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Ethics approval and consent to participate	All experimental procedures involving animals were conducted following the Animal Experimental Guidelines provided by the Seoul National University Institutional Animal Care and Use Committee (SNUIACUC; SNU-210811-6).

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Abstract

This experiment investigated the effects of varying dietary crude protein (CP) levels on growth performance, blood profiles, nutrient digestibility, pork quality, and odor emission in growing-finishing pigs. A total of 210 growing ([Yorkshire × Landrace] × Duroc) pigs (39.93 ± 0.080 kg body weight [BW]) were assigned to 1 of 6 treatments with 5 replicates of 7 pigs per pen. Diets with different CP levels (%) for early growing, late growing, early finishing, and late finishing phases, respectively, were as follows: CP1411: 14, 13, 12, 11; CP1512: 15, 14, 13, 12; CP1613: 16, 15, 14, 13; CP1714: 17, 16, 15, 14; CP1815: 18, 17, 16, 15; CP1916: 19, 18, 17, 16. Overall average daily gain decreased with increased dietary CP (linear, $P < 0.01$), while average daily feed intake increased during the late finishing period (linear, $P < 0.01$). Final BW increased as dietary CP decreased (linear, $P < 0.01$). Total protein concentration increased with higher CP levels at the 7th, 11th, and 13th weeks (linear, $P = 0.02$; $P < 0.01$; $P < 0.01$; respectively). Lower CP levels decreased creatinine concentration at the 4th and 13th weeks (linear, $P = 0.03$; $P < 0.01$; respectively). Blood urea nitrogen and urea concentrations decreased with lower CP (linear, $P < 0.01$). Emissions of ammonia, amine, mercaptan, and hydrogen sulfide decreased with lower CP (linear, $P < 0.01$; respectively). Excreted nitrogen in urine increased with higher CP (linear, $P < 0.01$). No significant differences were observed in carcass characteristics, pH, or pork color among treatments. Reducing CP levels in the diet did not negatively impact growth performance and improved protein metabolism, reducing odor emissions from feces and urine in growing-finishing pigs.

Keywords: Blood metabolites, Nitrogen excretion, Environmental impact, Meat quality

Introduction

Pigs are economically important animals, and extensive research has been conducted for many years to optimize their growth. With the specialization and large-scale expansion of the livestock industry, there has been an emerging need for enhanced productivity and standardization of these economic animals. Standards for nutrient requirements at each growth stage of pigs have been proposed by authorities such as the national research council [1] and agricultural research council [2]. The growing and finishing periods are crucial as pigs gain considerable weight and mainly develop muscle mass [3]. To maximize growth during this period, it is necessary to provide a diet that supports muscle development [4]. The optimal level of nutrients ensures that pigs receive what they need as they grow; conversely, excess nutrients may lead to waste through manure. Furthermore, pigs require a balanced ratio of amino acids and adequate nutrients for body protein synthesis to ensure optimal growth [5]. The finishing period, which follows the growth phase, is characterized by the completion of muscle growth and the onset of active fat accumulation [6]. This stage is critical for the accumulation of intramuscular fat, which directly influences pork quality.

The livestock industry is currently focusing on the reduction of gas emissions [7]. The main source of these emissions in the pig industry is the crude protein (CP) in feed, prompting extensive research into the reduction of CP levels in swine diets [8]. Numerous studies have demonstrated that reducing CP levels in growing-finishing diets reduced growth performance and increased pork quality [9,10]. Dietary CP also influences feed intake and the overall nutrient intake [1]. When pigs were fed diets with low-CP levels, the meat quality was affected [11].

According to Jongbloed and Lenis [12], phase feeding is a prominent method for reducing manure emissions from pigs. This approach involves feeding animals with precise levels of nutrients needed for their growth phase, thereby reducing overfeeding and unnecessary nutrient excretion [13]. Minimizing the volume of manure excreted by pigs helps reduce environmental pollution and cut down the costs associated with manure disposal [14]. Unfortunately, some pig farmers, aiming to increase profits by shortening the marketing age, often feed a high-nutrient diet continuously until the finishing period without adjusting to appropriate growth-stage diets, leading to inefficiencies and increased nutrient waste [15].

Thus, it was hypothesized that the effects of low CP could improve nutrient digestibility and utilization, leading to improved growth performance in growing-finishing pigs. Therefore, this experiment was designed to evaluate the effect of different levels of dietary CP on growth performance, blood profiles, nutrient digestibility, pork quality, and odor emission in growing-finishing pigs.

Materials and Methods

Experimental animals and management

All experimental procedures involving animals were conducted following the animal experimental guidelines provided by the Seoul National University institutional animal care and use committee (SNUIACUC; SNU-210811-6). A total of 210 growing-finishing ([Yorkshire × Landrace]) × Duroc) pigs (39.93 ± 0.080 kg) were allotted to 1 of 6 treatments based on sex and initial body weight (BW), with 5 replicates of 7 pigs per pen (4 barrows and 3 gilts) in a randomized complete block design. The pigs were allotted randomly to their respective treatments using an experimental animal allotment program [16]. The pens were contained within a concrete-floored, environmentally controlled facility (2.60 × 2.84 m^2) equipped with a feeder and water nipples at the Seoul National University farm. The experimental period was 13 weeks (phase I: 0-4 weeks, phase II: 4-7 weeks, phase III: 7-11 weeks, and phase IV: 11-13 weeks).

Experimental design and diet

The experimental corn–soybean-based diets with different CP levels (%) for early growing, late growing, early finishing, and late finishing phases, respectively, were as follows: CP1411: 14, 13, 12, 11; CP1512: 15, 14, 13, 12; CP16/13: 16, 15, 14, 13; CP1714: 17, 16, 15, 14; CP1815: 18, 17, 16, 15; CP1916: 19, 18, 17, 16. The experimental diets were formulated for the early/late growing and early/late finishing phases. All the other nutrients were formulated to meet or exceed the NRC [1] requirements. The formula and chemical composition of the experimental diets are listed in Tables 1-2.

Growth performance

BW and feed intake were measured at the end of each phase to calculate the average daily gain (ADG), average daily feed intake (ADFI), and gain-to-feed (G:F). In addition, the feed given to all growing and finishing pigs was recorded daily, and the feed waste in the feeder was recorded at the end of each phase.

Blood sampling and analyses

Blood samples were taken from the jugular vein of twelve pigs with nearly average BW in each treatment after 3 h of fasting to measure the concentrations of blood urea nitrogen (BUN), creatinine, glucose, total protein, triglyceride, and urea when BW was recorded. The blood samples were centrifuged for 15 min at 3,000 rpm and 4°C (centrifuge 5810R; Eppendorf, Hamburg, Germany). The sera were transferred to 1.5-mL plastic tubes (serum tubes, BD Vacutainer SST™II Advance; Becton-Dickinson, London, UK) and stored at −20°C until analysis. BUN was analyzed using a Cobas 6000 by a kinetic/photometric method. Creatinine and total protein were analyzed using a Cobas 6000 by a colorimetric method. Glucose was analyzed using a Cobas 6000 by an enzymatic UV/hexokinase method. Triglycerides were analyzed using a Cobas 6000 by an enzymatic colorimetric method. Urea was analyzed using a Cobas 8000 by enzymatic UVS (UV spectrophotometry method).

Nutrient digestibility

A total of 18 crossbred barrows (mean, 38.39 ± 0.826 kg BW) were allotted to individual metabolic crates (40 × 80 × 90 cm) in a completely randomized design with 3 replicates to evaluate nutrient digestibility and nitrogen retention. The total collection method was employed to determine the apparent total tract digestibility. A 5-day collection period followed the 5-day adaptation period. To identify the first and last collection days, 0.05% of iron oxide or chromium oxide were added to the feed amount per feeding on the first and last days as selection markers. During the experimental period, all pigs were fed the experimental diet twice daily at 7:00 and 19:00, which was three times the maintenance energy, and water was provided *ad libitum*. Feces were collected using the total collection method, and urine was collected daily in a plastic container. Feed intake, feces, and urine were recorded daily. The feces and urine samples were stored at −20°C until analysis. The excreta were pooled and dried in a forced-air drying oven at 60°C for 72 h and then ground into 1-mm particles using a Wiley mill for chemical analysis. A sulfuric acid solution, which collected the ammonia in urine by a chemical reaction, was titrated from a 99% sulfuric acid solution to a 10% sulfuric acid solution and was put into a 50-mL plastic case. Glass wool was put into a funnel that was attached to the plastic case to prevent impurities from entering. The urine was then passed through glass wool into the plastic case and diluted with 2 L of water. The diluted urine was collected in a 50-mL conical tube and stored at −20°C before analysis. Moisture, CP, crude fat, and crude ash were analyzed by AOAC (1995) [17] methods for chemical composition analysis of feed, feces, and urine. Experimental diet and excreta were analyzed for contents of dry matter (procedure 967.03; AOAC, 1995), ash (procedure 923.03; AOAC, 1995), N by using the Kjeldahl procedure with a Kjeltec instrument (KjeltecTM 2200, Foss Tecator, Sweden) and CP content (Nitrogen × 6.25; procedure 981.10; AOAC, 1995).

pH, pork color, and physiochemical properties

At the end of the experiment, six finishing pigs from each treatment were selected and slaughtered for pork quality analysis. Pork samples were collected from the nearby 10th rib on the right side of the carcass. Because of the chilling procedure, 30 min after slaughter was regarded as the initial time. The pH and pork color were measured at 0, 3, 6, 12, and 24 h. The pH was measured using a pH meter (Model 720, Thermo, Orion, USA), whereas the pork color was determined by the CIE color L*, a*, and b* values using a CM-M6 (Minolta Camera Co., Japan). Water holding capacity (WHC) was measured by the centrifuge method [17]. The longissimus muscles were ground and sampled in filter tubes, heated in a water bath at 80°C for 20 min, and then centrifuged for 10 min at 2,000 rpm and 4°C (Eppendorf centrifuge 5810R, Germany). Subsequently, to calculate the cooking loss, the longissimus muscles were packed in polyethylene bags, heated in a water bath until the core temperature reached 70°C, and weighed before and after cooking. After heating, the samples were cored (0.5-in diameter) parallel to the muscle fiber, and the cores were used to measure the shear force using the Warner-Bratzler meat shearing machine (Salter 235, GR, USA). The shear force, cooking loss, and WHC of the pork were analyzed by animal origin food science, Seoul National University.

Odor gas emission

A total of 18 crossbred barrows (mean, 38.39 ± 0.826 kg BW) were allotted to individual metabolic crates (40 × 80 × 90 cm) in a completely randomized design with 3 replicates to evaluate odor gas emission. To estimate the odor gas emission, 500 g of fresh feces and 400 g of urine were mixed following the methods described by Kim [18]. Mixtures of fecal and urine were fermented at a room temperature of 35°C for 72 h. The odor-causing materials (amines, ammonia, mercaptans and hydrogen sulfide) were analyzed every 24 h for 7 days using a gas detector (GV-110S, Gastec, Ayase, Japan) and tube (namely, an amine detector tube (180, 5-100 ppm), ammonia detector tube (3L, 0.5-78 ppm), mercaptan detector tube (70, 0.35-84 ppm), and hydrogen sulfide detector tube (4 LT, 0.05-4 ppm)).

Statistical and chemical analyses

Statistical analyses were performed using SAS[19]. The General Linear Model (GLM) procedure was used to analyze the effects of dietary crude protein levels on measured parameters. The statistical model included dietary crude protein levels as fixed effects. For growth performance, the pen was considered the experimental unit, while individual pigs served as experimental units for analyses of nutrient digestibility, blood profiles, meat quality, and odor emission. Least squares means were compared using the PDIFF option in the LSMEANS statement, allowing pairwise comparisons among treatment means. Orthogonal polynomial contrasts were performed using the CONTRAST statement to evaluate linear and quadratic responses to increasing dietary crude protein levels. Statistical significance was declared at $P < 0.05$, and tendencies were defined as $0.05 \leqslant P < 0.10$. All statistical tests were two-tailed, and the results were expressed as means with their corresponding standard errors.

Results

Growth performance

The effects of different levels of dietary CP on growth performance are presented in Table 3. As a result of the experiment, the final BW increased when the dietary CP level decreased (linear, $P < 0.01$). The overall results showed that ADG decreased linearly as the protein level increased (linear, $P < 0.01$). Also, a decrease in dietary CP level resulted in an increase in ADFI during late finishing period (linear, $P < 0.01$).

Blood profiles

The effects of different levels of dietary CP on blood profiles are presented in Table 4. The concentrations of BUN and urea decreased when the dietary CP level decreased during the entire experimental period (linear, $P < 0.01$; linear, $P < 0.01$; respectively). At the 7^{th}, 11^{th}, and 13^{th} weeks, the concentration of total protein increased when the dietary CP level increased (linear, $P = 0.02$; linear, $P < 0.01$; linear, $P < 0.01$; respectively). Also, a decrease in the dietary CP level resulted in a decrease in the concentration of creatinine at the 4^{th} and 13^{th} weeks (linear, $P = 0.03$; linear, $P < 0.01$; respectively).

Nutrient digestibility and odor emission

The effects of different levels of dietary CP on nutrient digestibility are shown in Table 5. The excreted nitrogen in urine increased as the CP level increased (linear, $P < 0.01$). The effects of different levels of dietary CP on odor emission are shown in Table 6. As a result of the experiment, ammonia, amines, mercaptans and hydrogen sulfide emissions decreased when the dietary CP level decreased during the entire experimental period (linear, $P < 0.01$; linear, $P < 0.01$; linear, $P < 0.01$; linear, $P < 0.01$; respectively).

pH, color, and physiochemical properties of pork

The effects of different levels of dietary CP on the pH of pork are presented in Table 7. The pH was not significantly affected by the dietary CP levels at 24 h after slaughter. Meanwhile, the effects of different levels of dietary CP on the color of pork are presented in Table 8. The color was not significantly affected by the dietary CP levels at 24 h after slaughter. Furthermore, the effects of different levels of dietary CP on the physiochemical properties of pork are presented in Table 9. As a result of the experiment, no significant difference was observed in the carcass characteristics of pork among the treatments.

Discussion

The influence of dietary CP levels on the growth performance of growing-finishing pigs remains a subject of debate among researchers, with various studies reporting conflicting results. Kerr et al. [20] reported that supplementation with dietary CP levels of 12% or 16% for growing-finishing pigs had no effect on the BW, ADG, ADFI, and G:F. Morales et al. [21] showed that growth performance did not exhibit significant differences as the CP level increased (14%, 16%, and 22%). Prandini et al. [22] demonstrated that when different levels of CP (15.3%, 15.7%, and 18.7%) were added to the diet of growing-finishing pigs, no significant differences were observed among the treatments in growth performance. Portejoie et al. [23] reported that the BW, ADG, ADFI, and G:F of growing-finishing pigs were not negatively affected when CP levels (12%, 16%, and 20%) were added to growing-finishing diet. Bühler et al. [24] reported that there were no significant differences in the growth performance of growing-finishing pigs when dietary CP levels of 16.5% and 18.9% were added. Monteiro et al. [15] reported that the reduction of the dietary CP levels from 18.2% to 14.8% had no influence on the ADG, ADFI, and G:F throughout the entire period. Xie et al. [26] reported that decreasing the CP level from 15.27% to 12% in the diet of growing-finishing pigs had no effect on the BW and G:F. Galassi et al. [27] reported that the reduction of the CP level from 12.2% to 9.8% in the diet of growing-finishing pigs did not affect growth performance during the growing and finishing periods. Ball et al. [28] reported that the ADFI and feed efficiency linearly decreased during the late finishing period as the CP level increased (13.6%, 14.9%, 16.2%, 17.5%, and 18.8%). Tous et al. [29] reported an increase in the ADG and G:F in treatments with a 12% CP level during the growing period and the entire period when 12% or 13% CP was added to the diet of growing-finishing pigs.

In this study, similar results for the ADFI and ADG were reported by Ball et al. [28] and Tous et al. [29], which indicated that the reduction of the dietary CP levels improved the utilization of CP and amino acids in the blood. Large undigested amounts of protein move to the large intestine, which promotes the growth of pathogenic bacteria in the gastrointestinal tract during their migration. Therefore, the reduction of the dietary CP levels in this study improved the gut health and growth performance of the growing-finishing pigs. Many studies have demonstrated that protein levels affect BUN concentration. Wang et al. [30] reported that when different levels of CP during the growing (15.09% and 17.31%) and finishing (13.29% and 15.62%) periods were added to the diet of growing-finishing pigs, the BUN concentration linearly decreased as the CP level decreased. Hong et al. [31] reported that the BUN concentration linearly decreased during the late growing period as the CP level decreased, with dietary CP added by level during the early growing 17.2% and 18%), late growing (15.6% and 16.3%), early finishing (14.4% and 15.5%), and late finishing periods (12.8% and 13.2%). Prandini et al. [22] reported that the BUN concentration linearly increased as the CP level increased during the growing 15.32%, 15.71%, and 18.73%) and finishing (12.7%, 12.74%, and 15.64%) periods. However, the urea concentration in serum did not show a significant difference among the treatments. Xie et al. [26] demonstrated that the BUN concentration did not show any negative effect when 12% or 15.27% CP was added to the growing-finishing pig diet. Furthermore, Shriver et al. [32] reported that when 14% or 18% CP was added to the diet of growing-finishing pigs, the BUN concentration was low in the treatment with 14% CP throughout the entire experimental period. Carpenter et al. [33] also reported that the BUN concentration decreased as the level of dietary CP decreased (12.3%, 15%, 17%, and 20.8%). In this study, the growing-finishing pigs fed a low-CP diet had lower BUN and urea concentrations than those fed a high-CP diet during the growing-finishing period. These results were in agreement with those of some researchers [30,31], indicating that the reduction of the CP level in the diet of growing-finishing pigs decreased the BUN and urea concentrations. This could be mainly attributed to improved nitrogen utilization. When an excessive amount of protein is supplied, an excessive amount of nitrogen cannot be utilized by the animal's body and thus continues to circulate in the blood. Therefore, it is considered that the BUN, urea, total protein, and creatinine concentrations in the blood increase. Pig excretions contain proteins and metabolites, such as urea, which serve as substrates for bacteria that produce odors and ammonia. Odor substances produced by microbial protein fermentation in the gastrointestinal tract and residual manure have a higher odor problem than fermentable carbohydrates [34,35]. In addition, Mackie et al. [35] reported that proteins and their metabolites are precursors for all major classes of odor substances. Therefore, dietary protein alteration should be prioritized when aiming to minimize odors through dietary adjustments. Generally, dietary CP levels exceed the animals' nutritional requirements. To meet the animals' nutritional needs, the dietary CP level should be reduced, and essential amino acids should be supplemented. Finally, the present study confirms the conclusion by Hayers et al. [36] that the reduction of the dietary CP level from 16% to 13% reduced odor emissions from finished pig housing by 2%, indicating a negligible reduction. As reported by Le et al. [37], a more substantial decrease in CP is expected to result in significant changes in odor emissions. The odor emissions from pig feces decreased by 80% when the dietary protein content in diet was reduced from 18% to 12%. This reduction may be due to bacteria having access to up to 15% of dietary protein and fermentable carbohydrates in the gastrointestinal system and manure, which serve as energy sources. These nutrients are used to convert most proteins and their metabolites into bacterial biomass.

The pH of pork changes after slaughter, impacting the freshness, WHC, tenderness, color, and storage of the meat, all of which contribute to its overall quality [38]. Park et al. [39] found that as pH decreases after slaughter, the protein concentration also increases. Furthermore, both cooking and drip losses decrease, whereas the WHC increases as the pH rises. The initial pH and the pH after slaughter are critical benchmarks for pork quality assessment. The baseline pH is considered to be the expected value for pale, soft, and exudative meat, whereas the final pH is the anticipated value for dry, firm, and dark meat. After death, anaerobic glycolysis of the muscle's stored glycogen increases lactic acid production, reducing the pH of the muscle. The handling methods before and during slaughter, the genetic factors of the animal, and the rate of anaerobic glycolysis significantly influence this pH reduction. A sudden drop in pH causes alteration in muscle protein structures, prompting the juices to seep out. The exuding juices, when scattered on the surface, cause the pork to appear pale, thus contributing to the production of pale, soft, and exudative meat.

In numerous studies, the dietary CP levels did not influence the pH of pork. Kerr et al. [20] observed no significant changes in the pH of pork when 12% or 16% CP was incorporated into the diet of growing-finishing pigs. Similarly, Morales et al. [21] found no significant differences in pH as the CP level increased (14%, 16%, and 22%). Prandini et al. [22] also observed no significant variations in pork pH among treatments as the CP level increased during the growing (15.32%, 15.71%, and 18.73%) and finishing (12.7%, 12.74%, and 15.64%) periods. Furthermore, no significant changes in the pH of pork were detected when different levels of CP were added to the diets of growing-finishing pigs [25,27,29]. In this study, with the pH of pork maintained within the optimal range of 5.3–6.8, no adverse effects on pH levels were observed. When purchasing pork, consumers often first notice the color of the meat, which significantly influences their perception of its quality and their purchasing decisions. The color of pork, which is indicative of its muscle quality, is influenced by various factors, such as the rate of postmortem glycolysis, intramuscular fat content, pigment concentration, and pigment oxidation status [40]. Tous et al. [29] reported that the color of pork showed no adverse effects as the CP level increased during the growing (11.9% and 13.1%) and finishing (10.6% and 9.8%) periods. In addition, Monteiro et al. [21] reported no significant differences in pork color among treatments when the CP level was raised during the early growing (14.8% and 18.2%), late growing (14.6% and 17.1%), early finishing (14.4% and 16.1%), and finishing (12.5% and 13.5%) periods. Galassi et al. [27] observed no significant changes in pork color as the CP levels increased (9.8%, 9.9%, 12.0%, and 12.2%). The findings of this study agree with those of Monteiro et al. [25], Galassi et al. [27], and Tous et al. [29]. WHC, which reflects the ability of meat to retain moisture under internal and external environmental changes, is influenced by changes in the moisture content of the meat during cutting or its microstructure. This capacity is also closely associated with pH variations in the meat. It has been established that WHC significantly influences pork quality; higher WHC is correlated with better pork quality [41], whereas lower capacity is associated with increased shear force in the meat [42]. Cooking loss, an indirect indicator of WHC, is typically inversely correlated with WHC and directly impacts meat toughness, as measured by shear force [43]. Tous et al. [29] noted a reduction in cooking loss with lower CP levels during the growing (11.9% and 13.1%) and finishing (10.6% and 9.8%) periods. Similarly, Shriver et al. [32] found no significant differences in WHC, shear force, or cooking loss among the treatments. In addition, Madrid et al. [44] reported no significant differences in WHC, shear force, and cooking loss during the growing (14%, 15%, and 16%) and finishing (13.5%, 14.5%, and 15.5%) periods. The absence of significant differences among these indicators confirms that the adjustments in dietary protein did not adversely affect pork quality.

These results indicated that reducing CP levels in growing-finishing diet did not exert detrimental effects on growth performance. Emission in manure was decreased. Furthermore, the reduction of BUN could indicate improved protein metabolism, potentially reducing odor emissions from feces and urine in growing-finishing pigs.

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Table 1. Formula of the experimental diets and the calculated chemical compositions during the growing phases.

Phases	Early growing (0-4 weeks)						Late growing (4-7 weeks)					
Treatments	CP1411	CP1512	CP1613	CP1714	CP1815	CP1916	CP1411	CP1512	CP1613	CP1714	CP1815	CP1916
Ground corn	73.96	71.13	68.3	65.47	62.64	59.81	77.17	74.34	71.51	68.68	65.85	63.03
Soybean meal, 45%	16.89	19.89	22.89	25.88	28.88	31.88	14.13	17.13	20.13	23.12	26.12	29.12
Wheat bran	4	4	4	4	4	4	4	4	4	4	4	4
Tallow	1.40	1.51	1.61	1.72	1.83	1.93	1.16	1.27	1.38	1.48	1.59	1.69
L-Lys-Hcl, 50%	0.76	0.61	0.46	0.30	0.15	0	0.76	0.61	0.46	0.30	0.15	0
DL-Met, 99%	0.07	0.06	0.04	0.03	0.01	0	0.07	0.06	0.04	0.03	0.01	0
L-Thr, 98.5%	0.23	0.18	0.14	0.09	0.05	0	0.23	0.18	0.14	0.09	0.05	0
L-Trp, 99%	0.08	0.07	0.05	0.03	0.02	0	0.08	0.06	0.05	0.03	0.02	0
DCP	1.40	1.33	1.26	1.20	1.13	1.06	1.27	1.20	1.14	1.07	1.01	0.94
Limestone	0.71	0.73	0.75	0.78	0.80	0.82	0.63	0.65	0.67	0.68	0.70	0.72
Vit. Mix[2)]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Min. Mix[3)]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Sum	100	100	100	100	100	100	100	100	100	100	100	100
ME (kcal/kg)	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300
Crude protein (%)	14	15	16	17	18	19	13	14	15	16	17	18
SID Lys (%)	1.03	1.03	1.03	1.03	1.03	1.03	0.96	0.96	0.96	0.96	0.96	0.96
SID Met (%)	0.29	0.29	0.29	0.29	0.29	0.29	0.28	0.28	0.28	0.28	0.28	0.28
SID Thr (%)	0.73	0.73	0.73	0.73	0.73	0.73	0.69	0.69	0.69	0.69	0.69	0.69
SID Trp (%)	0.23	0.23	0.23	0.23	0.23	0.23	0.21	0.21	0.21	0.21	0.21	0.21
SID Arg (%)	0.94	1.05	1.15	1.25	1.35	1.46	0.85	0.95	1.06	1.16	1.26	1.36
SID His (%)	0.41	0.45	0.48	0.51	0.54	0.58	0.39	0.42	0.45	0.48	0.52	0.55
SID Ile (%)	0.62	0.69	0.75	0.81	0.88	0.94	0.57	0.63	0.69	0.76	0.82	0.88
SID Leu (%)	1.40	1.48	1.57	1.66	1.75	1.84	1.32	1.41	1.50	1.59	1.68	1.76
SID Phe (%)	0.75	0.81	0.88	0.95	1.01	1.08	0.69	0.75	0.82	0.89	0.95	1.02
SID Val (%)	0.77	0.83	0.89	0.96	1.02	1.08	0.72	0.78	0.84	0.90	0.96	1.03
SID Phe+Tyr (%)	1.30	1.42	1.54	1.66	1.77	1.89	1.19	1.31	1.43	1.55	1.67	1.79
Total calcium (%)	0.66	0.66	0.66	0.66	0.66	0.66	0.59	0.59	0.59	0.59	0.59	0.59
STTD phosphorus (%)	0.31	0.31	0.31	0.31	0.31	0.31	0.27	0.27	0.27	0.27	0.27	0.27

DCP, di-calcium phosphate; ME, metabolizable energy; SID, standardized ileal digestibility; STTD, standardized total tract digestibility

[1] Diets with different CP levels (%) for early growing, late growing, early finishing, and late finishing phases, respectively, were as follows: CP1411: 14, 13, 12, 11; CP1512: 15, 14, 13, 12; CP1613: 16, 15, 14, 13; CP1714: 17, 16, 15, 14; CP1815: 18, 17, 16, 15; CP1916: 19, 18, 17, 16.

[2] Quantities of vitamins provided per kg of complete diet: vitamin A, 8,000 IU; vitamin D3, 800 IU; vitamin E, 40 mg; vitamin. K3, 4 mg; vitamin B1, 2 mg; vitamin B2, 9.2 mg; vitamin B6, 3 mg; calcium pantothenic acid, 20 mg; niacin, 50 mg; Folic acid, 600 ug; D–biotin, 200 ug; vitamin B12, 30 ug.

[3] Quantities of minerals provided per kg of complete diet Fe, 80 mg; Cu, 20 mg; Zn, 60 mg; Mn, 40 mg; I, 0.45 mg; Se, 0.2 mg; Co, 0.5 mg.

Table 2. Formula of the experimental diets and the calculated chemical compositions during the finishing phases.

Phases	Early finishing (7-11 weeks)						Late finishing (11-13 weeks)					
Treatments	CP1411	CP1512	CP1613	CP1714	CP1815	CP1916	CP1411	CP1512	CP1613	CP1714	CP1815	CP1916
Ground corn	80.49	77.66	74.83	71.99	69.16	66.33	83.68	80.85	78.02	75.19	72.36	69.53
Soybean meal, 45%	11.35	14.35	17.35	20.34	23.34	26.34	8.60	11.60	14.60	17.59	20.59	23.59
Wheat bran	4	4	4	4	4	4	4	4	4	4	4	4
Tallow	0.89	1.00	1.11	1.21	1.32	1.43	0.66	0.76	0.87	0.98	1.09	1.19
L-Lys-Hcl, 50%	0.76	0.61	0.46	0.30	0.15	0	0.76	0.61	0.46	0.30	0.15	0
DL-Met, 99%	0.07	0.06	0.04	0.03	0.01	0	0.07	0.06	0.04	0.03	0.01	0
L-Thr, 98.5%	0.23	0.18	0.14	0.09	0.05	0	0.23	0.18	0.14	0.09	0.05	0
L-Trp, 99%	0.08	0.06	0.05	0.03	0.02	0	0.08	0.06	0.05	0.03	0.02	0
DCP	1.01	0.94	0.88	0.81	0.75	0.68	0.84	0.77	0.70	0.64	0.57	0.50
Limestone	0.62	0.64	0.66	0.68	0.70	0.72	0.58	0.60	0.62	0.65	0.67	0.69
Vit. Mix[2)]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Min. Mix[3)]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Sum	100	100	100	100	100	100	100	100	100	100	100	100
ME (kcal/kg)	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300
Crude protein (%)	12	13	14	15	16	17	11	12	13	14	15	16
SID Lys (%)	0.89	0.89	0.89	0.89	0.89	0.89	0.82	0.82	0.82	0.82	0.82	0.82
SID Met (%)	0.27	0.27	0.27	0.27	0.27	0.27	0.26	0.26	0.26	0.26	0.26	0.26
SID Thr (%)	0.65	0.65	0.65	0.65	0.65	0.65	0.61	0.61	0.61	0.61	0.61	0.61
SID Trp (%)	0.20	0.20	0.20	0.20	0.20	0.20	0.18	0.18	0.18	0.18	0.18	0.18
SID Arg (%)	0.76	0.76	0.76	0.76	0.76	0.76	0.67	0.77	0.87	0.97	1.08	1.18
SID His (%)	0.36	0.36	0.36	0.36	0.36	0.36	0.33	0.36	0.39	0.43	0.46	0.49
SID Ile (%)	0.51	0.51	0.51	0.51	0.51	0.51	0.46	0.52	0.58	0.64	0.71	0.77
SID Leu (%)	1.24	1.24	1.24	1.24	1.24	1.24	1.17	1.26	1.35	1.43	1.52	1.61
SID Phe (%)	0.63	0.63	0.63	0.63	0.63	0.63	0.57	0.64	0.70	0.77	0.84	0.90
SID Val (%)	0.66	0.66	0.66	0.66	0.66	0.66	0.61	0.67	0.73	0.79	0.86	0.92
SID Phe+Tyr (%)	1.09	1.09	1.09	1.09	1.09	1.09	0.98	1.10	1.22	1.34	1.46	1.58
Total calcium (%)	0.52	0.52	0.52	0.52	0.52	0.52	0.46	0.46	0.46	0.46	0.46	0.46
STTD phosphorus (%)	0.24	0.24	0.24	0.24	0.24	0.24	0.21	0.21	0.21	0.21	0.21	0.21

DCP, di-calcium phosphate; ME, metabolizable energy; SID, standardized ileal digestibility; STTD, standardized total tract digestibility

[1] Diets with different CP levels (%) for early growing, late growing, early finishing, and late finishing phases, respectively, were as follows: CP1411: 14, 13, 12, 11; CP1512: 15, 14, 13, 12; CP1613: 16, 15, 14, 13; CP1714: 17, 16, 15, 14; CP1815: 18, 17, 16, 15; CP1916: 19, 18, 17, 16.

[2] Quantities of vitamins provided per kg of complete diet: vitamin A, 8,000 IU; vitamin D3, 800 IU; vitamin E, 40 mg; vitamin. K3, 4 mg; vitamin B1, 2 mg; vitamin B2, 9.2 mg; vitamin B6, 3 mg; calcium pantothenic acid, 20 mg; niacin, 50 mg; Folic acid, 600 ug; D–biotin, 200 ug; vitamin B12, 30 ug.

[3] Quantities of minerals provided per kg of complete diet Fe, 80 mg; Cu, 20 mg; Zn, 60 mg; Mn, 40 mg; I, 0.45 mg; Se, 0.2 mg; Co, 0.5 mg.

Table 3. Effects of different levels of dietary crude protein on growth performance in growing-finishing pigs[1]

Criteria	Treatment[2]						SEM[3]	p-value	
	CP1411	CP1512	CP1613	CP1714	CP1815	CP1916		Linear	Quadratic.
BW, kg									
Initial	------------------------ 39.93 ------------------------								
4 week	61.46	60.61	60.15	61.42	59.72	59.58	1.001	0.63	0.95
7 week	81.37	80.84	78.63	82.85	80.16	79.04	1.203	0.72	0.87
11 week	110.91	110.64	107.28	112.18	108.04	107.55	1.168	0.44	0.88
13 week	117.79	115.75	115.43	114.67	114.47	114.60	0.351	<0.01	0.12
ADG, g									
0-4 week	769.40	741.40	721.80	767.40	706.40	702.40	13.326	0.17	0.88
4-7 week	975.89	991.07	947.86	1,048.53	965.46	954.96	24.298	0.88	0.62
7-11 week	1,111.59	1,064.28	1,042.65	1,070.59	1,018.33	1018.23	21.221	0.22	0.82
11-13 week	964.44	1,168.89	973.86	801.11	986.77	953.33	47.612	0.44	0.76
0-13 week	926.83	903.43	898.64	889.64	887.26	889.14	4.185	<0.01	0.11
ADFI, g									
0-4 week	1,887.80	1,834.80	1,869.40	1,978.60	1,824.40	1850.40	27.241	0.85	0.57
4-7 week	2,517	2,650.40	2,622.20	2,781.60	2,636	2687.00	40.732	0.27	0.36
7-11 week	3,157.40	3,125.40	3,323.57	3,235.60	3,234.60	3261.60	31.907	0.26	0.50
11-13 week	3,320	3,350	3,240	3,410	3,390	3370.00	10.321	<0.01	0.21
0-13 week	2,717.38	2,725.75	2,868.20	2,796.77	2,767.86	2778.61	25.130	0.50	0.25
G:F									
0-4 week	0.408	0.406	0.387	0.387	0.389	0.380	0.007	0.19	0.77
4-7 week	0.386	0.374	0.361	0.379	0.368	0.354	0.008	0.35	1.00
7-11 week	0.350	0.341	0.332	0.332	0.317	0.329	0.006	0.15	0.54
11-13 week	0.290	0.349	0.300	0.235	0.291	0.283	0.014	0.15	0.54
0-13 week	0.341	0.332	0.313	0.319	0.322	0.323	0.004	0.15	0.12

BW, body weight; ADG, average daily gain; ADFI, average daily feed intake; G:F, gain-to-feed

[1] A total of 210 growing pigs were used in the experiment, with 35 pigs per treatment.

[2] Diets with different CP levels (%) for early growing, late growing, early finishing, and late finishing phases, respectively, were as follows: CP1411: 14, 13, 12, 11; CP1512: 15, 14, 13, 12; CP1613: 16, 15, 14, 13; CP1714: 17, 16, 15, 14; CP1815: 18, 17, 16, 15; CP1916: 19, 18, 17, 16.[3] Standard error of the mean.

Table 4. Effects of different levels of dietary crude protein on blood profiles in growing-finishing pigs[1]

Criteria	Treatment[2]						SEM[3]	p-value	
	CP1411	CP1512	CP1613	CP1714	CP1815	CP1916		Linear	Quadratic
Creatinine, mg/dL									
Initial		------------------------ 1.09 ------------------------							
4 week	0.80	0.90	0.91	0.93	0.96	1.02	0.029	0.03	0.93
7 week	1.01	1.06	1.11	1.12	1.16	1.17	0.029	0.07	0.71
11 week	1.19	1.28	1.29	1.38	1.35	1.36	0.051	0.26	0.62
13 week	0.81	0.88	0.97	1.02	1.03	1.08	0.029	<0.01	0.45
Total protein, g/dL									
Initial		------------------------ 6.60 ------------------------							
4 week	6.84	6.84	6.90	6.94	7.00	7.14	0.065	0.16	0.65
7 week	5.72	6.28	6.60	6.65	6.90	7.06	0.171	0.02	0.55
11 week	4.66	6.22	6.68	6.82	6.88	6.68	0.171	<0.01	0.21
13 week	5.65	5.68	6.10	6.23	6.65	7.10	0.153	<0.01	0.48
Triglyceride, mg/dL									
Initial		------------------------ 56.14 ------------------------							
4 week	48.20	60.40	50.00	37.60	52.00	48.60	2.960	0.56	0.75
7 week	44.20	52.20	44.00	52.20	53.80	38.60	2.433	0.77	0.17
11 week	62.00	44.80	112.00	43.20	101.20	32.80	13.649	0.87	0.35
13 week	43.50	48.75	65.75	52.00	131.75	85.75	12.375	0.09	0.99
BUN, mg/dL									
Initial		------------------------ 9.43------------------------							
4 week	9.68	9.82	11.08	13.14	13.76	16.54	0.634	<0.01	0.34
7 week	9.70	11.84	11.90	14.38	16.88	16.82	0.795	<0.01	0.94
11 week	10.54	11.40	12.80	13.26	15.02	17.10	0.534	<0.01	0.39
13 week	7.80	9.10	9.45	9.63	11.50	12.08	0.417	<0.01	0.76
Urea, mg/dL									
Initial		------------------------ 20.17------------------------							
4 week	20.76	21.04	23.74	28.14	29.46	35.42	1.356	<0.01	0.34
7 week	20.78	25.34	25.48	30.78	36.16	36.02	1.703	<0.01	0.94
11 week	22.58	24.44	27.42	28.40	32.18	36.62	1.143	<0.01	0.39
13 week	16.70	19.50	20.20	20.63	24.63	25.85	0.892	<0.01	0.75

BUN, blood urea nitrogen

[1] A total of 210 growing pigs were used in the experiment, with 35 pigs per treatment.

[2] Diets with different CP levels (%) for early growing, late growing, early finishing, and late finishing phases, respectively, were as follows: CP1411: 14, 13, 12, 11; CP1512: 15, 14, 13, 12; CP1613: 16, 15, 14, 13; CP1714: 17, 16, 15, 14; CP1815: 18, 17, 16, 15; CP1916: 19, 18, 17, 16.[3] Standard error of the mean.

Table 5. Effects of different levels of dietary crude protein on nutrient digestibility in growing-finishing pigs[1]

Criteria	Treatment[2]						SEM[3]	p-value	
	CP1411	CP1512	CP1613	CP1714	CP1815	CP1916		Linear	Quadratic
Nutrient digestibility, %									
Dry matter	84.61	83.24	83.74	85.33	85.05	83.71	0.438	0.80	0.78
Crude protein	75.50	74.42	76.93	79.70	79.49	79.08	0.879	0.07	0.71
Crude ash	65.73	40.8	62.14	56.59	60.47	45.82	3.012	0.38	0.75
Crude fat	67.75	72.9	75.08	76.99	66.53	63.38	1.741	0.23	0.02
N retention, g/d									
N intake	8.62	9.16	10.32	11.19	11.88	12.36	-	-	-
Fecal N	2.11	2.34	2.38	2.27	2.44	2.59	0.080	0.13	0.95
Urinary N	0.28	0.38	0.45	0.49	0.71	0.95	0.081	<0.01	0.27
N retention[4]	6.23	6.44	7.49	8.43	8.73	8.82	1.010	0.6	0.35

N, nitrogen

[1] A total of 18 barrows (initial body weight, 38.39 ± 0.826 kg).

[2] Diets with different CP levels (%) for early growing, late growing, early finishing, and late finishing phases, respectively, were as follows: CP1411: 14, 13, 12, 11; CP1512: 15, 14, 13, 12; CP1613: 16, 15, 14, 13; CP1714: 17, 16, 15, 14; CP1815: 18, 17, 16, 15; CP1916: 19, 18, 17, 16.

[3] Standard error of the mean.

[4] N retention = N intake (g) − fecal N (g) − urinary N (g)

Table 6. Effects of different levels of dietary crude protein on odor emission in growing-finishing pigs[1]

Criteria	Treatment[2]						SEM[3]	p-value	
	CP1411	CP1512	CP1613	CP1714	CP1815	CP1916		Linear	Quadratic
Amines, ppm									
0-4 week	13.24	16.41	37.57	47.07	68.57	87.14	6.631	<0.01	0.10
4-7 week	13.64	16.64	27.64	34.67	42.86	53.50	3.443	<0.01	0.11
7-11 week	10.06	12.11	18.55	25.51	38.97	49.64	3.495	<0.01	0.21
11-13 week	11.06	10.92	15.13	21.00	31.18	39.55	2.793	<0.01	0.37
Ammonia, ppm									
0-4 week	12.00	14.79	15.74	16.50	25.86	6.50	1.826	<0.01	0.07
4-7 week	10.71	10.57	10.71	20.00	20.71	30.07	2.253	<0.01	0.22
7-11 week	9.88	9.92	10.18	12.54	15.33	16.02	0.735	<0.01	0.23
11-13 week	10.75	10.69	11.34	14.11	14.56	18.93	1.168	<0.01	0.41
Mercaptans, ppm									
0-4 week	0.41	0.66	0.95	1.04	1.11	1.11	0.070	<0.01	0.12
4-7 week	0.69	0.75	0.97	1.10	1.24	2.20	0.181	<0.01	0.26
7-11 week	0.33	0.41	0.39	0.95	1.02	1.24	0.132	<0.01	0.70
11-13 week	0.21	0.37	0.52	0.79	1.05	1.64	0.152	<0.01	0.34
Hydrogen sulfide, ppm									
0-4 week	0.00	0.84	1.06	1.71	1.79	2.14	0.176	<0.01	0.15
4-7 week	0.86	1.07	1.13	1.27	2.00	2.14	0.175	<0.01	0.51
7-11 week	0.59	0.64	0.89	1.06	1.17	1.92	0.152	<0.01	0.33
11-13 week	0.68	0.59	0.92	1.11	1.82	2.51	0.222	<0.01	0.19

[1] A total of 18 barrows. (initial body weight, 38.39 ± 0.826 kg)

[2] Diets with different CP levels (%) for early growing, late growing, early finishing, and late finishing phases, respectively, were as follows: CP1411: 14, 13, 12, 11; CP1512: 15, 14, 13, 12; CP1613: 16, 15, 14, 13; CP1714: 17, 16, 15, 14; CP1815: 18, 17, 16, 15; CP1916: 19, 18, 17, 16.[3] Standard error of the mean.

Table 7. Effects of different levels of dietary crude protein on pH in growing-finishing pigs[1]

Criteria	Treatment[2]						SEM[3]	p-value	
	CP1411	CP1512	CP1613	CP1714	CP1815	CP1916		Linear	Quadratic
Time after slaughter									
0 hours	5.74	5.69	5.62	5.70	5.66	5.66	0.022	0.41	0.46
3 hours	5.71	5.46	5.60	5.44	5.60	5.51	0.026	0.10	0.08
6 hours	5.42	5.45	5.50	5.45	5.45	5.43	0.022	0.98	0.45
12 hours	5.55	5.46	5.55	5.51	5.49	5.45	0.017	0.21	0.64
24 hours	5.39	5.40	5.47	5.45	5.36	5.43	0.010	0.59	0.05

[1] A total of 210 growing pigs were fed, with least squares means of five observations per treatment.

[2] Diets with different CP levels (%) for early growing, late growing, early finishing, and late finishing phases, respectively, were as follows: CP1411: 14, 13, 12, 11; CP1512: 15, 14, 13, 12; CP1613: 16, 15, 14, 13; CP1714: 17, 16, 15, 14; CP1815: 18, 17, 16, 15; CP1916: 19, 18, 17, 16.[3] Standard error of the mean.

Table 8. Effects of different levels of dietary crude protein on pork color in growing-finishing pigs[1]

Criteria	Treatment[2]						SEM[3]	p-value	
	CP1411	CP1512	CP1613	CP1714	CP1815	CP1916		Linear	Quadratic
CIE value[4], L*									
0 hours	53.14	51.41	50.97	51.78	52.69	51.38	0.767	0.81	0.69
3 hours	52.11	54.10	52.03	50.72	52.63	51.47	0.646	0.53	0.99
6 hours	52.12	53.57	50.47	51.21	52.53	53.40	0.665	0.78	0.35
12 hours	54.98	50.47	53.79	51.70	51.10	53.08	0.712	0.51	0.31
24 hours	53.64	51.23	53.41	52.23	52.91	52.56	0.540	0.90	0.74
CIE value[4], a*									
0 hours	6.70	6.46	6.49	6.46	6.21	6.23	0.145	0.34	0.96
3 hours	6.70	6.31	6.33	6.34	6.57	6.33	0.063	0.41	0.27
6 hours	6.77	6.85	6.76	6.51	6.46	6.53	0.087	0.18	0.96
12 hours	6.67	6.85	6.65	6.54	6.23	6.42	0.280	0.61	0.96
24 hours	6.83	6.84	6.58	6.40	6.57	6.78	0.195	0.78	0.57
CIE value[4], b*									
0 hours	13.84	13.67	13.43	13.35	13.54	13.38	0.066	0.08	0.22
3 hours	13.53	13.69	13.57	13.82	13.59	13.77	0.072	0.46	0.86
6 hours	13.65	13.63	13.64	13.67	13.69	13.63	0.061	0.96	0.93
12 hours	13.36	13.56	13.42	13.66	13.91	13.59	0.148	0.47	0.78
24 hours	13.54	13.57	13.42	13.62	13.39	13.73	0.070	0.70	0.48

[1] A total of 210 growing pigs were fed, with least squares means of five observations per treatment.

[2] Diets with different CP levels (%) for early growing, late growing, early finishing, and late finishing phases, respectively, were as follows: CP1411: 14, 13, 12, 11; CP1512: 15, 14, 13, 12; CP1613: 16, 15, 14, 13; CP1714: 17, 16, 15, 14; CP1815: 18, 17, 16, 15; CP1916: 19, 18, 17, 16.[3] Standard error of the mean.

[4] CIE L*: luminance or brightness (varies from black to white)

CIE a*: red-green component (+a=red, -a=green)

CIE b*: yellow-blue component (+b=yellow, -b=blue)

Table 9. Effects of different levels of dietary crude protein on physiochemical properties in growing-finishing pigs[1]

Criteria	Treatment[2]						SEM[3]	p-value	
	CP1411	CP1512	CP1613	CP1714	CP1815	CP1916		Linear	Quadratic
Proximate analysis, %									
Moisture	73.99	73.83	73.97	73.37	77.35	72.90	0.508	0.65	0.57
Crude protein	22.18	21.45	20.19	21.83	22.64	22.08	0.307	0.44	0.19
Crude fat	4.76	4.86	3.85	5.20	3.01	4.69	0.302	0.46	0.63
Crude ash	0.44	0.52	0.44	0.44	0.52	0.59	0.043	0.37	0.45
Physiochemical property									
Cooking loss, %	30.16	31.95	32.17	31.95	32.37	32.35	0.346	0.11	0.30
Shear force, kg/0.5 inch[2]	39.96	59.82	46.28	61.17	48.98	54.82	2.641	0.27	0.25
WHC, %	73.99	73.83	73.97	73.37	77.35	72.90	0.508	0.65	0.57

WHC, water holding capacity

[1] A total of 210 growing pigs were fed, with least squares means of five observations per treatment.

[2] Diets with different CP levels (%) for early growing, late growing, early finishing, and late finishing phases, respectively, were as follows: CP1411: 14, 13, 12, 11; CP1512: 15, 14, 13, 12; CP1613: 16, 15, 14, 13; CP1714: 17, 16, 15, 14; CP1815: 18, 17, 16, 15; CP1916: 19, 18, 17, 16.

[3] Standard error of the mean.