
Histidine	0.64	0.58	0.51	0.45	0.39	0.58	0.52	0.46	0.40	0.34
Arginine	1.45	1.27	1.09	0.90	0.72	1.32	1.15	0.97	0.79	0.61
Phenylalanine	1.17	1.05	0.94	0.82	0.70	1.06	0.95	0.83	0.72	0.60
Analyzed, %										
CP	23.44	21.40	19.42	17.63	15.16	20.97	19.27	16.99	14.98	13.66
Lysine	1.15	1.14	1.16	1.16	1.12	1.00	0.99	0.98	0.96	0.93
Methionine	0.38	0.35	0.33	0.34	0.34	0.36	0.34	0.31	0.28	0.31
Methionine + cysteine	0.76	0.69	0.66	0.63	0.61	0.70	0.67	0.61	0.55	0.56
Threonine	0.88	0.77	0.76	0.74	0.78	0.78	0.71	0.64	0.62	0.67
Tryptophan	0.27	0.24	0.23	0.22	0.22	0.23	0.20	0.19	0.20	0.18
Isoleucine	0.96	0.86	0.79	0.70	0.62	0.85	0.76	0.64	0.60	0.55
Valine	1.10	1.00	0.92	0.81	0.75	0.99	0.90	0.79	0.70	0.66
Leucine	2.12	1.94	1.88	1.71	1.48	1.93	1.83	1.62	1.48	1.36
Histidine	0.60	0.56	0.51	0.45	0.38	0.54	0.49	0.44	0.38	0.33
Arginine	1.45	1.26	1.15	0.98	0.75	1.28	1.12	0.97	0.80	0.63
Phenylalanine	1.15	1.02	0.96	0.84	0.68	1.02	0.93	0.80	0.69	0.60

[1]C = control diet formulated to meet 95% of the SID lysine requirement; RCP1 = reduced CP diet with added L-lysine hydrochloride; RCP2 = reduced CP diet with added L-lysine, L-threonine, and L-tryptophan; RCP3 = low CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine; and RCP4 = lowest CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine.

Table 4. Amino acid composition (as-fed basis) of finisher diets[1]

	Finisher-1 (59 to 82 kg)					Finisher-2 (82 to 104 kg)				
	C	RCP1	RCP2	RCP3	RCP4	C	RCP1	RCP2	RCP3	RCP4
CP, %:	18.97	17.34	15.74	14.16	12.68	17.66	16.30	14.96	13.64	12.37
Calculated, %										
Lysine	0.90	0.89	0.88	0.87	0.86	0.81	0.80	0.79	0.78	0.77
Methionine	0.34	0.31	0.29	0.27	0.26	0.32	0.30	0.28	0.26	0.24
Methionine + cysteine	0.69	0.64	0.59	0.54	0.50	0.65	0.61	0.57	0.53	0.49
Threonine	0.71	0.64	0.60	0.59	0.58	0.66	0.60	0.54	0.54	0.53
Tryptophan	0.20	0.17	0.17	0.16	0.16	0.18	0.15	0.15	0.15	0.14
Isoleucine	0.75	0.66	0.57	0.51	0.50	0.68	0.61	0.54	0.47	0.45
Valine	0.90	0.81	0.73	0.64	0.60	0.84	0.76	0.69	0.62	0.55
Leucine	1.83	1.71	1.58	1.45	1.33	1.74	1.64	1.54	1.43	1.32
Histidine	0.52	0.47	0.42	0.37	0.32	0.48	0.44	0.40	0.36	0.32
Arginine	1.12	0.98	0.83	0.69	0.55	1.01	0.90	0.78	0.66	0.54
Phenylalanine	0.92	0.83	0.73	0.64	0.55	0.85	0.77	0.70	0.62	0.54
Analyzed, %										
CP	19.05	17.64	15.53	14.17	12.82	17.54	16.54	15.21	14.08	12.50
Lysine	0.85	0.84	0.79	0.84	0.88	0.76	0.77	0.76	0.78	0.72
Methionine	0.33	0.32	0.29	0.27	0.26	0.32	0.31	0.29	0.27	0.25
Methionine + cysteine	0.66	0.62	0.57	0.53	0.50	0.63	0.61	0.58	0.53	0.50
Threonine	0.70	0.64	0.57	0.58	0.57	0.65	0.60	0.55	0.55	0.53
Tryptophan	0.21	0.18	0.17	0.16	0.15	0.18	0.16	0.16	0.15	0.14
Isoleucine	0.74	0.66	0.57	0.51	0.49	0.67	0.61	0.56	0.50	0.45
Valine	0.88	0.81	0.70	0.63	0.60	0.81	0.75	0.71	0.64	0.55
Leucine	1.78	1.66	1.54	1.40	1.30	1.73	1.66	1.59	1.48	1.37
Histidine	0.49	0.45	0.39	0.35	0.32	0.46	0.43	0.40	0.37	0.32
Arginine	1.11	1.00	0.83	0.71	0.58	1.02	0.93	0.82	0.70	0.59
Phenylalanine	0.91	0.83	0.73	0.64	0.56	0.85	0.79	0.73	0.65	0.57

[1]C = control diet formulated to meet 95% of the SID lysine requirement; RCP1 = reduced CP diet with added L-lysine hydrochloride; RCP2 = reduced CP diet with added L-lysine, L-threonine, and L-tryptophan; RCP3 = low CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine; and RCP4 = lowest CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine.

Table 4. Amino acid composition (as-fed basis) of finisher diets[1] Cont

	Finisher-3 (104 to 127 kg)				
	C	RCP1	RCP2	RCP3	RCP4
CP, %:	20.24	18.60	17.01	15.44	13.93
Calculated, %					
Lysine	1.02	1.01	1.00	0.99	0.98
Methionine	0.35	0.33	0.32	0.34	0.36
Methionine + cysteine	0.68	0.64	0.61	0.60	0.60
Threonine	0.78	0.74	0.73	0.72	0.71
Tryptophan	0.23	0.20	0.19	0.19	0.19
Isoleucine	0.81	0.73	0.64	0.59	0.58
Valine	0.92	0.84	0.76	0.69	0.68
Leucine	1.83	1.71	1.59	1.47	1.34
Histidine	0.52	0.47	0.42	0.38	0.33
Arginine	1.30	1.15	1.00	0.85	0.70
Phenylalanine	0.99	0.90	0.81	0.72	0.62
Analyzed, %					
CP	18.82	17.72	16.03	14.12	12.62
Lysine	1.00	0.99	0.99	0.97	0.96
Methionine	0.30	0.29	0.28	0.29	0.31
Methionine + cysteine	0.61	0.58	0.55	0.53	0.53
Threonine	0.71	0.71	0.70	0.64	0.61
Tryptophan	0.23	0.21	0.20	0.19	0.18
Isoleucine	0.78	0.72	0.63	0.55	0.53
Valine	0.89	0.82	0.73	0.63	0.62
Leucine	1.66	1.57	1.43	1.27	1.15
Histidine	0.50	0.46	0.41	0.35	0.31
Arginine	1.26	1.14	1.00	0.83	0.69
Phenylalanine	0.95	0.87	0.78	0.65	0.56
Total Ca	0.45	0.45	0.45	0.45	0.45
ME, Mcal/kg	3.38	3.38	3.38	3.38	3.38

[1]C = control diet formulated to meet 95% of the SID lysine requirement; RCP1 = reduced CP diet with added L-lysine hydrochloride; RCP2 = reduced CP diet with added L-lysine, L-threonine, and L-tryptophan; RCP3 = low CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine; and RCP4 = lowest CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine.

Table 5. Main effects of gender and reduced CP diet on live pig performance

	Gender			Reduced CP[1]						
	Gilt	Barrow	SEM	C	RCP1	RCP2	RCP3	RCP4	SEM	Effect[2]
ADG, kg										
Grower-1	0.74[b]	0.78[a]	0.026	0.77	0.78	0.77	0.75	0.72	0.029	
Grower-2	0.85[b]	0.94[a]	0.029	0.93	0.88	0.91	0.90	0.86	0.031	L*, C*
Finisher-1	0.97[b]	1.07[a]	0.014	1.02	1.05	1.03	1.00	0.99	0.021	
Finisher-2	0.92[b]	0.97[a]	0.012	0.92	0.95	0.94	0.96	0.95	0.019	
Finisher-3	1.19	1.16	0.019	1.15	1.16	1.23	1.23	1.10	0.029	Qd**, C*
Overall	0.93[b]	0.99[a]	0.013	0.96	0.97	0.98	0.98	0.92	0.015	L*, Qd***
ADFI, kg										
Grower-1	1.46[b]	1.51[a]	0.07	1.46	1.46	1.53	1.52	1.48	0.07	
Grower-2	1.99[b]	2.22[a]	0.09	2.16	2.07	2.12	2.07	2.10	0.09	
Finisher-1	2.40[b]	2.74[a]	0.07	2.65	2.58	2.57	2.56	2.48	0.08	L*
Finisher-2	2.86[b]	3.21[a]	0.06	3.04	3.10	2.99	3.07	2.99	0.08	
Finisher-3	2.97[b]	3.16[a]	0.04	3.09[ab]	3.02[bc]	3.05[bc]	3.21[a]	2.93[c]	0.06	C**
Overall	2.34[b]	2.60[a]	0.06	2.51	2.47	2.48	2.48	2.42	0.06	
G:F										
Grower-1	0.51	0.52	0.00	0.53[ab]	0.53[a]	0.51[bc]	0.50[c]	0.49[c]	0.011	L***
Grower-2	0.43	0.42	0.01	0.43[a]	0.42[a]	0.43[a]	0.43[a]	0.41[b]	0.007	L*, C*
Finisher-1	0.40	0.39	0.01	0.39	0.41	0.40	0.39	0.40	0.007	C*
Finisher-2	0.32[a]	0.30[b]	0.01	0.30	0.31	0.32	0.32	0.32	0.008	L*
Finisher-3	0.40[a]	0.37[b]	0.01	0.37[b]	0.38[b]	0.40[a]	0.39[ab]	0.38[b]	0.008	Qd**
Overall	0.39[a]	0.38[b]	0.01	0.38[b]	0.39[a]	0.39[a]	0.38[ab]	0.38[b]	0.005	Qd***

[a – c]Within a row and main effect, least squares means lacking a common superscript letter differ, $P < 0.05$.

[1]C = control diet formulated to meet 95% of the SID lysine requirement; RCP1 = reduced CP diet with added L-lysine hydrochloride; RCP2 = reduced CP diet with added L-lysine, L-threonine, and L-tryptophan; RCP3 = low CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine; and RCP4 = lowest CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine.

[2]R = reduced CP main effect; L = linear effect of reduced CP; Qd = quadratic effect of reduced CP; C = cubic effect of reduced CP; and Qt = quartic effect of reduced CP (*$P \leq 0.05$; **$P \leq 0.01$; and ***$P \leq 0.001$).

[3]Lean muscle weight = 2.2 × (-0.534 + (0.291 × BW, lbs) – (16.498 × 10^{th} rib fat depth, in) + (5.425 × LM area, in^2) + (0.833 × gender)), where 1 = barrow and 2 = gilt.

[4]Grower-1 (23 to 41 kg); Grower-2 (41 to 59 kg); Finisher-1 (59 to 82 kg); Finisher-2 (82 to 104 kg); Finisher-3 (104 to 127 kg); Overall (23 to 127 kg).

Table 6. Main effects of gender and reduced CP diet on carcass quality

	Gender			Reduced CP[1]						
	Gilt	Barrow	SEM	C	RCP1	RCP2	RCP3	RCP4	SEM	Effect[2]
10th rib fat depth, mm										
Grower-1	6.9[b]	7.2[a]	0.27	6.5[b]	6.9[ab]	7.0[a]	7.4[a]	7.4[a]	0.31	L***
Grower-2	8.5[b]	9.5[a]	0.25	8.5	8.8	9.5	8.8	9.4	0.36	
Finisher-1	12.1[b]	15.1[a]	0.32	13.3	13.3	13.5	13.4	14.4	0.49	
Finisher-2	18.4[b]	24.5[a]	0.76	20.8	20.9	21.0	21.9	22.5	0.95	
Finisher-3	20.4[b]	24.4[a]	0.69	23.4	22.9	23.8	24.6	24.8	0.84	L*
LM area, cm^2										
Grower-1	19.1	18.5	0.92	18.4[bc]	19.6[a]	18.5[bc]	19.2[a]	18.2[c]	0.96	Qd*
Grower-2	26.2	26.7	1.06	26.3[bc]	27.5[a]	26.3[bc]	26.8[ab]	25.3[c]	1.11	L*, Qd*
Finisher-1	31.8[b]	39.3[a]	1.04	32.1[a]	33.0[a]	32.7[a]	32.4[a]	30.8[b]	1.09	L*, Qd**
Finisher-2	40.1	32.3	1.17	39.5	39.4	40.0	40.6	38.8	1.30	
Finisher-3	44.6	43.9	0.87	44.5[a]	45.2[a]	45.0[a]	44.8[a]	41.8[b]	0.95	L***, Qd***
Calculated lean wt, kg[3]										
Grower-1	16.6[a]	16.1[b]	0.84	16.4[a]	16.8[a]	16.4[a]	16.4[a]	15.8[b]	0.85	L**, Qd*
Grower-2	24.1[b]	24.6[a]	1.05	24.6[a]	24.8[a]	24.3[a]	24.6[a]	23.4[b]	1.07	L**, Qd*
Finisher-1	31.3	31.6	1.09	31.8[a]	32.0[a]	31.9[a]	31.6[a]	30.1[b]	1.11	L***, Qd**
Finisher-2	40.1	39.4	1.04	39.9	40.0	40.1	40.0	38.7	1.10	
Finisher-3	48.2[a]	47.3[b]	0.91	48.0[a]	48.6[a]	48.6[a]	48.3[a]	45.3[b]	0.97	L***, Qd***

[a – c]Within a row and main effect, least squares means lacking a common superscript letter differ, $P < 0.05$.

[1]C = control diet formulated to meet 95% of the SID lysine requirement; RCP1 = reduced CP diet with added L-lysine hydrochloride; RCP2 = reduced CP diet with added L-lysine, L-threonine, and L-tryptophan; RCP3 = low CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine; and RCP4 = lowest CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine.

[2]R = reduced CP main effect; L = linear effect of reduced CP; Qd = quadratic effect of reduced CP; C = cubic effect of reduced CP; and Qt = quartic effect of reduced CP (*$P \leq 0.05$; **$P \leq 0.01$; and ***$P \leq 0.001$).

[3]Lean muscle weight = 2.2 × (-0.534 + (0.291 × BW, lbs) – (16.498 × 10th rib fat depth, in) + (5.425 × LM area, in^2) + (0.833 × gender)), where 1 = barrow and 2 = gilt.

[4]Grower-1 (23 to 41 kg); Grower-2 (41 to 59 kg); Finisher-1 (59 to 82 kg); Finisher-2 (82 to 104 kg); Finisher-3 (104 to 127 kg)

Table 7. Main effects of gender and reduced CP diet on carcass and fresh ham composition

	Gender			Reduced CP[1]						
	Gilt	Barrow	SEM	C	RCP1	RCP2	RCP3	RCP4	SEM	Effect[2]
HCW, kg	92.2[b]	97.0[a]	0.99	93.8	94.7	95.3	96.2	93.2	1.56	
Dressing percent	72.37[b]	73.09[a]	0.187	72.64	72.66	72.50	72.73	73.12	0.253	
10th rib fat depth, mm	18.3[b]	23.1[a]	0.34	19.7	19.8	20.6	21.6	21.8	0.54	L***
LM depth, mm	63.6	64.1	0.22	64.3	64.5	63.4	64.6	62.3	1.43	
Fat-free lean yield, %	53.92[a]	51.96[b]	0.217	53.43	53.33	52.81	52.70	52.41	0.343	L*
Fresh ham wt, kg	11.11	11.28	0.146	11.14	11.32	11.21	11.48	10.85	0.231	
Ham lean, %	70.69[a]	68.27[b]	0.284	70.38	69.94	69.39	69.36	68.33	0.449	L**
Semimembranosus, %	16.53[a]	15.78[b]	0.244	16.30	16.38	16.00	15.93	16.16	0.385	
Biceps femoris, %	17.92	17.48	0.217	17.81	17.52	17.88	17.53	17.77	0.343	
Semitendinosus, %	5.25[a]	5.01[b]	0.068	5.10	5.25	5.14	5.09	5.07	0.107	
Quadriceps complex, %	11.95[a]	11.58[b]	0.088	11.88	11.91	11.79	11.62	11.64	0.140	
Ham fat, %	10.03[b]	12.80[a]	0.329	10.56	11.13	11.03	12.18	12.17	0.520	L*
Ham bone, %	11.54	11.10	0.191	11.29	11.26	11.61	10.77	11.67	0.301	
Ham skin, %	7.71	7.82	0.087	7.77	7.69	7.94	7.64	7.79	0.138	

[a – c]Within a row and main effect, least squares means lacking a common superscript letter differ, $P < 0.05$.

[1]C = control diet formulated to meet 95% of the SID lysine requirement; RCP1 = reduced CP diet with added L-lysine hydrochloride; RCP2 = reduced CP diet with added L-lysine, L-threonine, and L-tryptophan; RCP3 = low CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine; and RCP4 = lowest CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine.

[2]R = reduced CP main effect; L = linear effect of reduced CP; Qd = quadratic effect of reduced CP; C = cubic effect of reduced CP; and Qt = quartic effect of reduced CP (*$P \leq 0.05$; **$P \leq 0.01$; and ***$P \leq 0.001$)."

Table 8. Main effects of gender and reduced CP diet on LM quality attributes

	Gender			Reduced CP[1]						
	Gilt	Barrow	SEM	C	RCP1	RCP2	RCP3	RCP4	SEM	Effect[2]
Ultimate LM pH	5.66[b]	5.78[a]	0.031	5.69	5.67	5.73	5.78	5.73	0.048	
Drip loss, %	1.95[a]	0.62[b]	0.107	1.82	1.97	1.81	1.65	1.65	0.162	
Moisture, %	71.36[a]	70.88[b]	0.137	70.82	71.05	71.23	71.08	71.43	0.216	
American color[3]	3.4[b]	3.6[a]	0.11	3.4	3.4	3.5	3.6	3.6	0.08	
Japanese color[4]	3.5[b]	3.7[a]	0.12	3.5	3.6	3.6	3.7	3.7	0.08	
Lightness (L*)[5]	54.43[a]	52.82[b]	0.810	54.23	53.66	54.19	52.77	53.27	0.564	
Redness (a*)[5]	7.47	7.60	0.219	7.47	7.23	7.68	8.02	7.28	0.138	C**
Yellowness (b*)[5]	14.84	14.40	0.264	14.77	14.40	14.84	14.59	14.51	0.167	
Firmness[6]	2.3	2.3	0.07	2.2	2.3	2.4	2.4	2.3	0.05	
Marbling[7]	2.1[b]	2.4[a]	0.09	2.3	2.5	2.1	2.1	2.4	0.09	C*
Intramuscular fat, %	5.68[b]	6.93[a]	0.278	6.03	6.68	6.32	6.48	6.01	0.432	
Protein, %	81.67	81.08	0.437	81.85	81.14	81.03	81.51	81.36	0.569	
Ash, %	3.90	4.01	0.105	4.25	4.02	3.75	3.67	4.09	0.166	Qd*
Cooking loss, %	14.63	15.33	0.275	15.32	14.70	14.92	14.93	15.04	0.420	
Shear force, kg	3.47	3.32	0.118	3.17	3.52	3.52	3.23	3.51	0.156	C*

[a,b]Within a row and main effect, least squares means lacking a common superscript letter differ, $P < 0.05$.

[1]C = control diet formulated to meet 95% of the SID lysine requirement; RCP1 = reduced CP diet with added L-lysine hydrochloride; RCP2 = reduced CP diet with added L-lysine, L-threonine, and L-tryptophan; RCP3 = low CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine; and RCP4 = lowest CP diet with added L-lysine, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine.

[2]R = reduced CP main effect; L = linear effect of reduced CP; Qd = quadratic effect of reduced CP; C = cubic effect of reduced CP; and Qt = quartic effect of reduced CP (*$P \leq 0.05$; **$P \leq 0.01$; and ***$P \leq 0.001$).

[3]1 = pale pinkish gray to 6 = dark purplish red (NPPC, 1999).

[4]1 = pale gray to 6 = dark purple (Nakai et al., 1975).

[5]L* = measure of darkness to lightness (larger value indicates a lighter color); a* = measure of redness (larger value indicates a redder color); and b* = measure of yellowness (larger value indicates a more yellow color).

[6]1 = soft to 3 very firm (NPPC, 2000).

[7]1 = 1% i.m. fat to 10% = 10% i.m. fat (NPPC, 1999).

Table 9. Least-square means and contrasts for fatty acid composition (%) of LM IMF

	Diet					Gender		*P*-value		
Fatty Acid	Control	RCP1	RCP2	RCP3	RCP4	Gilt	Barrow	D	G	D x G
Total SFA	38.71	38.82	38.85	38.28	38.21	38.05	39.09	0.35	<0.001	0.87
14:00	1.35	1.36	1.35	1.38	1.33	1.3	1.41	0.78	<0.001	0.85
16:00	24.6	24.48	24.38	24.37	24.05	24.05	24.71	0.16	<0.001	0.44
18:00	12.13	12.36	12.5	11.93	12.2	12.11	12.34	0.3	0.2	0.5
Total MUFA	46.19	45.6	45.59	47.08	46.93	45.83	46.73	0.22	0.09	0.3
16:1c	3.31	3.27	3.19	3.49	3.49	3.26	3.44	0.12	0.049	0.06
18:1c9	37.18	36.69	36.76	37.75	37.6	36.89	37.5	0.46	0.18	0.6
18:1c11	4.75	4.73	4.76	4.94	4.92	4.79	4.86	0.2	0.32	0.18
Total PUFA	13.82	14.25	14.15	13.31	13.48	14.74	12.87	0.77	0.001	0.39
18:2n6	10.5	10.71	10.56	10.03	10.12	11.01	9.76	0.76	0.002	0.37
18:3n3	0.32	0.29	0.26	0.25	0.23	0.28	0.27	<0.001	0.06	0.57
PUFA:SFA	0.36	0.37	0.37	0.32	0.35	0.39	0.33	0.093	<0.001	0.42

C: control; RCP: reduced crude protein; DDGS: dried distiller's grains; D: diet; G: gender; SFA: saturated fatty acid; MUFA: monounsaturated fatty acid; PUFA: polyunsaturated fatty acid.

Table 10. Least-square means and contrasts for fatty acid composition (%) of jowl fat

	Diet					Gender		*P*-value		
Fatty Acid	Control	RCP1	RCP2	RCP3	RCP4	Gilt	Barrow	D	G	D x G
Total SFA	32.88	32.86	32.28	31.52	31.22	31.76	32.54	<0.001	<0.01	0.39
14:00	1.26	1.24	1.29	1.27	1.31	1.23	1.31	0.33	<0.01	0.56
16:00	21.36	21.26	21.09	20.87	20.84	20.80	21.36	0.21	<0.01	0.24
18:00	9.39	9.56	9.08	8.61	8.30	8.94	9.04	<0.001	0.58	0.58
Total MUFA	46.01	46.55	47.37	48.78	48.91	47.32	47.73	<0.001	0.25	0.97
16:1c	2.35	2.31	2.52	2.70	2.91	2.45	2.66	<0.001	0.01	0.59
18:1c9	38.62	39.25	39.65	40.65	40.41	39.70	39.74	<0.001	0.88	1.00
18:1c11	3.83	3.79	3.99	4.20	4.35	3.97	4.09	<0.001	0.21	0.91
Total PUFA	19.71	19.29	19.00	18.40	18.51	19.57	18.40	0.008	<0.001	0.42
18:2n6	17.24	16.89	16.69	16.16	16.28	17.16	16.14	0.022	<0.001	0.49
18:3n3	0.80	0.75	0.69	0.65	0.61	0.72	0.68	<0.001	<0.001	0.27
PUFA:SFA	0.60	0.59	0.59	0.59	0.59	0.62	0.57	0.90	<0.001	0.15

C: control; RCP: reduced crude protein; DDGS: dried distiller's grains; D: diet; G: gender; SFA: saturated fatty acid; MUFA: monounsaturated fatty acid; PUFA: polyunsaturated fatty acid.

References

Alonso, V., M. del Mar Campo, L. Provincial, P. Roncalés, and J. A. Beltrán. 2010. Effect of protein level in commercial diets on pork meat quality. Meat Sci. 85:7-14. doi:10.1016/j.meatsci.2009.11.015

Apple, J. K., P. J. Rinker, F. K. McKeith, S. N. Carr, T. A. Armstrong, and P. D. Matzat. 2007. Review: Meta-analysis of the ractopamine response in finishing swine. The Prof. Anim. Sci. 23:179-196. doi:10.15232/S1080-7446(15)30964-5

Apple, J. K., J. R. Davis, L. K. Rakes, C. V. Maxwell, M. R. Stivarius, and F. W. Pohlman. 2001. Effects of dietary magnesium and duration of refrigerated storage on the quality of vacuum-packaged, boneless pork loins. Meat Sci. 57:43-53. doi:10.1016/s0309-1740(00)00075-9

Apple, J. K., C. V. Maxwell, B. deRodas, H. B. Watson, and Z. B. Johnson. 2000. Effect of magnesium mica on performance and carcass quality of growing-finishing swine. J. Anim. Sci. 78:2135-2143. doi:/2000.7882135x

Barton-Gade, P., C. Bejerholm. 1985. Eating quality of pork. Pig Farming. 33, 55.

Bejerholm, C. and P. A. Barton-Gade. 1986. Effect of intramuscular fat level on eating quality of pig meat. In: Proc. 32nd Euro. Meet. Meat Res. Workers, Ghent, BE. Pp. 389-391.

Brewer, M. S., L. G. Zhu, and F. K. McKeith. 2001. Marbling effects on quality characteristics of pork loin chops: consumer purchase intent, visual and sensory characteristics. Meat Sci. 59:153-163. doi:10.1016/S0309-1740(01)00065-1

Cameron, N. D. and M. Enser. 1991. Fatty acid composition of lipid *longissimus dorsi* muscle of Duroc and British Landrace pigs and its relationship with eating quality. Meat Sci. 29:295-307. doi:10.1016/0309-1740(91)90009-f

Carpenter, D. A., F. P. O'Mara, and J. V. O'Doherty. 2004. The effect of dietary crude protein concentration on growth performance, carcass composition and nitrogen excretion in entire grower-finisher pigs. Ir. J. Agric. Food Res. 43:227-236.

Chen, H. Y., P. S. Miller, A. J. Lewis, C. K. Wolverton, and W. W. Stroup. 1995. Changes in plasma urea concentration can be used to determine protein requirements of two populations of pigs with different protein accretion rates. J. Anim. Sci. 73:2631-2639. doi:/1995.7392631x

Chen, H. Y., A. J. Lewis, P. S. Miller, and J. T. Yen. 1999. The Effect of Excess Protein on Growth Performance and Protein Metabolism of Finishing Barrows and Gilts. J. Anim. Sci. 77:3238-3247. doi:/1999.77123238x

Cisneros, F., M. Ellis, D. H. Baker, R. A. Easter, and F. K. McKeith. 1996. The influence of short-term feeding of amino acid-deficient diets and high dietary leucine levels on the

intramuscular fat content of pig muscle. J. Anim. Sci. 63:517-522. doi:10.1017/s1357729800015411

Cromwell, G. L., T. R. Cline, J. D. Crenshaw, T. D. Crenshaw, R. C. Ewan, C. R. Hamilton, A. J. Lewis, D. C. Mahan, E. R. Miller, and J. E. Pettigrew. 1993. The dietary protein and (or) lysine requirements of barrows and gilts. NCR-42 Committee on Swine Nutrition. J. Anim. Sci. 71:1510-1519. doi:/1993.7161510x

Cromwell, G. L. 1996. Synthetic amino acid may improve performance, reduce nitrogen excretion. Feedstuffs. 68(49):12-31.

Damron, W. S. 2013. Introduction to Animal Science. Global, Biological, Social, and Industry Perspectives. 5th ed. Pearson Education, Inc, Upper Saddle River, NJ.

DeCamp, S. A., S. L. Hankins, A. L. Carroll, D. J. Ivers, B. T. Richert, A. L. Sutton, and D. B. Anderson. 2001. Effects of ractopamine and level of dietary crude protein on nitrogen and phosphorus excretion from finishing pigs. Purdue University Swine Research Report. Pp. 97-102.

Dourmad, J. Y., D. Guillou, B. Sève, Y. Henry. 1996. Response to dietary lysine supply during the finishing period in pigs. Livest. Prod. Sci., 45(1996), pp. 179-186. doi:10.1016/0301-6226(96)00004-8

Enser, M. 1984. The chemistry, biochemistry and nutritional importance of animal fats. In J. Wiseman, Fats in Anim. Nut. (pp. 23-51). Buttersworth. doi:10.1016/b978-0-408-10864-5.50008-5

Feed Additive Compendium. 2010. Supplement # 4. Miller Publishing Company, 12400 Whitewater Drive, Suite 160. Minnetonka, Minn. 55343.

Fernandez, X., G. Monin, A. Talmant, J. Mourot, and B. Lebret. 1999b. Influence of intramuscular fat content on the quality of pig meat 2. Consumer acceptability of muscle longissimus lumborum. Meat Sci. 53:67-72. doi:10.1016/s0309-1740(99)00038-8

Figueroa, J. L., A. J. Lewis, P. S. Miller, R. L. Fischer, R. S. Gómez, and R. M. Diedrichsen. 2002. Nitrogen metabolism and growth performances of gilts fed standard corn-soybean meal diets or low-crude protein, amino acid-supplemented diets. J. Anim. Sci. 80:2911-2919. doi:/2002.80112911x

Fortin, A., W. M. Robertson, and A. K. W. Tong. 2004. The eating quality of Canadian pork and its relationship with intramuscular fat. Meat Sci. 69:297-305. doi:10.1016/j.meatsci.2004.07.011

Gaines, A. M., B. W. Ratliff, P. Srichana, G. L. Allee, and J. L. Usry. 2004. Evaluation of high synthetic lysine diets for pigs fed ractopamine HCl (Paylean). J. Anim. Sci. 82:68

Gatel, F., and F. Grosjean. 1992. Effect of protein content of the diet on nitrogen excretion by pigs. Livest. Prod. Sci. 31:109-120. doi:10.1016/0301-6226(92)90059-d

Goerl, K. F., S. J. Eilert, R. W. Mandigo, H. Y. Chen, and P. S. Miller. 1995. Pork characteristics as affected by two populations of swine and six crude protein levels. J. Anim. Sci. 73:3621-3626. doi:/1995.73123621x

Gómez, R. S., A. J. Lewis, P. S. Miller, and H. Y. Chen. 2002. Growth performance, diet apparent digestibility, and plasma metabolite concentrations of barrows fed corn-soybean meal diets or low-protein amino acid-supplemented diets at different feeding level. J. Anim. Sci. 80(3):644-653. doi:/2002.803644x

Hansen, B. C., and A. J. Lewis. 1993. Effects of dietary protein concentration (corn:soybean meal) on the performance and carcass characteristics of growing boars, barrows, and gilts: Mathematical descriptions. J. Anim. Sci. 71:2122-2132. doi:/1993.7182122x

Hinson, R. B., A. P. Schinckel, J. S. Radcliffe, G. L. Allee, A. L. Sutton, and B. T. Richert. 2009. Effect of feeding reduced crude protein and phosphorus diets on weaning-finishing pig growth performance, carcass characteristics, and bone characteristics. J. Anim. Sci. 87:1502-1517. doi:10.2527/jas.2008-1325

Honikel, D. O., C. J. Kim, R. Hamm, and P. Roncales. 1986. Sarcomere shortening of prerigor muscles and its influence on drip loss. Meat Sci. 16:267-282. doi:10.1016/0309-1740(86)90038-0

Kerr, B. J., and R. A. Easter. 1995. Effect of feeding reduced protein, amino-acid supplemented diets on nitrogen and energy balance in grower pigs. J. Anim. Sci. 73:3000-3008. doi:/1995.73103000x

Kerr, B. J., F. K. McKeith, and R. A. Easter. 1995. Effect on Performance and Carcass Characteristics of Nursery to Finisher Pigs Fed Reduced Crude Protein, Amino Acid-Supplemented Diets. J. Anim. Sci. 73:433-440. doi:/1995.732433x

Kerr, B. J., J. T. Yen, J. A. Nienabar, and R. A. Easter. 2003. Influences of dietary protein, level, amino acid supplementation and environmental temperature on performance, body composition, organ weights and total heat production of growing pigs. J. Anim. Sci. 81:1998-2007. doi:/2003.8181998x

Knowles, T. A., L. L. Southern, T. D. Bidner, B. J. Kerr, and K. G. Friesen. 1998. Effect of dietary fiber or fat in low-crude protein, crystalline amino acid-supplemented diets for finishing pigs. J. Anim. Sci. 76:2818-2832. doi:/1998.76112818x

Lee, J. H., J. H. Kim, J. D. Kim, S. W. Kim, In K. Han. 2001. Effects of Low Crude Protein Diets Supplemented with Synthetic Amino Acids on Performance, Nutrient Utilization and Carcass Characteristics in Finishing Pigs Reared Using a Phase Feeding Regimen. Asian-Australas. J. Anim. Sci. 14(5):655-667. doi:10.5713/ajas.2001.655

Lopez, J., R. D. Goodband, G. L. Allee, G. W. Jesse, J. L. Nelssen, M. D. Tokach, D. Spiers, and B. A. Becker. 1994. The effects of diets formulated on an ideal protein basis on growth performance, carcass characteristics, and thermal balance of finishing gilts housed in a hot, diurnal environment. J. Anim. Sci. 72:367-379. doi:/1994.722367x

Miller, P. S., A. J. Lewis, C. K. Wolverton, and C. A. Borland. 1996. Performance of growing-finishing pigs consuming diets formulated on an ideal protein (first four limiting amino acids) basis. In: Nebraska Swine Report. University of Nebraska. pp. 27.

Murrieta, C. M., B. W. Hess, and D. C. Rule. 2003. Comparison of acidic and alkaline catalysts for preparation of fatty acid methyl esters from ovine muscle with emphasis on conjugated linoleic acid. Meat Sci. 65:523-529. doi:10.1016/S0309-1740(02)00244-9

Nakai, H., F. Saito, T. Ikeda, S. Ando, and A. Komatsu. 1975. Standard models of pork colour. Bull. Natl. Inst. Anim. Ind. (Chiba) 29:69-75.

Nold, R. A., J. R. Romans, W. J. Costello, and G. W. Libal. 1999. Characterization of muscles from boars, barrows, and gilts slaughtered at 100 or 110 kilograms: differences in fat, moisture, color, water-holding capacity, and collagen. J. Anim. Sci. 77:1746-1754. doi:/1999.7771746x

NPPC. 1999. Official Color and Marbling Standards. Natl. Pork. Prod. Counc. Des Moines, IA.

NPPC. 2000. Pork Composition and Quality Assessment Procedures. Natl. Pork. Prod. Counc. Des Moines, IA.

NRC. 2000. Nutrient requirements of swine. 11th rev. ed. Natl. Acad. Press, Washington, DC.

PIC. 2011. Nutrient Specification Manual. PIC, Inc., Hendersonville, TN.

Teye, G. A., P. R. Sheard, F. M. Whittington, G. R. Nute, A. Stewart, and J. D. Wood. 2006. Influence of dietary oils and protein level on pork quality. 1. Effects on muscle fatty acid composition, carcass, meat and eating quality. Meat Sci. 73:157-165. doi:10.1016/j.meatsci.2005.11.010

Tuitoek, J. K., L. G. Young, C. F. M. de Lange, and B. J. Kerr. 1997. Body Composition and Protein and Fat Accretion in Various Body Components in growing Gilts Fed Diets with Different Protein Levels but Estimated to Contain Similar Levels of Ideal Protein. J. Anim. Sci. 75:1584-1590. doi:/1997.7561584x

Tuitoek, K., L. G. Young, C. F. M. de Lange, and B. J. Kerr. 1997b. The effect of reducing excess dietary amino acids on growing-finishing pig performance: An evaluation of the ideal protein concept. J. Anim. Sci. 75:1575-1583. doi:/1997.7561575x

Tous, N., R. Lizardo, B. Vilà, M. Gispert, M. Font-i-Furnols, and E. Esteve-Garcia. 2014. Effects of reducing dietary protein and lysine on growth performance, carcass characteristics, intramuscular fat, and fatty acid profile of finishing barrows. J. Anim. Sci. 92:129-140. doi:10.2527/jas.2012-6222

Widmer, M. R., L. M. McGinnis, D. M. Wulf, and H. H. Stein. 2008. Effects of feeding distillers dried grains with solubles, high-protein distillers dried grains, and corn germ to growing-

finishing pigs on pig performance, carcass quality, and the palatability of pork. J. Anim. Sci. 86:1819-1831. doi:10.2527/jas.2007-0594

Wood, J. D., N. R. Lambe, G. A. Walling, H. Whitney, S. Jagger, P. J. Fullarton, J. Bayntun. 2013. Effects of low protein diets on pigs with a lean genotype. 1. Carcass composition measured by dissection and muscle fatty acid composition. Meat Sci. 95:123-128. doi:10.1016/j.meatsci.2013.03.001

Xu, G., S. K. Baidoo, L. J. Johnson, D. Bibus, J. E. Cannon, and G. C. Shurson. 2010. Effects of feeding diets containing increasing content of corn distillers dried grains with soluble to grower-finisher pigs on growth performance, carcass composition, and pork fat quality. J. Anim. Sci. 88:1398-1410. doi:10.2527/jas.2008-1404