Grower/ Finisher study 1.
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Project Title: Effects of Amino Acid Supplementation of Reduced Crude Protein Diets on the Performance, Carcass Characteristics, and Longissimus Muscle Quality of Growing-Finishing Swine

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ABSTRACT: Crossbred barrows (n = 205) and gilts (n = 205) were blocked, within gender, into 7 BW blocks, and pens (6 pigs/pen) within each block and gender were assigned randomly to 1 of 5 dietary treatments: 1) control corn-soybean meal-diets (**Ctrl**) formulated to contain no crystalline lysine; 2) reduced CP diets (**RCP1**), where 0.188, 0.179, 0.146, and 0.129% lysine hydrochloride were added in the first 4 feeding phases, respectively (no other indispensible AA were added); 3) reduced CP diets (**RCP2**), where 0.375, 0.358, 0.293, and 0.129% lysine hydrochloride were added in the first 4 feeding phases, (L-threonine and L-tryptophan were added); 4) reduced CP diets (**RCP3**), where 0.563, 0.536, 0.439, and 0.386% lysine hydrochloride were added in the first 4 feeding phases, respectively (L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine were added); or 5) reduced CP diets (**RCP4**), where 0.750, 0.715, 0.585, and 0.515% lysine hydrochloride were added in the first 4 feeding phases, respectively (L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine were added). During the last 3-wk feeding phase, 10 mg/kg of ractopamine hydrochloride was included in all diets, and the CP content was formulated to 20.24, 18.60, 17.01, 15.44, and 13.93% for feeding phases 1 through 5, respectively, and lysine was added at 0.15% increments to ensure an SID lysine:ME of 2.67 g/Mcal. At slaughter, HCW and FOM data were recorded before carcasses were subjected to a rapid-chilling process. A subsample of whole hams (3/pen) and whole loins (2/pen)

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were transported under refrigeration to the University of Arkansas. Hams were knife-dissected into lean, fat, bone, and skin, whereas LM chops were used to measure fresh pork quality characteristics. Across the entire feeding trial, ADG increased only 2.1% between Ctrl and RCP3, but dropped 6.1% between RCP3 and RCP4 (quadratic, $P < 0.001$), whereas ADFI tended to decreased linearly ($P = 0.085$) as CP was reduced in swine diets. Gain efficiency (G:F) increased 4.6% in gilts between Ctrl and RCP2 before decreasing to values similar to Ctrl; yet, G:F remained relatively unchanged in barrows across the 5 dietary treatments (quadratic gender × reduced CP diet, $P = 0.041$). Fat depth increased linearly ($P = 0.001$), and carcass fat-free lean yields decreased linearly ($P = 0.018$), as CP was reduced in swine diets. Furthermore, the percent of ham muscle decreased (linear, P = 0.002), and the percent of ham fat increased (linear, $P = 0.012$), with decreasing dietary CP. Incorporating crystalline AA in diets of growing-finishing swine can reduce dietary CP by 19.7 to 28.6% across the 5 feeding phases, and, more importantly, live pig performance was actually improved with lower inclusion levels of synthetic AA in reduced CP diets, but ADG, ADFI, and G:F declined when fed the reduced CP diet with the highest synthetic AA inclusion levels. Lastly, reducing dietary CP and replacing with crystalline AA had did not negatively affect fresh pork quality.

Key Words: Carcass composition, Crude protein level, Growth performance, Pork quality, Ractopamine hydrochloride, Swine

Introduction

Nitrogen (**N_2**) compounds from swine feces and urine are oxidized and reduced by soil and air, whereas some N_2 is released into the atmosphere as nitrous oxide (**N_2O**). The greenhouse effect of N_2O is approximately 288-fold that of carbon dioxide (**CO_2**); thus, N_2O has the third largest impact on total global warming after CO2 and methane. Research has demonstrated that reducing CP and maximizing crystalline AA in swine diets can dramatically reduce N_2 excretion when fed to either nursery or growing-finishing pigs (Kerr and Easter, 1995; Kendall, 2000; Figueroa et al., 2002; Hinson et al., 2009). Conversely, growth performance and carcass characteristics are quite variable when pigs were fed reduced CP diets (Dourmad et al., 1993; Kerr et al., 1995; Figueroa et al., 2002). In addition, a large segment of the swine industry feeds ractopamine hydrochloride (Paylean; Elanco Animal Health, a Division of Eli Lilly, Greenfield, IN) to finishing swine, but FDA regulations required Paylean to be fed in diets formulated to 16% CP (Feed Additive Compendium, 2011), even though research has shown that Paylean could be fed in low-CP diets supplemented with the appropriate AA without compromising growth performance or carcass composition (DeCamp et al., 2001; Gaines et al., 2004). Moreover, Gaines et al. (2004, 2007) observed that feeding finishing pigs a low-CP/AA-amended diet actually improved the reduction in carcass yield associated with increasing dietary soybean meal to meet the FDA minimum CP requirement. These studies have yet to determine the maximum level of CP reduction, in conjunction with the optimum AA inclusion rate(s), that can be fed with Paylean on growth performance and carcass characteristics.

Interestingly, reducing the CP content of grower and finisher pig diets has been repeatedly shown to increase intramuscular fat content in the LM from 14 to 65% (Kerr et al., 1995; Nold et al., 1999; Teye et al., 2006). On the other hand, dietary Paylean has been reported to reduce the intramuscular fat content and marbling scores, but these reductions associated with Paylean are more likely a response to dietary lysine levels in excess of 0.80% (Apple et al., 2007). Therefore, the primary objective of this study was to test the effects of minimizing dietary CP and maximizing the use of crystalline AA on live performance, carcass composition, and pork quality of growing-finishing pigs fed Paylean the last 3 wk before slaughter.

Materials and Methods

Pig care and handling, as well as all experimental procedures, were approved by the University of Arkansas Interdepartmental Animal Care and Use Committee (protocol no. 11023) before initiating the experiment.

Pig Allotment and Diets

Crossbred barrows (n = 205) and gilts (n = 205), from the mating of C-29 females to line-380 boars (PIC, Inc., Hendersonville, TN), were blocked, within gender, into 7 BW blocks, and allotted randomly within blocks to replicated pens (6 pigs/pen). Then, within gender and blocks, pens of pigs were assigned randomly to 1 of 5 dietary treatments (Tables 1 and 2): 1) control corn-soybean meal-diets (**Ctrl**) formulated to contain no crystalline lysine and meet 95% of the standardized ileal digestible (SID) AA requirements for growing-finishing swine (PIC Nutrient Specification Manual, 2011); 2) reduced CP diets (**RCP1**), where soybean meal was reduced by 5.8, 5.8, 4.6, and 3.8 percentage units, and 0.188, 0.179, 0.146, and 0.129% lysine hydrochloride were added, in the Grower-1, Grower-2, Finisher-1, and Finisher-2 feeding phases, respectively (no other indispensible AA were added); 3) reduced CP diets (**RCP2**), where soybean meal was reduced by 11.7, 11.5, 9.1, and 7.5 percentage units, and 0.375, 0.358, 0.293, and 0.129% lysine hydrochloride were added, in the Grower-1, Grower-2, Finisher-1, and Finisher-2 feeding phases, respectively (L-threonine and L-tryptophan were added); 4) reduced CP diets (**RCP3**), where soybean meal was reduced by 17.5, 17.3, 13.6, and 11.3 percentage units, and 0.563, 0.536, 0.439, and 0.386% lysine hydrochloride were added, in the Grower-1, Grower-2, Finisher-1, and Finisher-2 feeding phases, respectively (L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine were added); or 5) reduced CP diets (**RCP4**), where soybean meal was reduced by 23.3, 23.0, 18.1, and 15.0 percentage units, and 0.750, 0.715, 0.585, and 0.515% lysine hydrochloride were added, in the Grower-1, Grower-2, Finisher-1, and Finisher-2 feeding phases, respectively (L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L-valine were added). During the last 3-wk feeding phase (Finisher-3), 10 mg/kg of ractopamine hydrochloride (Paylean; Elanco Animal Health, a division of Eli Lilly, Greenfield, IN) was included in all diets, and the CP content was formulated to 20.24, 18.60, 17.01, 15.44, and 13.93% for Ctrl, RCP1, RCP2, RCP3, and RCP4, respectively. In addition, the Ctrl, RCP1, RCP2, RCP3, and RCP4 diets were formulated with 0.0, 0.15, 0.30, 0.45, and 0.60% lysine hydrochloride, respectively, to insure an SID lysine:ME of 2.67 g/Mcal (Apple et al., 2004).

Pigs were housed in curtain-sided buildings with slatted floors, and each 1.49 × 3.96-m pen was equipped with a single-opening feeder and nipple waterer, which afforded each pig ad libitum access to both feed and water. Pigs were fed a 5-phase dietary program with transition from Grower-1 to Grower-2, Grower-2 to Finisher-1, Finisher-1 to Finisher-2, and Finisher-2 to Finisher-3 diets at mean block weights of 41, 59, 82, and 104 kg, respectively. All diets were formulated to 95% of the average SID lysine requirement for barrows and gilts to ensure that lysine was not above these requirements. Moreover, diets were formulated to exceed the SID AA ratio recommendations for other indispensable AA by 2.0 percentage units for growing-finishing barrows and gilts (PIC, 2011) for all phases of production. Dried distillers' grains with solubles (DDGS) was included in the first 4 feeding phases at 20.0% (as-fed basis), but DDGS were eliminated for the Finisher-3 diets. It should be noted that gilts and barrows were fed the same diets within each feeding phase but gilts were fed on a separate feed budget to adjust for expected gender differences in BW gain. Moreover, within each feeding phase, diets were formulated to maintain a constant lysine-to-ME ratio across the dietary treatments.

During the first 4 feeding phases, individual pig BW was measured weekly, and pen feed disappearance was recorded at the end of each feeding period to calculate ADG, ADFI, and G:F. In addition, 10^{th} rib fat depth and LM area were measured at the beginning of the study, as well as at the end of the first 4 feeding phases, by a trained certified ultrasound technician. Due to the number of pigs on this trial, 3 gilts and 3 barrows were selected randomly from each BW block to allow for estimation of carcass gain.

Pig Slaughter and Pork Carcass Data Collection

When the average block weight of 127.0 kg was achieved, all pigs were transported approximately 10 h to a commercial pork slaughter/fabrication facility (Cargill Meat Solutions, Ottumwa, IA), where pigs were slaughtered according to humane, industry-accepted procedures after a 6-h lairage. Then, 10^{th}-rib fat and LM depths were measured on-line with a Fat-O-Meater (FOM) probe and hot carcass weight was recorded before carcasses were exposed to a 24-h rapid chilling system. After approximately 6 h of chilling, a subsample of randomly selected, left-side hams (3/pen) and loins (2/pen) were individually identified, and identified whole, bone-in hams (IMPS #401) and whole, bone-in loins (IMPS #410) were collected during carcass fabrication, boxed, and transported under refrigeration to the University of Arkansas Red Meat Research Abattoir for additional data collection.

Ham fabrication. Upon arrival, each ham was weighed, skinned, and subsequently knife-dissected into the "flat" (biceps femoris), "pillow" (semimembranosus), "knuckle" (quadriceps complex), semitendinosus, lean muscle trim, fat trim, and bone. Weights of each component were recorded, and individual muscle weights, along with the weights of all lean, fat, bone, and skin were divided by the whole ham weight to calculate yields.

Loin fabrication. After 7 d of vacuum-aging at 2°C, loins were removed from their packaging material, and pH and temperature of the LM was recorded before the blade, tenderloin, and sirloin sections of each loin were removed. Then, center-cut loins were processed into: 1) a 2.5-cm-thick chop for visual and instrumental color, firmness, and marbling data collection; 2) two 3.8-cm-thick chops used for drip loss determination; 3) a 2.5-cm-thick chop for proximate analyses; and 4) two 2.5-cm-thick chops that was vacuum-packaged and immediately frozen for Warner-Bratzler shear force (WBSF) determinations at a later date.

Pork quality data collection. After a 45-min bloom period at 2°C, trained, experimented university personnel visually evaluated each LM chop 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), as well as firmness (1 = soft to 3 = very firm; NPPC, 2000) and marbling (1 = 1% i.m. fat to 10 = 10% i.m. fat; NPPC, 1999). Then, instrumental color (L*, a*, and b*) values were determined from 3 readings on each LM chop with a Hunter MiniScan XE (Hunter Associate Laboratory, Reston, VA) using illuminant A and a 25-mm viewing diameter. The spectrocolorimeter was calibrated against a standard white tile (M04207; Hunter Associate Laboratory) before data collection.

Drip loss was determined according to the suspension method of Honikel et al. (1986), with modifications described by Apple et al. (2000). Briefly, 3.0-cm-diameter cores were manually removed from the center of each 3.8-cm-thick LM chop, weighed, and suspended on a barbless fishhook mounted to the lid of a 46 × 66 × 38 plastic container, and stored for 48 h at 4°C. After storage, each core was removed from its hook, blotted dry on paper towels, and reweighed. The weight loss was divided by the original core weight to calculated 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) for quantification of total protein, fat, and ash according to AOAC-approved procedures.

Warner-Bratzler Shear Force (WBSF) Determination.

Longissimus muscle chops were thawed for 16 h at 2°C, deboned and trimmed free of any external fat, weighed, and cooked to an internal endpoint temperature of 71°C on electric, counter-top griddles (model 07047; National Presto Industries, Inc., Eau Claire, WI). Chops were turned every 3 min until reaching the endpoint temperature, and internal temperature was monitored with a hand-held, FoodCheck digital thermometer (Comark Instruments, Inc., Beaverton, OR). Immediately after cooking, LM chops were blotted dry on paper towels, and reweighed, and the difference between the raw and cooked weights was used to calculate cooking loss percentages. Then, chops were allowed to cool approximately 2 h to room temperature before six 1.3-cm-diameter cores were mechanically removed parallel to the muscle fiber orientation. Each core was subsequently sheared once through the center with a WBSF device attached to an Instron Universal Testing Machine (model 4466; Instron Corp., Canton, MA), equipped with a 55-kg tension/compression laod cell and performed at a crosshead speed of 250 mm/min. The average of 6 cores/LM chop was averaged for statistical purposes.

Statistical Analyses

Performance, carcass and ham composition, and fresh LM quality data were analyzed as a randomized complete block design, with blocks based on initial BW, pen as the experimental unit, and treatments in a 2 × 5 factorial arrangement. The analysis of variance was generated with the mixed models procedure of SAS (SAS Inst., Inc., Cary, NC), with gender, reduced CP dietary treatment, and the gender × reduced CP diet as the lone fixed effects included in the model. When a significant (P ≤ 0.05) F-test was observed, least squares means were separated using the PDIFF option of SAS. 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. In addition, linear, quadratic, cubic, and quartic polynomial contrasts were generated to discern the interactive effects of gender and reduced CP diet on performance, carcass/ham composition, and fresh pork quality characteristic.

Results

Growth Performance

Live weights of pigs decreased linearly with decreasing dietary CP during the Grower-1 (P = 0.009), Grower-2 (P = 0.005), and Finisher-1 (P = 0.002) phases (Figure 1A). Additionally, BW increased quadratically during the Finisher-2 (P = 0.032) and Finisher-3 (P < 0.001) phases, with BW dropping off in pigs fed RCP4. Moreover, when Paylean was included in the diet, pig weights increased with as dietary CP was reduced from Ctrl to RCP3, but BW decreased approximately 4.4, 4.8, and 6.2 kg between RCP2 and RCP4 during the first, second, and third week of the Finisher-3 phase, respectively (quadratic, $P \leq 0.01$; Figure 1B).

During the Grower-1 and Grower-2 phases, barrows had greater ($P \leq 0.020$) ADG and ADFI than gilts, and barrows were fatter (P < 0.030) at the 10^{th} rib than gilts, resulting in lower ($P \leq 0.042$) calculated lean muscle weights than gilts (Table 6). Both ADG and G:F decreased linearly ($P \leq 0.055$) during the Grower-1 and Grower-2 phases, whereas 10^{th} rib fat depth increased linearly (P < 0.001) in the Grower-1 phase, as CP decreased in the diet. Even though LM area was greater (P < 0.05) greater in pigs fed RCP1 and RCP3 than those fed Ctrl, RCP2, and RCP4 during the Grower-1 phases, LM area increased (quadratic, P = 0.034) with decreasing dietary CP content. Moreover, calculated lean muscle weight decreased linearly ($P \leq$ 0.007) in growing pigs as CP content was reduced.

Barrows had greater ADG and ADFI in the Finisher-1 (P < 0.001) and Finisher-2 ($P \leq$ 0.003) phases (Table 6). In addition, barrows had greater 10^{th} rib fat depths (P < 0.001) and LM areas (P = 0.042) than gilts during the Finisher-1 phases, whereas barrows had larger (P = 0.046) LM areas than gilts during the Finisher-2 phase; however, calculated lean muscle weight was similar between genders during the Finisher-1 (P = 0.225) and Finisher-2 (P = 0.103) phases. Both ADG (P = 0.056) and ADFI (P = 0.034) increased linearly as CP was reduced in the Finisher-1 diets, but neither ADG ($P \geq 0.178$) nor ADFI ($P \geq 0.135$) were affected by dietary CP reductions during the Finisher-2 phase. During the Finisher-1 (*P* = 0.095) and Finisher-2 (*P* = 0.062) phases, fat depth tended to increase as dietary CP was decreased, resulting in decreases in estimated lean muscle weights during the Finisher-1 (linear, *P* < 0.001) and Finisher-2 (quadratic, *P* = 0.089) feeding phases.

When Paylean was included in the Finisher-3 diets, barrows had greater (*P* < 0.001) ADFI and 10th rib fat depth, as well as lower (*P* = 0.023) estimated lean muscle weights, than gilts (Table 6). Pigs fed RCP3 had greater (*P* < 0.05) ADFI than those fed RCP1, RCP2, and RCP4, and Ctrl-fed pigs had greater (*P* < 0.05) ADFI than those fed RCP4. Barrows fed the Ctrl diet may have had greater ADG than Ctrl-fed gilts, but RCP1-, RCP2-, and RCP3-fed gilts had greater ADG than their castrated male counterparts (quadratic gender × reduced CP diet, *P* = 0.007; Figure 2A). Furthermore, G:F increased between Ctrl and RCP2 in gilts and decreased between RCP2 and RCP4, but G:F was relatively unchanged across dietary treatments in barrows during the Finisher-3 phase (quadratic gender × reduced CP diet, *P* = 0.014; Figure 2B). Even though ultrasound-measured fat depth increased linearly (*P* = 0.022) with decreasing dietary CP, both LM area and calculated muscle weight increased (quadratic, *P* < 0.001) with decreasing dietary CP, with the greatest LMA and muscle weights in RCP1- and RCP2-fed pigs.

Across the entire feeding trial, barrows had greater (*P* < 0.001) ADG and ADFI than gilts, but gilts had greater (*P* < 0.001) G:F than barrows (Table 6). Daily BW gain increased only 2.1% between Ctrl and RCP3, but dropped 6.1% between RCP3 and RCP4 (quadratic, *P* < 0.001). On the other hand, ADFI tended to decreased linearly (*P* = 0.085) as CP was reduced in swine diets. Gain efficiency increased 4.6% in gilts between Ctrl and RCP2 before decreasing when G:F values were similar between Ctrl and RCP4; however, G:F remained relatively unchanged in barrows across the 5 dietary treatments (quadratic gender × reduced CP diet, *P* = 0.041; Figure 3).

Carcass and Ham Compositions

Barrows produced greater (*P* = 0.008) dressing percentages, resulting in heavier (*P* = 0.001) carcasses, than gilts (Table 8). Carcasses from barrows also had more (*P* = 0.008) fat opposite the 10th rib than gilts, and, even though LM depth was not (*P* = 0.688) affected by gender, estimated fat-free lean yield was almost 2 percentage units greater (*P* < 0.001) in gilt and barrow carcasses. In addition, hams from gilts had a greater (*P* < 0.001) proportion of muscle, and a lower (*P* < 0.001) percentage of fat, than hams from barrows.

Reducing dietary CP and optimizing the use of crystalline AA had no (*P* ≥ 0.208) effects on HCW, dressing percentage, or LM depth; however, fat depth increased linearly (*P* = 0.001), and carcass fat-free lean yields decreased linearly (*P* = 0.018), as CP was reduced in swine diets (Table 8). Fresh ham weights did not (*P* = 0.157) differ among dietary treatments, but the percent of muscle in the fresh ham decreased (linear, *P* = 0.002), and the percent of fat in the fresh ham increased (linear, *P* = 0.012), with decreasing dietary CP. In addition, the yield of the pillow (biceps femoris) decreased in carcasses from gilts, but increased in carcasses from barrows, as dietary CP was reduced (linear gender × reduced CP diet, *P* = 0.016; Figure 4).

Longissimus Muscle Quality Characteristics

Ultimate muscle pH was greater (*P* = 0.006) in the LM from barrows than gilts, but drip loss (*P* = 0.022) and LM moisture (*P* = 0.016) were greater, and cooking loss percentage tended to be less (*P* = 0.059), in the LM of gilts than barrows (Table 9). The LM from barrows received greater American (*P* = 0.033) and Japanese (*P* = 0.044) color scores than the LM from gilts, and the LM from barrows was darker (lower L* values, *P* = 0.021) than that from gilts, but neither redness (a*) nor yellowness (b*) values differed (*P* ≥ 0.072) between genders. Interesting, the observed increases in carcass fatness in barrows may be the reasons that marbling scores were greater (*P* = 0.002) in the LM from barrows when compared to the LM of gilts.

The ultimate pH, water-holding capacity, and American color scores of the LM were not (*P* ≥ 0.111) altered by dietary CP content (Table 9). Even though neither L* (*P* ≥ 0.245) nor b* (*P* ≥ 0.290) values were altered by the dietary CP treatments, Japanese color scores (linear, *P* = 0.066) and redness (a*) values (cubic, *P* = 0.013) increases as CP was reduced in swine diets. Firmness scores increased with decreasing dietary CP in the LM of gilts, but the LM of barrows fed RCP2 received greater firmness scores than that of pigs fed Ctrl or RCP4 (quadratic gender × reduced CP diet, *P* = 0.045; Figure 5). Additionally, marbling scores were greatest in pigs fed RCP1 and RCP4 and least in pigs fed RCP2 and RCP3 (cubic, *P* = 0.021).

The intramuscular fat (IMF) content of the LM from barrows increased as CP was reduced in the diet, but IMF content decreased with decreasing dietary CP (linear gender × reduced CP diet, *P* = 0.028; Figure 6B). Additionally, WBSF values of cooked LM chops from gilts decreased quadratically, whereas WBSF values for LM chops from barrows increased quadratically, as CP was reduced in the diets of growing-finishing pigs (quadratic gender × reduced CP diet, *P* = 0.034; Figure 7).

Conclusions

Incorporating crystalline AA in grower and finisher swine diets can reduce dietary CP by 24.8, 28.6, 25.6, 19.7, and 25.0% in the Grower-1, Grower-2, Finisher-1, Finisher-2, and Finisher-3 feeding phases, respectively. More importantly, across the entire feeding trial, ADG, ADFI, and G:F improved with lower inclusion levels of synthetic AA in reduced CP diets, but live pig performance and carcass composition declined when fed the reduced CP diet with the highest synthetic AA inclusion levels. Results of the present study indicate that adding crystalline lysine hydrochloride up to 0.56, 0.54, 0.44, 0.36, and 0.45% in the Grower-1, Grower-2, Finisher-1, Finisher-2, and Finisher-3 (with 10 mg/kg Paylean) has no detrimental effects on growth rate and feed consumption. In addition, fresh pork quality, in particular IMF, was improved by reducing dietary CP; however, improvements in pork quality associated with feeding reduced CP diets appear to be gender specific.

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Table 1. 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
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
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 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.

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

	Finisher-1 (59 to 82 kg)					Finisher-2 (82 to 104 kg)					Finisher-3 (104-127 kg)				
	C	RCP1	RCP2	RCP3	RCP4	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	20.24	18.60	17.01	15.44	13.93
Ingredient, %															
Corn	59.35	63.76	68.03	71.78	75.55	62.97	66.63	69.97	73.08	76.24	69.14	73.76	78.24	82.25	86.23
Soybean meal	18.40	13.83	9.28	4.75	0.25	15.00	11.20	7.45	3.73	0.00	28.65	23.85	19.10	14.35	9.60
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	0.60	0.62	0.65	0.67	0.69
Restaurant grease	0.31	0.28	0.26	0.42	0.47	0.33	0.30	0.38	0.50	0.58	0.45	0.40	0.36	0.46	0.49
Salt	0.50	0.50	0.50	0.50	0.50	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	0.36	0.40	0.43	0.46	0.49
Vitamin premix[3]	0.13	0.13	0.13	0.13	0.13	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	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	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	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	0.00	0.00	0.00	0.25	0.50
L-lysine	0.00	0.15	0.29	0.44	0.59	0.00	0.12	0.24	0.36	0.48	0.00	0.15	0.30	0.45	0.60
L-threonine	0.00	0.00	0.03	0.10	0.16	0.00	0.00	0.01	0.06	0.11	0.00	0.03	0.10	0.16	0.23
DL-methionine	0.00	0.00	0.00	0.00	0.01	---	---	---	---	---	0.00	0.00	0.02	0.06	0.10
L-isoleucine	0.00	0.00	0.00	0.03	0.10	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.03	0.11
L-valine	0.00	0.00	0.00	0.00	0.05	---	---	---	---	---	0.00	0.00	0.00	0.02	0.10
L-tryptophan	0.00	0.00	0.02	0.05	0.07	0.00	0.00	0.02	0.04	0.06	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	0.90	0.89	0.88	0.87	0.86	0.81	0.80	0.79	0.78	0.77	1.02	1.01	1.00	0.99	0.98
SID lysine	0.74	0.74	0.74	0.74	0.74	0.65	0.65	0.65	0.65	0.65	0.90	0.90	0.90	0.90	0.90
Total P	0.43	0.42	0.41	0.39	0.38	0.42	0.41	0.39	0.38	0.37	0.46	0.44	0.43	0.41	0.40
Available P	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.25	0.25	0.25	0.25
Total Ca	0.56	0.56	0.56	0.56	0.56	0.46	0.46	0.46	0.46	0.46	0.45	0.45	0.45	0.45	0.45
ME, Mcal/kg	3.37	3.37	3.37	3.37	3.37	3.38	3.38	3.38	3.38	3.38	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)					Finisher-3 (104-127 kg)				
	C	RCP1	RCP2	RCP3	RCP4	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	20.24	18.60	17.01	15.44	13.93
Calculated, %															
Lysine	0.90	0.89	0.88	0.87	0.86	0.81	0.80	0.79	0.78	0.77	1.02	1.01	1.00	0.99	0.98
Methionine	0.34	0.31	0.29	0.27	0.26	0.32	0.30	0.28	0.26	0.24	0.35	0.33	0.32	0.34	0.36
Methionine + cysteine	0.69	0.64	0.59	0.54	0.50	0.65	0.61	0.57	0.53	0.49	0.68	0.64	0.61	0.60	0.60
Threonine	0.71	0.64	0.60	0.59	0.58	0.66	0.60	0.54	0.54	0.53	0.78	0.74	0.73	0.72	0.71
Tryptophan	0.20	0.17	0.17	0.16	0.16	0.18	0.15	0.15	0.15	0.14	0.23	0.20	0.19	0.19	0.19
Isoleucine	0.75	0.66	0.57	0.51	0.50	0.68	0.61	0.54	0.47	0.45	0.81	0.73	0.64	0.59	0.58
Valine	0.90	0.81	0.73	0.64	0.60	0.84	0.76	0.69	0.62	0.55	0.92	0.84	0.76	0.69	0.68
Leucine	1.83	1.71	1.58	1.45	1.33	1.74	1.64	1.54	1.43	1.32	1.83	1.71	1.59	1.47	1.34
Histidine	0.52	0.47	0.42	0.37	0.32	0.48	0.44	0.40	0.36	0.32	0.52	0.47	0.42	0.38	0.33
Arginine	1.12	0.98	0.83	0.69	0.55	1.01	0.90	0.78	0.66	0.54	1.30	1.15	1.00	0.85	0.70
Phenylalanine	0.92	0.83	0.73	0.64	0.55	0.85	0.77	0.70	0.62	0.54	0.99	0.90	0.81	0.72	0.62
Analyzed, %															
CP	19.05	17.64	15.53	14.17	12.82	17.54	16.54	15.21	14.08	12.50	18.82	17.72	16.03	14.12	12.62
Lysine	0.85	0.84	0.79	0.84	0.88	0.76	0.77	0.76	0.78	0.72	1.00	0.99	0.99	0.97	0.96
Methionine	0.33	0.32	0.29	0.27	0.26	0.32	0.31	0.29	0.27	0.25	0.30	0.29	0.28	0.29	0.31
Methionine + cysteine	0.66	0.62	0.57	0.53	0.50	0.63	0.61	0.58	0.53	0.50	0.61	0.58	0.55	0.53	0.53
Threonine	0.70	0.64	0.57	0.58	0.57	0.65	0.60	0.55	0.55	0.53	0.71	0.71	0.70	0.64	0.61
Tryptophan	0.21	0.18	0.17	0.16	0.15	0.18	0.16	0.16	0.15	0.14	0.23	0.21	0.20	0.19	0.18
Isoleucine	0.74	0.66	0.57	0.51	0.49	0.67	0.61	0.56	0.50	0.45	0.78	0.72	0.63	0.55	0.53
Valine	0.88	0.81	0.70	0.63	0.60	0.81	0.75	0.71	0.64	0.55	0.89	0.82	0.73	0.63	0.62
Leucine	1.78	1.66	1.54	1.40	1.30	1.73	1.66	1.59	1.48	1.37	1.66	1.57	1.43	1.27	1.15
Histidine	0.49	0.45	0.39	0.35	0.32	0.46	0.43	0.40	0.37	0.32	0.50	0.46	0.41	0.35	0.31
Arginine	1.11	1.00	0.83	0.71	0.58	1.02	0.93	0.82	0.70	0.59	1.26	1.14	1.00	0.83	0.69
Phenylalanine	0.91	0.83	0.73	0.64	0.56	0.85	0.79	0.73	0.65	0.57	0.95	0.87	0.78	0.65	0.56

[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. Probability values[1] for main and interactive effects, as well as orthogonal contrasts, of gender and reduced CP on live pig performance

	Reduced CP (RCP)						RCP × gender				
	RCP	Lin	Quad	Cubic	Quart	Gender	Inter	Lin	Quad	Cubic	Quart
Grower-1 (23 to 41 kg)											
ADG, kg	0.056	0.010	0.106	0.910	0.963	0.004	0.947	0.476	0.743	0.765	0.927
ADFI, kg	0.170	0.242	0.099	0.214	0.348	0.019	0.167	0.527	0.434	0.071	0.134
G:F	< 0.001	< 0.001	0.961	0.288	0.537	0.127	0.396	0.783	0.777	0.154	0.174
10^{th} rib fat depth, mm	0.006	< 0.001	0.415	0.744	0.304	0.029	0.534	0.388	0.434	0.225	0.590
LM area, cm^2	0.022	0.520	0.034	0.527	0.011	0.057	0.114	0.249	0.026	0.284	0.778
Calculated lean wt, kg[2]	0.015	0.007	0.051	0.754	0.219	0.002	0.687	0.383	0.252	0.699	0.986
Grower-2 (41 to 59 kg)											
ADG, kg	0.050	0.055	0.740	0.024	0.359	< 0.001	0.340	0.400	0.263	0.123	0.687
ADFI, kg	0.273	0.265	0.285	0.690	0.106	< 0.001	0.760	0.665	0.495	0.281	0.884
G:F	0.014	0.027	0.105	0.019	0.680	0.239	0.653	0.462	0.614	0.209	0.832
10^{th} rib fat depth, mm	0.187	0.095	0.627	0.407	0.114	0.002	0.715	0.871	0.198	0.810	0.557
LM area, cm^2	0.010	0.042	0.020	0.695	0.035	0.118	0.500	0.904	0.867	0.265	0.154
Calculated lean wt, kg[2]	0.002	0.002	0.042	0.269	0.091	0.042	0.855	0.918	0.433	0.702	0.462
Finisher-1 (59 to 82 kg)											
ADG, kg	0.192	0.056	0.230	0.309	0.964	< 0.001	0.546	0.118	0.613	0.683	0.696
ADFI, kg	0.264	0.034	0.924	0.433	0.889	< 0.001	0.281	0.090	0.141	0.993	0.967
G:F	0.200	0.986	0.434	0.023	0.727	0.238	0.822	0.842	0.549	0.302	0.863
10^{th} rib fat depth, mm	0.406	0.131	0.310	0.515	0.620	< 0.001	0.882	0.895	0.378	0.702	0.645
LM area, cm^2	0.011	0.027	0.004	0.988	0.444	0.046	0.711	0.264	0.364	0.940	0.886
Calculated lean wt, kg[2]	< 0.001	< 0.001	0.006	0.392	0.667	0.225	0.432	0.168	0.187	0.748	0.851
Finisher-2 (82 to 104 kg)											
ADG, kg	0.473	0.178	0.336	0.982	0.381	0.003	0.877	0.349	0.742	0.973	0.658
ADFI, kg	0.577	0.502	0.672	0.941	0.135	< 0.001	0.973	0.770	0.800	0.937	0.564
G:F	0.166	0.019	0.416	0.902	0.674	< 0.001	0.753	0.194	0.964	0.716	0.937
10^{th} rib fat depth, mm	0.393	0.062	0.534	0.902	0.720	< 0.001	0.941	0.459	0.908	0.760	0.744
LM area, cm^2	0.462	0.874	0.215	0.168	0.743	0.238	0.470	0.221	0.201	0.555	0.829
Calculated lean wt, kg[2]	0.213	0.135	0.089	0.428	0.774	0.103	0.808	0.271	0.678	0.798	0.732
Finisher-3 (104 to 127 kg)											
ADG, kg	0.011	0.734	0.003	0.037	0.812	0.376	0.073	0.597	0.007	0.801	0.342
ADFI, kg	0.018	0.474	0.197	0.004	0.198	< 0.001	0.565	0.505	0.154	0.497	0.903
G:F	0.018	0.587	0.002	0.964	0.133	< 0.001	0.032	0.148	0.014	0.624	0.137

10^{th} rib fat depth, mm	0.162	0.022	0.640	0.321	0.868	< 0.001	0.585	0.342	0.682	0.248	0.526
LM area, cm^2	< 0.001	< 0.001	< 0.001	0.206	0.331	0.145	0.356	0.314	0.090	0.876	0.502
Calculated lean wt, kg[2]	< 0.001	< 0.001	< 0.001	0.136	0.444	0.023	0.212	0.209	0.055	0.491	0.756
Overall (23 to 127 kg)											
ADG, kg	0.001	0.050	< 0.001	0.078	0.684	< 0.001	0.318	0.107	0.178	0.730	0.685
ADFI, kg	0.295	0.085	0.629	0.193	0.909	< 0.001	0.776	0.294	0.551	0.606	0.876
G:F	0.006	0.478	< 0.001	0.402	0.444	< 0.001	0.135	0.314	0.041	0.532	0.221

[1]Probability values ($P > F$) for the main effect of reduced CP (RCP), Gender, and interactive effect of RCP × Gender (Inter), as well as for the linear (Lin), quadratic (Quad), cubic, and quartic (Quart) polynomial contrasts.

[2]Lean muscle weight = 2.2 × (-0.534 + (0.291 × BW, lbs) – (16.498 × 10^{th} rib fat depth, in) + (5.425 × LM area, in2) + (0.833 × gender)), where 1 = barrow and 2 = gilt.

Table 6. 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]
Grower-1 (23 to 41 kg)										
ADG, kg	0.74^{b}	0.78^{a}	0.026	0.77	0.78	0.77	0.75	0.72	0.029	L**
ADFI, kg	1.46^{b}	1.51^{a}	0.07	1.46	1.46	1.53	1.52	1.48	0.07	
G:F	0.51	0.52	0.00	0.53^{ab}	0.53^{a}	0.51^{bc}	0.50^{c}	0.49^{c}	0.011	L***
10^{th} rib fat depth, mm	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***
LM area, cm^2	19.1	18.5	0.92	18.4^{bc}	19.6^{a}	18.5^{bc}	19.2^{a}	18.2^{c}	0.96	Qd*
Calculated lean wt, kg[3]	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 (41 to 59 kg)										
ADG, kg	0.85^{b}	0.94^{a}	0.029	0.93	0.88	0.91	0.90	0.86	0.031	L*, C*
ADFI, kg	1.99^{b}	2.22^{a}	0.09	2.16	2.07	2.12	2.07	2.10	0.09	
G:F	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*
10^{th} rib fat depth, mm	8.5^{b}	9.5^{a}	0.25	8.5	8.8	9.5	8.8	9.4	0.36	
LM area, cm^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*
Calculated lean wt, kg[3]	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 (59 to 82 kg)										
ADG, kg	0.97^{b}	1.07^{a}	0.014	1.02	1.05	1.03	1.00	0.99	0.021	
ADFI, kg	2.40^{b}	2.74^{a}	0.07	2.65	2.58	2.57	2.56	2.48	0.08	L*
G:F	0.40	0.39	0.01	0.39	0.41	0.40	0.39	0.40	0.007	C*
10^{th} rib fat depth, mm	12.1^{b}	15.1^{a}	0.32	13.3	13.3	13.5	13.4	14.4	0.49	
LM area, cm^2	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**
Calculated lean wt, kg[3]	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 (82 to 104 kg)										
ADG, kg	0.92^{b}	0.97^{a}	0.012	0.92	0.95	0.94	0.96	0.95	0.019	
ADFI, kg	2.86^{b}	3.21^{a}	0.06	3.04	3.10	2.99	3.07	2.99	0.08	
G:F	0.32^{a}	0.30^{b}	0.01	0.30	0.31	0.32	0.32	0.32	0.008	L*
10^{th} rib fat depth, mm	18.4^{b}	24.5^{a}	0.76	20.8	20.9	21.0	21.9	22.5	0.95	
LM area, cm^2	40.1	32.3	1.17	39.5	39.4	40.0	40.6	38.8	1.30	
Calculated lean wt, kg[3]	40.1	39.4	1.04	39.9	40.0	40.1	40.0	38.7	1.10	

Finisher-3 (104 to 127 kg)										
ADG, kg	1.19	1.16	0.019	1.15	1.16	1.23	1.23	1.10	0.029	Qd**, C*
ADFI, kg	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**
G:F	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**
10^{th} rib fat depth, mm	20.4^{b}	27.4^{a}	0.69	23.4	22.9	23.8	24.6	24.8	0.84	L*
LM area, cm^{2}	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]	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***
Overall (23 to 127 kg)										
ADG, kg	0.93^{b}	0.99^{a}	0.013	0.96	0.97	0.98	0.98	0.92	0.015	L*, Qd***
ADFI, kg	2.34^{b}	2.60^{a}	0.06	2.51	2.47	2.48	2.48	2.42	0.06	
G:F	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.

Table 7. Probability values[1] for main and interactive effects, as well as orthogonal contrasts, of gender and reduced CP on carcass characteristics and pork quality attributes

	Reduced CP (RCP)						RCP × gender				
	RCP	Lin	Quad	Cubic	Quart	Gender	Inter	Lin	Quad	Cubic	Quart
HCW, kg	0.691	0.952	0.208	0.476	0.712	0.001	0.903	0.343	0.763	0.936	0.836
Dressing percent	0.659	0.280	0.305	0.713	0.748	0.008	0.464	0.117	0.782	0.722	0.343
10th rib fat depth, mm	0.021	0.001	0.876	0.410	0.937	< 0.001	0.495	0.103	0.891	0.692	0.479
LM depth, mm	0.759	0.381	0.604	0.614	0.432	0.688	0.676	0.530	0.795	0.568	0.222
Fat-free lean yield, %	0.195	0.018	0.972	0.822	0.610	< 0.001	0.424	0.099	0.619	0.490	0.544
Fresh ham wt, kg	0.405	0.556	0.157	0.391	0.331	0.415	0.997	0.991	0.706	0.972	0.979
Ham lean, %	0.030	0.002	0.687	0.500	0.555	< 0.001	0.843	0.824	0.802	0.447	0.403
Semimembranosus, %	0.907	0.558	0.677	0.522	0.802	0.033	0.780	0.671	0.818	0.737	0.239
Biceps femoris, %	0.916	0.942	0.781	0.952	0.361	0.161	0.149	0.016	0.336	0.804	0.975
Semitendinosus, %	0.743	0.530	0.473	0.353	0.713	0.016	0.805	0.290	0.675	0.617	0.914
Quadriceps complex, %	0.446	0.082	0.897	0.455	0.898	0.004	0.804	0.410	0.420	0.953	0.571
Ham fat, %	0.112	0.012	0.956	0.764	0.327	< 0.001	0.920	0.830	0.909	0.618	0.435
Ham bone, %	0.238	0.778	0.545	0.153	0.081	0.113	0.245	0.641	0.925	0.707	0.026
Ham skin, %	0.594	0.980	0.851	0.782	0.105	0.408	0.718	0.312	0.514	0.709	0.487

[1]Probability values ($P > F$) for the main effect of reduced CP (RCP), Gender, and interactive effect of RCP × Gender (Inter), as well as for the linear (Lin), quadratic (Quad), cubic, and quartic (Quart) polynomial contrasts.

Table 8. 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 9. Probability values[1] for main and interactive effects, as well as orthogonal contrasts, of gender and reduced CP on LM quality attributes

	Reduced CP (RCP)						RCP × gender				
	RCP	Lin	Quad	Cubic	Quart	Gender	Inter	Lin	Quad	Cubic	Quart
Ultimate pH	0.528	0.196	0.690	0.263	0.590	0.006	0.872	0.480	0.394	0.879	0.988
Drip loss, %	0.571	0.191	0.607	0.350	0.892	0.022	0.559	0.768	0.115	0.590	0.796
Moisture, %	0.369	0.073	0.918	0.426	0.519	0.016	0.517	0.498	0.430	0.882	0.150
American color[2]	0.571	0.111	0.865	0.748	0.703	0.033	0.545	0.235	0.308	0.475	0.934
Japanese color[3]	0.392	0.066	0.727	0.716	0.570	0.044	0.716	0.340	0.383	0.584	0.823
Lightness (L*)[4]	0.602	0.245	0.950	0.732	0.274	0.021	0.516	0.262	0.445	0.425	0.405
Redness (a*)[4]	0.082	0.561	0.177	0.013	0.933	0.534	0.222	0.160	0.125	0.830	0.262
Yellowness (b*)[4]	0.751	0.687	0.908	0.425	0.290	0.072	0.807	0.855	0.610	0.517	0.354
Firmness[5]	0.222	0.060	0.198	0.955	0.546	0.931	0.182	0.323	0.045	0.366	0.506
Marbling[6]	0.102	0.810	0.271	0.021	0.268	0.002	0.508	0.087	0.889	0.840	0.636
Intramuscular fat, %	0.767	0.859	0.286	0.782	0.456	0.002	0.111	0.028	0.165	0.452	0.852
Protein, %	0.743	0.675	0.334	0.408	0.755	0.168	0.221	0.157	0.663	0.136	0.262
Ash, %	0.095	0.211	0.022	0.312	0.955	0.431	0.233	0.159	0.059	0.980	0.700
Cooking loss, %	0.871	0.809	0.410	0.570	0.691	0.059	0.658	0.552	0.775	0.254	0.408
Shear force, kg	0.159	0.338	0.400	0.037	0.476	0.220	0.071	0.164	0.034	0.357	0.200

[1]Probability values ($P > F$) for the main effect of reduced CP (RCP), Gender, and interactive effect of RCP × Gender (Inter), as well as for the linear (Lin), quadratic (Quad), cubic, and quartic (Quart) polynomial contrasts.
[2]1 = pale pinkish gray to 6 = dark purplish red (NPPC, 1999).
[3]1 = pale gray to 6 = dark purple (Nakai et al., 1975).
[4]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).
[5]1 = soft to 3 very firm (NPPC, 2000).
[6]1 = 1% i.m. fat to 10% = 10% i.m. fat (NPPC, 1999).

Table 10. 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).

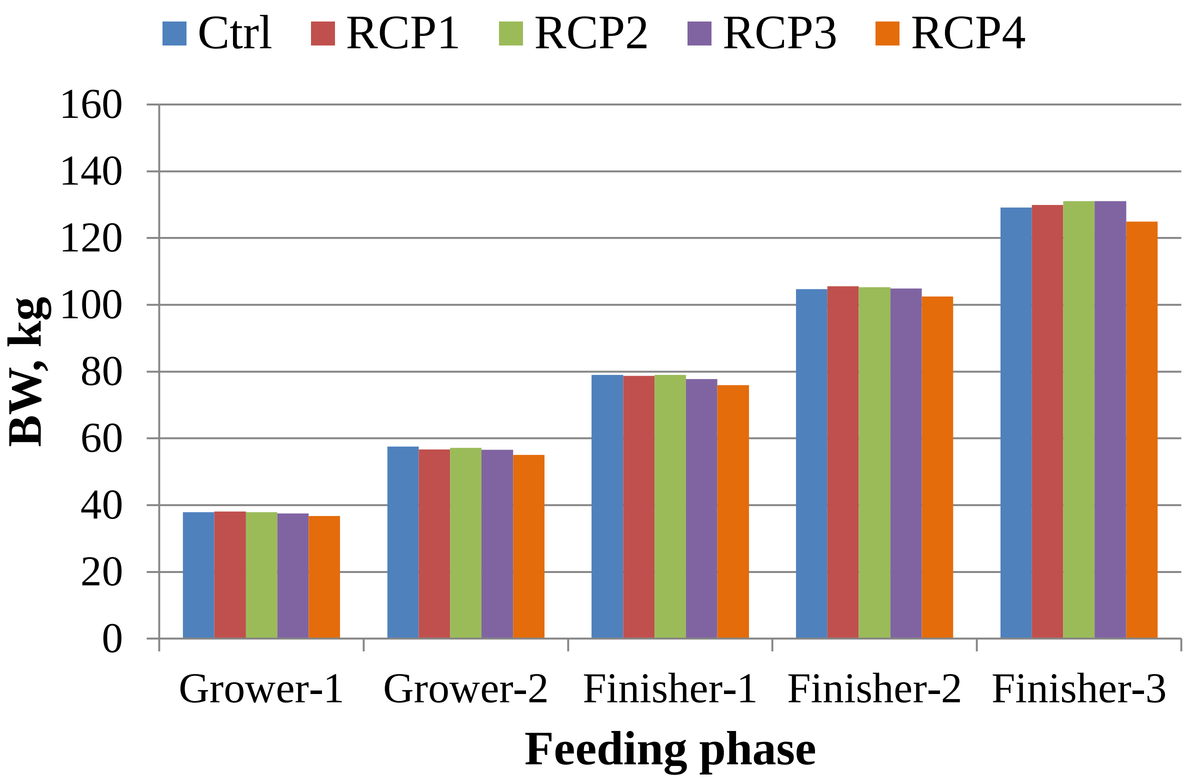
[5]L* = measure of darkness to lightness (larger value indicates a lighter color); a* = measure of redness (larger value indicates a redder color); and b* = measure of yellowness (larger value indicates a more yellow color).

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

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

Figure 1. Effect of reduced CP diets on BW of growing-finishing pigs: A) during each feeding phase, and B) during the last 3 wk of the finisher-3 phase when Paylean was included in all diets.

A



B

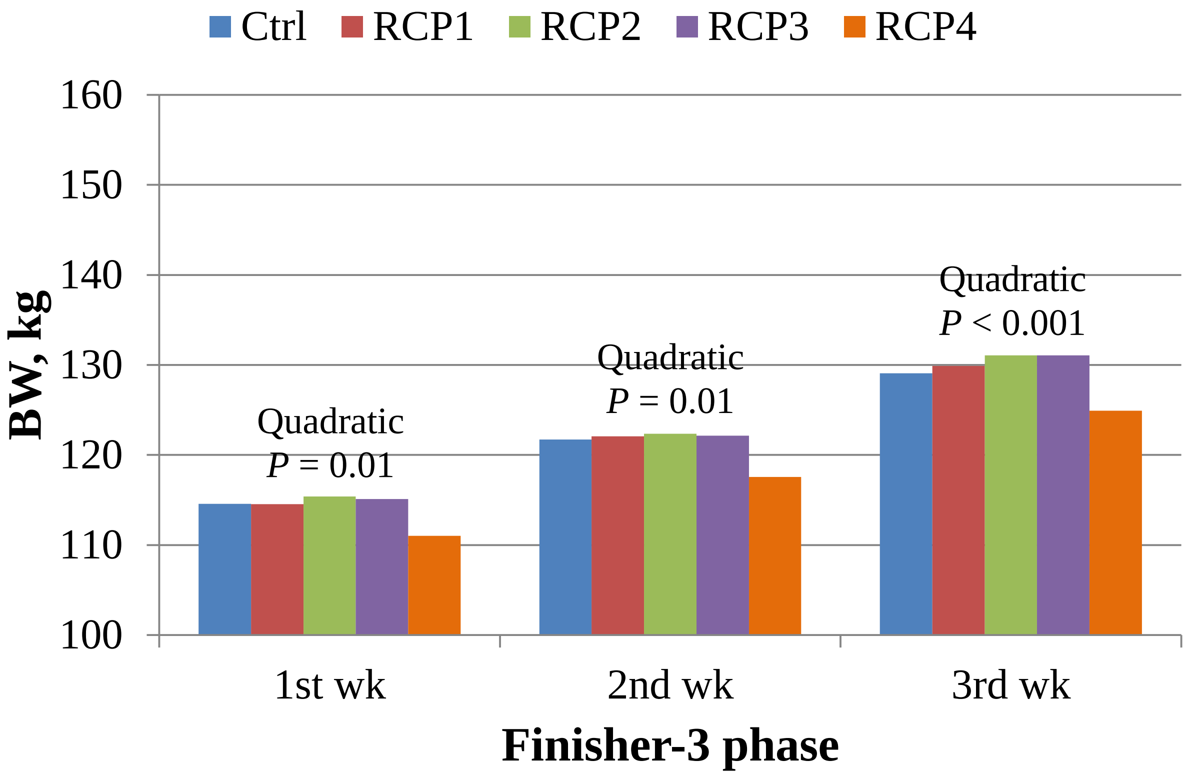

Ctrl
RCP1
RCP2
RCP3
RCP4
160
150
140
130
120
110
100
BW, kg
Quadratic
P = 0.01
Quadratic
P = 0.01
Quadratic
P < 0.001
1st wk
2nd wk
3rd wk
Finisher-3 phase

Figure 2. Interactive effects of gender and reduced CP diet on: A) ADG (P = 0.073) and B) G:F (P = 0.032) during the last (Finisher-3) feeding phase.

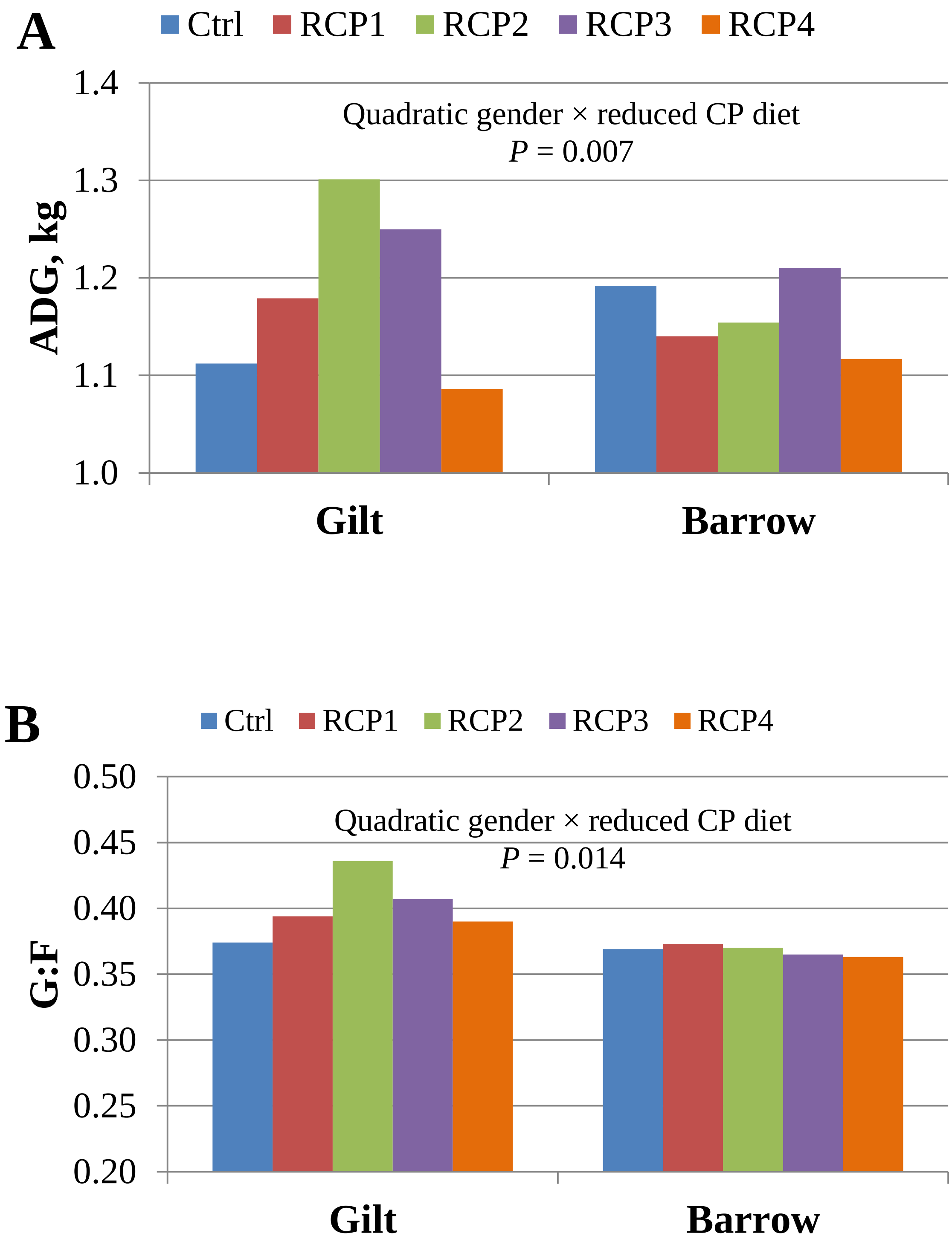


Figure 3. Interactive effect of gender and reduced CP diet on overall G:F (P = 0.135).

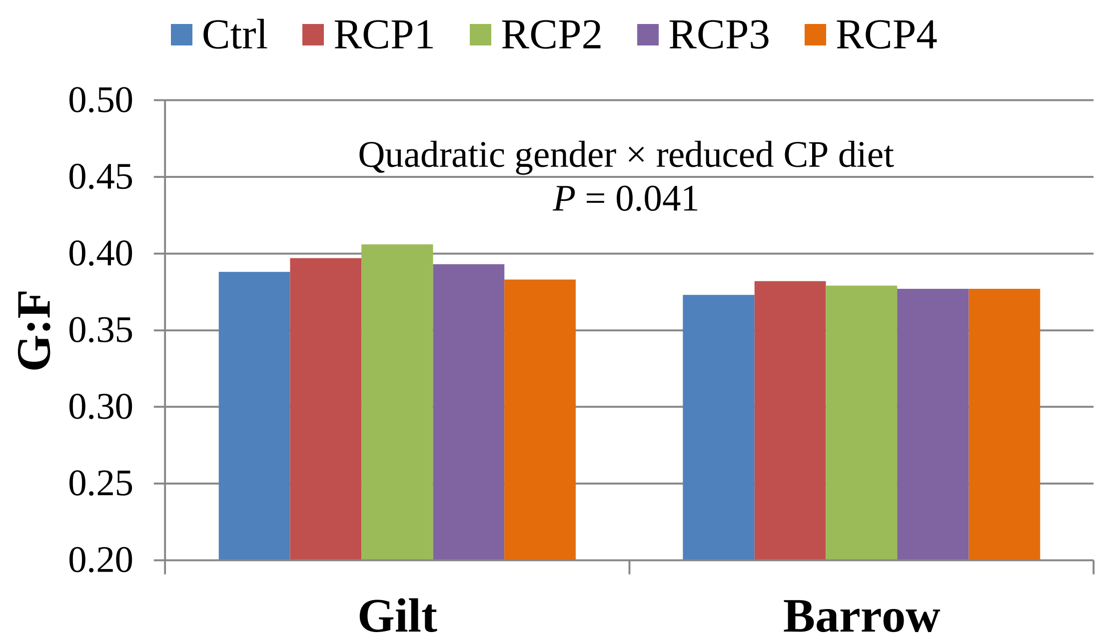


Figure 4. Interactive effect (P = 0.149) of gender and reduced CP diet on knife-dissection yield of the pillow (biceps femoris) from fresh hams.

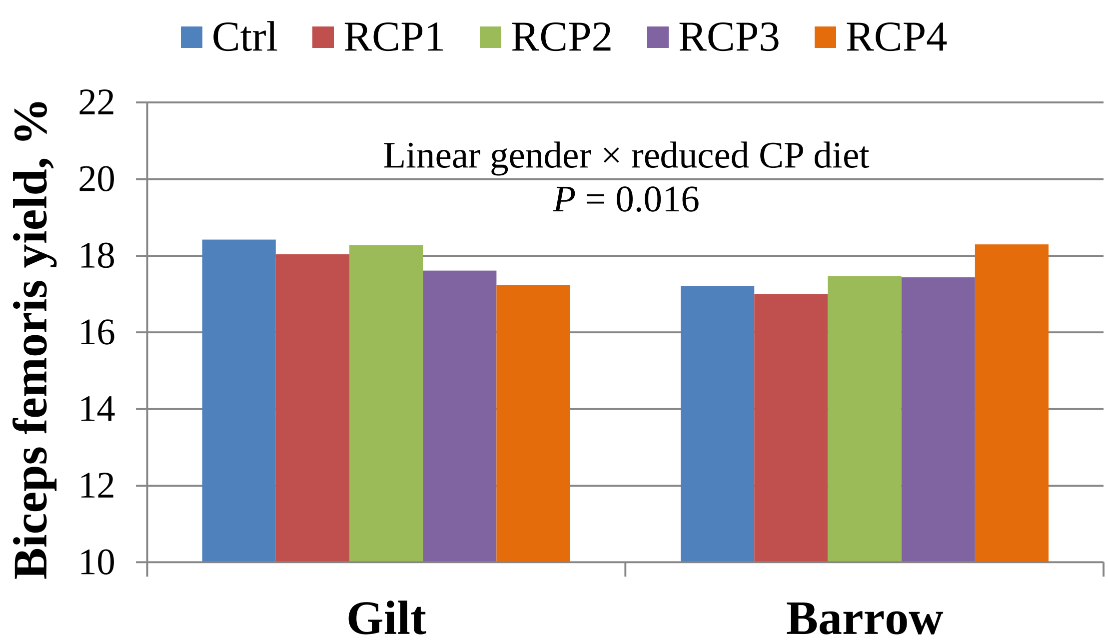


Figure 5. Interactive effect (*P* = 0.182) of gender and reduced CP diet on LM firmness scores (1 = soft to 3 = very firm; NPPC, 2000).

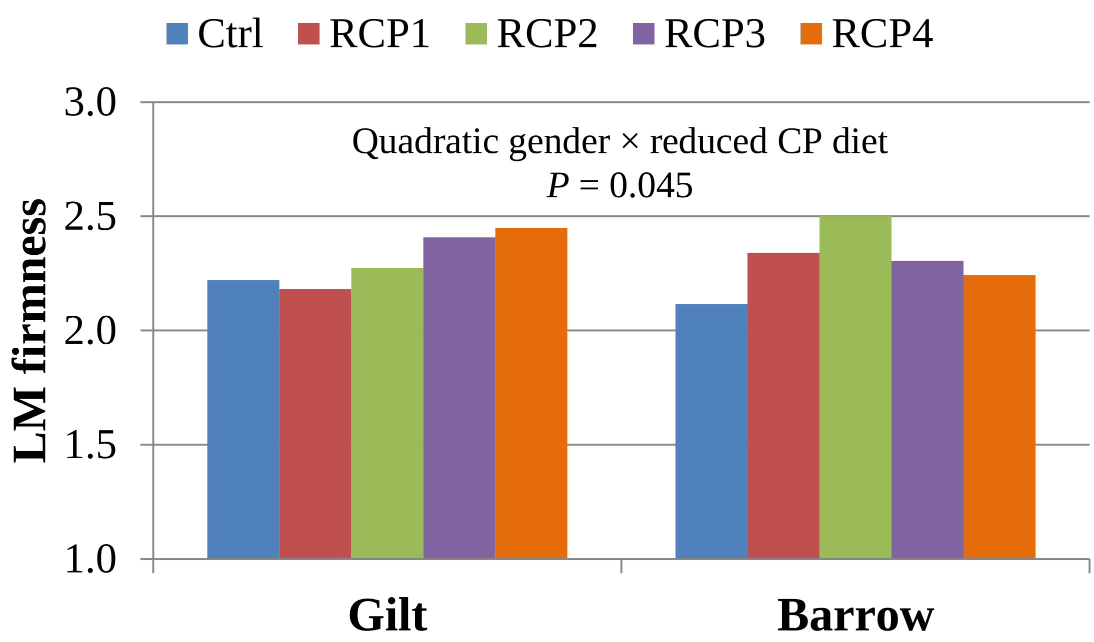
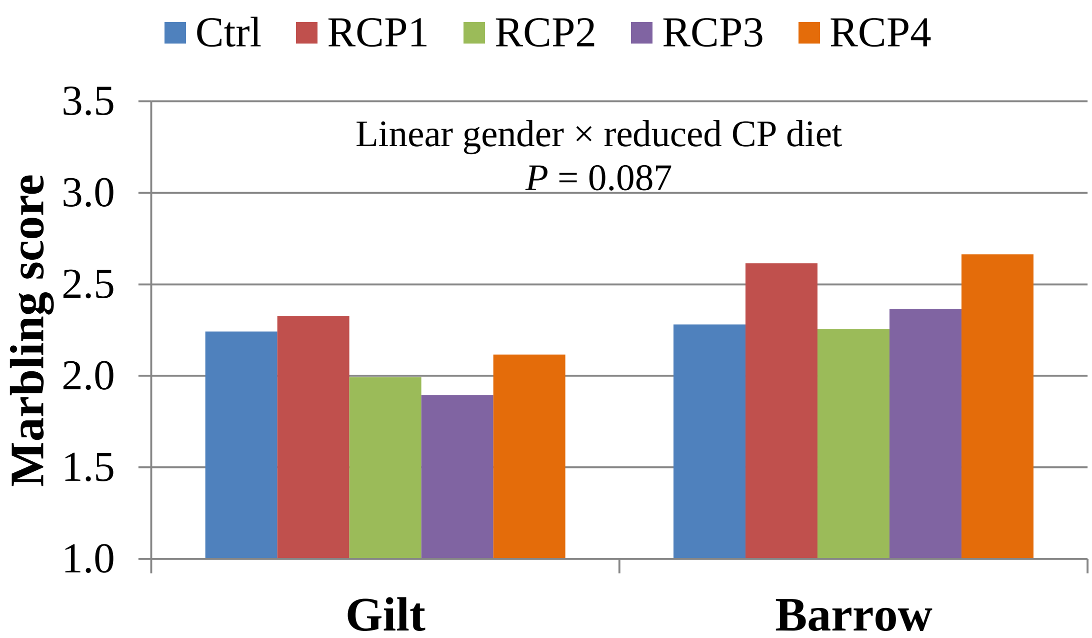


Figure 6. Interactive effect of gender and reduced CP diet on: A) marbling scores (*P* = 0.508), and B) intramuscular fat content (*P* = 0.111) of the LM.

A



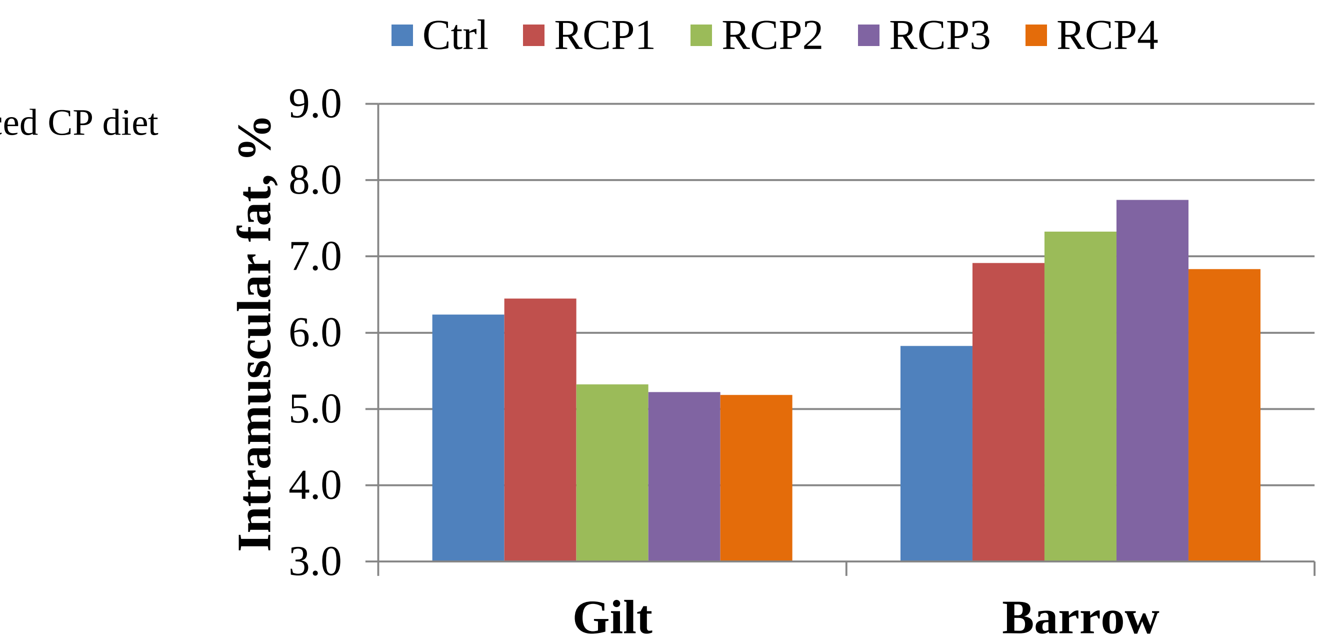


Figure 7. Interactive effect (*P* = 0.071) of gender and reduced CP diet on Warner-Bratzler shear force (WBSF) of the cooked LM.