Effects of Dietary Isoleucine Level on Growth Performance, Carcass Traits, and Meat Quality of Finishing Pigs (Postprint)

Authors: Luo Yanhong, Zhang Xin, Qin Chunfu, Jiao Ning, YIN Jingdong

Date: 2017-10-23T00:00:00+00:00

Abstract

This experiment aimed to investigate the effects of dietary isoleucine levels on growth performance, carcass traits, and meat quality in finishing pigs. Seventy-two Duroc × Landrace × Yorkshire crossbred barrows with a body weight of (77.0$±$0.1) kg were randomly allocated to 3 groups, with 6 replicates per group and 4 pigs per replicate. The experimental pigs in the 3 groups were fed diets containing 0.25% (low isoleucine level, representing isoleucine deficiency, L-Ile group), 0.39% (NRC-recommended isoleucine level, N-Ile group, serving as the control group), and 0.53% (high isoleucine level, representing isoleucine excess supplementation, H-Ile group) standardized ileal digestible isoleucine, respectively. The experimental period lasted 28 days. The results showed that dietary isoleucine level had no significant effect on average daily gain and average daily feed intake of finishing pigs ($P>0.05$), but the feed-to-gain ratio of the L-Ile group was significantly increased compared with the control group ($P<0.05$); with increasing dietary isoleucine levels, intramuscular fat content in the longissimus dorsi muscle of finishing pigs increased linearly ($P<0.05$), while shear force decreased linearly ($P<0.05$); compared with the control group, finishing pigs fed the isoleucine-deficient diet had significantly reduced backfat thickness, loin eye area, and meat color score ($P<0.05$), finishing pigs fed the isoleucine-deficient or excess-supplemented diets had significantly reduced hot carcass weight, dressing percentage, and drip loss and b* value (yellowness) in the longissimus dorsi muscle ($P<0.05$); with increasing dietary isoleucine levels, serum triglyceride content increased linearly ($P<0.05$), while serum urea nitrogen content decreased linearly ($P<0.05$); compared with the control group, finishing pigs fed the excess isoleucine-supplemented diet had significantly increased serum glucose content ($P<0.05$), finishing pigs fed the isoleucine-deficient diet had significantly reduced concentrations of free essential amino acids, non-essential amino acids, and total amino acids in serum ($P<0.05$), while finishing pigs fed the isoleucine-deficient or excess-supplemented diets had significantly reduced serum total cholesterol,

low-density lipoprotein, and high-density lipoprotein contents ($P<0.05$). It was concluded that isoleucine deficiency in the diet negatively affected growth performance, carcass traits, and intramuscular fat content in finishing pigs, while excess isoleucine supplementation significantly improved muscle shear force and drip loss, increased intramuscular fat content, but at the cost of reduced hot carcass weight and dressing percentage.

Full Text

Effects of Dietary Isoleucine Level on Growth Performance, Carcass Traits, and Meat Quality of Finishing Pigs

LUO Yanhong, ZHANG Xin, QIN Chunfu, JIAO Ning, YIN Jingdong*

State Key Laboratory of Animal Nutrition, College of Animal Science and Technology, China Agricultural University, Beijing 100193, China
*Corresponding author: yinjd@cau.edu.cn

Abstract

This experiment aimed to investigate the effects of dietary isoleucine level on growth performance, carcass traits, and meat quality of finishing pigs. Seventy-two Duroc × Landrace × Large White crossbred barrows with an initial body weight of (77.0 ± 0.1) kg were randomly allocated to three groups, each consisting of six replicates with four pigs per replicate. The three experimental groups were fed diets containing 0.25% (low isoleucine level, representing isoleucine deficiency; L-Ile group), 0.39% (NRC-recommended isoleucine level; N-Ile group, serving as the control), and 0.53% (high isoleucine level, representing isoleucine excess; H-Ile group) standardized ileal digestible isoleucine. The experimental period lasted 28 days. The results showed that dietary isoleucine level had no significant effect on average daily gain or average daily feed intake of finishing pigs ($P > 0.05$), but the feed-to-gain ratio in the L-Ile group was significantly higher than in the control group ($P < 0.05$). As dietary isoleucine level increased, intramuscular fat content in the longissimus dorsi muscle increased linearly ($P < 0.05$), while shear force decreased linearly ($P < 0.05$). Compared with the control group, finishing pigs fed the isoleucine-deficient diet showed significantly reduced backfat thickness, loin eye area, and meat color score ($P < 0.05$), while pigs fed either deficient or excess isoleucine diets exhibited significantly lower hot carcass weight, dressing percentage, drip loss, and b* value of the longissimus dorsi muscle ($P < 0.05$). With increasing dietary isoleucine level, serum triglyceride content increased linearly ($P < 0.05$), whereas serum urea nitrogen content decreased linearly ($P < 0.05$). Compared with the control group, finishing pigs fed the excess isoleucine diet had significantly increased serum glucose content ($P < 0.05$), while those fed the deficient diet showed significantly reduced concentrations of serum free essential amino acids, non-essential amino acids, and total amino acids ($P < 0.05$). Additionally, pigs fed either deficient or excess isoleucine diets had significantly reduced serum total cholesterol, low-density lipoprotein, and high-density lipoprotein contents ($P < 0.05$). These results indicate that isoleucine deficiency negatively affects growth performance, carcass traits, and intramuscular fat content in finishing pigs, whereas excess isoleucine supplementation significantly improves muscle shear force and drip loss while increasing intramuscular fat content, albeit at the cost of reduced hot carcass weight and dressing percentage.

Keywords: isoleucine; growth performance; carcass traits; meat quality; serum physiological and biochemical indexes; serum free amino acids

Introduction

With economic development and rising living standards, consumer demand for meat has shifted from quantity to quality. In 2015, China' s total production of pork, beef, mutton, and poultry reached 86.25 million tons, with pork production accounting for 54.865 million tons—more than 60% of total meat output. However, producers' excessive focus on growth rate, feed conversion efficiency, and lean percentage has led to declining pork quality. In livestock production, improving growth performance must be accompanied by attention to pork quality.

Branched-chain amino acids (BCAAs), including leucine, isoleucine, and valine, are essential amino acids primarily oxidized in extrahepatic tissues, with muscle being the main site of oxidation. Numerous studies have demonstrated that BCAAs play important roles in energy balance and lipid metabolism, yet research on isoleucine specifically remains limited, with most previous studies focusing on requirement levels. Isoleucine deficiency in diets has been shown to significantly reduce growth performance in finishing pigs, while further isoleucine supplementation beyond requirements does not significantly affect growth performance. In production practice, isoleucine is often deficient in finishing pig diets, but few reports have addressed the effects of dietary isoleucine level on carcass traits and meat quality in pigs. Dean et al. found that adding isoleucine to corn-soybean meal diets quadratically increased backfat thickness, total fat content, and body fat percentage in finishing pigs, though the effects of isoleucine on pork quality remain unclear. Therefore, this study investigated the effects of dietary isoleucine deficiency or excess on carcass traits and meat quality in finishing pigs to provide a theoretical basis for improving pork quality.

Materials and Methods

1.1 Experimental Design and Diets Seventy-two Duroc × Landrace × Large White crossbred barrows with an initial body weight of (77.0 ± 0.1) kg were randomly divided into three groups based on body weight, with six replicates per group and four pigs per replicate. The three groups of experimental pigs were fed diets containing 0.25% (low isoleucine level, representing isoleucine deficiency; L-Ile group), 0.39% (NRC-recommended isoleucine level; N-Ile group, serving as control), and 0.53% (high isoleucine level, representing isoleucine excess; H-Ile group) standardized ileal digestible isoleucine. The experimental diets were formulated based on a corn-soybean meal diet, with synthetic amino acids added to ensure that all essential amino acids except isoleucine, as well as nitrogen levels, met the NRC (2012) recommendations for finishing pigs (75–100 kg). Alanine content was adjusted to maintain isonitrogenous levels across the three experimental diets. Diet composition and nutrient levels are presented in Table 1 .

The experimental animals were selected as crossbred barrows weighing (77.0 ± 0.1) kg. Since Chinese feeding standards (NY/T 65-2004) only provide recommendations for lean-type growing-finishing pigs up to 60–90 kg, the nutrient levels in this experiment were based on NRC (2012) recommendations for finishing pigs (75–100 kg). As shown in Table 1, all essential amino acids except isoleucine, as well as nitrogen levels, were consistent across the three experimental diets and met NRC (2012) recommendations, ensuring that the observed effects were primarily attributable to differences in dietary isoleucine levels.

1.2 Animal Management The experiment was conducted at the Animal Experimental Base of the Feed Industry Center, Ministry of Agriculture (Fengning, Hebei). Pigs were housed in a fully enclosed building that was thoroughly disinfected and cleaned before the trial. Experimental pigs underwent routine deworming and vaccination. Temperature, humidity, and ventilation were artificially controlled, with room temperature maintained at approximately 20 °C. Pigs were randomly assigned to 18 pens (2.6 m × 1.8 m × 0.9 m) by replicate, with consistent equipment and conditions in each pen. Stainless steel adjustable feeders and nipple drinkers were provided, allowing ad libitum access to feed and water. The entire experimental procedure strictly followed the farm management regulations and animal welfare standards of China Agricultural University. The experimental period lasted 28 days.

1.3 Sample Collection At the end of the feeding trial, pigs were fasted for 12 hours. One pig per pen with body weight close to the average was selected for blood collection from the anterior vena cava. Blood samples were left to stand for 0.5 hours, then centrifuged at 3,500 r/min for 10 minutes at 4 °C to prepare serum, which was stored at -20 °C for analysis of serum physiological and biochemical indexes and amino acid content. The following day, 18 pigs (six per group) were transported for 45 minutes to a slaughterhouse, rested for 2 hours, then stunned electrically and slaughtered by exsanguination for determination of carcass quality and meat quality.

1.4 Measurement Methods 1.4.1 Dietary Nutrient Component Analysis

Dietary ingredients and diets were analyzed for crude protein, calcium, phosphorus (total and available phosphorus), and amino acid content according to AOAC (2003) standards. Crude protein, calcium, and phosphorus were determined using the Kjeldahl method, EDTA titration method, and ammonium molybdate spectrophotometry, respectively. Amino acid content was determined as follows: samples were hydrolyzed with hydrochloric acid and analyzed for 15 amino acids using an automatic amino acid analyzer (L-8800, Japan); sulfur-containing amino acids were determined after formic acid oxidation using an automatic amino acid analyzer; tryptophan content was measured after sodium hydroxide hydrolysis using reversed-phase liquid chromatography (Waters2690, MA, USA).

1.4.2 Growth Performance Measurement

Pigs were weighed individually at the beginning and end of the experiment to calculate average daily gain (ADG). Feed was weighed weekly by pen to calculate average daily feed intake (ADFI). The feed-to-gain ratio (F/G) was calculated based on ADG and ADFI.

1.4.3 Carcass Trait Measurement

After slaughter, the 18 pigs were dehaired and eviscerated (with leaf fat and kidneys retained). Carcass traits were measured according to the "Technical Specification for Determination of Lean-type Pig Carcass Traits" (NY/T 825-2004). Dressing percentage, hot carcass weight, and backfat thickness (measured at three points: the thickest part of the shoulder, the last rib, and the lumbosacral junction, with the average of the three values used) were determined using vernier calipers. The length and width of the longissimus dorsi cross-section at the last rib were measured with vernier calipers, and loin eye area was calculated using the following formula:

Loin eye area (cm^2) = Length of longissimus dorsi cross-section at last rib (cm) $\times$ Width of longissimus dorsi cross-section at last rib (cm) $\times$ 0.7.

1.4.4 Meat Quality Measurement

Meat color, marbling score, flesh color score, and pH_{45} (pH at 45 minutes post-slaughter) were measured on-site after slaughter. Samples of longissimus dorsi muscle from the 10th–12th ribs were collected and stored at 4 °C for determination of pH_{24} (pH at 24 hours post-slaughter) and drip loss. Additional samples (approximately 50 g) were stored at -20 °C for intramuscular fat content determination.

A pH meter (DK-2730, SFK-Technology, Denmark) electrode probe was completely embedded in the longissimus dorsi muscle to a depth of at least 1 cm at 45 minutes and 24 hours post-slaughter, and pH values were recorded after stabilization. Marbling and flesh color scores were evaluated using the Official Color and Marbling Standards (NPPC, USA). Meat color parameters [lightness (L*), redness (a*), and yellowness (b*)] were measured using a colorimeter (CR410, Minolta, Japan).

Drip loss was determined according to the "Technical Specification for Determination of Pork Quality" (NY/T 821-2004). Approximately 100 g of muscle sample (1 cm thick) was sealed in a plastic bag and placed in a 70 °C water bath. When the core temperature reached 70 °C, surface water was absorbed with filter paper, and cooking loss was calculated based on weight before and after cooking. Additionally, approximately 100 g of muscle sample was heated in a 70 °C water bath for 20 minutes, then ten 1 cm-thick samples were taken along the muscle fiber direction using a 1.27 cm corer. Shear force was measured using a muscle tenderness meter (C-LM3B, Tenovo, Harbin), with the average of ten samples reported as the shear force value.

Longissimus dorsi muscle samples (approximately 50 g) stored at -20 °C were cut into 2–3 mm slices, freeze-dried in a vacuum freeze dryer (Model 4.5, Labconco Corp, USA) for 72 hours, then ground into powder. Intramuscular fat content was determined using the Soxhlet extraction method.

1.4.5 Serum Physiological and Biochemical Indexes and Free Amino Acid Content

Serum total cholesterol (TC), triglycerides (TG), high-density lipoprotein (HDL), low-density lipoprotein (LDL), free fatty acids (FFA), and insulin were measured using kits from Zhongsheng Beikong Technology Co., Ltd. on an automatic biochemical analyzer (BS-420, Beckman, USA). Serum lactic dehydrogenase (LDH), creatine kinase (CK), and lipase (LPS) activities, as well as urea nitrogen and glucose content, were determined using kits from Nanjing Jiancheng Bioengineering Institute according to the manufacturer' s instructions.

Serum free amino acid concentrations were measured using the classical ninhydrin post-column derivatization method with an amino acid analyzer (S-433D, Sykam, Germany). Briefly, 0.5 mL of serum was placed in a centrifuge tube, mixed with 1.5 mL of 4% sulfosalicylic acid, shaken, and placed on ice for 20 minutes. Then 0.175 mL of lithium hydroxide was added, mixed, and balanced on an electronic scale before centrifugation at 110,000 r/min for 30 minutes at 4 °C. The supernatant was filtered through a 0.1 m membrane and analyzed for serum free amino acid concentration.

1.5 Statistical Analysis Experimental data were analyzed using the General Linear Model (GLM) procedure in SAS 9.4 software for linear and quadratic regression analysis. When significant differences were detected, Duncan's multiple comparison test was performed. $P < 0.05$ was considered statistically significant, and $0.05 \le P < 0.10$ was considered a trend toward significance.

Results

2.1 Effects of Dietary Isoleucine Level on Growth Performance of Finishing Pigs As shown in Table 2 , dietary isoleucine level had no significant effect on average daily gain or average daily feed intake of finishing pigs ($P > 0.05$). However, the feed-to-gain ratio decreased linearly ($P < 0.05$) and quadratically ($P < 0.05$) with increasing isoleucine level. Compared with the control group, the feed-to-gain ratio of finishing pigs fed the isoleucine-deficient diet was significantly increased ($P < 0.05$).

2.2 Effects of Dietary Isoleucine Level on Carcass Traits of Finishing Pigs As shown in Table 3 , increasing dietary isoleucine level resulted in linear ($P < 0.05$) and quadratic ($P < 0.05$) increases in hot carcass weight, while backfat thickness, dressing percentage, and loin eye area showed quadratic increases ($P < 0.05$). Compared with the control group, finishing pigs fed the isoleucine-deficient diet had significantly reduced hot carcass weight, dressing percentage, backfat thickness, and loin eye area ($P < 0.05$). Additionally, pigs fed the excess isoleucine diet also showed significantly lower hot carcass weight and dressing percentage ($P < 0.05$).

2.3 Effects of Dietary Isoleucine Level on Meat Quality of Finishing Pigs As shown in Table 4 , dietary isoleucine level had no significant effect on pH_{45} , pH_{24} , cooking loss, or marbling score of the longissimus dorsi muscle ($P > 0.05$). However, with increasing dietary isoleucine level, intramuscular fat content increased linearly ($P < 0.05$) and shear force decreased linearly ($P < 0.05$), while flesh color score, b* value, and drip loss showed quadratic increases ($P < 0.05$). Compared with the control group, finishing pigs fed the isoleucine-deficient diet had significantly reduced flesh color score, b* value, and drip loss ($P < 0.05$), while pigs fed the excess isoleucine diet showed significantly lower b* value and drip loss ($P < 0.05$).

2.4 Effects of Dietary Isoleucine Level on Serum Physiological and Biochemical Indexes of Finishing Pigs As shown in Table 5 , increasing dietary isoleucine level resulted in linear increases in serum TG content ($P < 0.05$) and linear decreases in serum urea nitrogen content ($P < 0.05$), with a trend toward increased serum LPS activity ($P = 0.08$). Serum TC, HDL, and LDL contents showed quadratic increases ($P < 0.05$). Compared with the control group, finishing pigs fed either deficient or excess isoleucine diets had significantly reduced serum TC, HDL, and LDL contents ($P < 0.05$), while pigs fed the excess isoleucine diet showed significantly increased serum glucose content ($P < 0.05$). Dietary isoleucine level had no significant effect on serum FFA or insulin content, nor on LDH or CK activity ($P > 0.05$).

2.5 Effects of Dietary Isoleucine Level on Serum Free Amino Acid Concentrations of Finishing Pigs As shown in Table 6 , dietary isoleucine level significantly affected serum free amino acid concentrations. With increasing dietary isoleucine level, serum concentrations of histidine, isoleucine, cysteine, and serine increased linearly ($P < 0.05$), while threonine, alanine, and proline showed quadratic increases ($P < 0.05$). Serum concentrations of leucine, lysine, phenylalanine, valine, glycine, and tyrosine increased both linearly ($P < 0.05$) and quadratically ($P < 0.05$). Categorical analysis revealed that serum concentrations of essential amino acids, non-essential amino acids, and total amino acids increased both linearly ($P < 0.05$) and quadratically ($P < 0.05$) with increasing dietary isoleucine level.

Discussion

3.1 Effects of Dietary Isoleucine Level on Growth Performance of Finishing Pigs When formulating corn-soybean meal-based diets, isoleucine is generally not deficient. However, isoleucine deficiency often occurs when soybean meal content is low, protein levels are reduced, or blood meal is used as a partial protein source. Numerous studies have shown that when formulating isoleucine-deficient basal diets with corn and blood meal, increasing isoleucine levels significantly improves average daily gain, average daily feed intake, and gain-to-feed ratio in finishing pigs. In corn-soybean meal-based diets, isoleucine deficiency significantly reduces feed-to-gain ratio, average daily gain, and average daily feed intake, but additional isoleucine supplementation beyond requirements does not significantly affect growth performance. In this experiment, dietary isoleucine level had no significant effect on average daily gain or average daily feed intake, but the feed-to-gain ratio decreased linearly and quadratically with increasing dietary isoleucine level, consistent with the findings of Dean et al. Therefore, isoleucine deficiency leads to a poorer feed-to-gain ratio in finishing pigs, while excess isoleucine supplementation does not further improve this parameter.

3.2 Effects of Dietary Isoleucine Level on Carcass Traits of Finishing Pigs This study found that increasing dietary isoleucine level resulted in linear and quadratic increases in hot carcass weight and backfat thickness, and quadratic increases in dressing percentage and loin eye area. These results partially align with Dean et al., who found that increasing dietary isoleucine level quadratically increased backfat thickness, total fat content, and body fat percentage in finishing pigs fed corn-soybean meal diets, but had no significant effect on loin eye area or dressing percentage. However, Figueroa et al. found that isoleucine supplementation in low-protein diets significantly reduced backfat thickness at the 10th rib and loin eye area in gilts, which contradicts the above results and may be related to differences in pig breed, sex, growth stage, and isoleucine requirements and utilization. The present results indicate that dietary isoleucine deficiency reduces carcass traits in finishing pigs, while excess isoleucine also adversely affects carcass traits, though less severely than deficiency.

3.3 Effects of Dietary Isoleucine Level on Meat Quality of Finishing Pigs The most critical characteristics of meat quality are color, flavor, tenderness, juiciness, and water-holding capacity. Fernandez et al. noted that when intramuscular fat content increases to approximately 2.5%, tenderness, juiciness, and flavor improve substantially. Font-i-Furnols et al. found that consumer acceptance of pork increases with higher intramuscular fat content. This experiment demonstrated that increasing dietary isoleucine level increased intramuscular fat content and decreased shear force, thereby improving muscle tenderness. Khliji et al. identified meat color as an important indicator of meat quality and freshness, with consumers' purchasing decisions heavily influenced by color. This study found that isoleucine deficiency or excess had no significant effect on the a* value of the longissimus dorsi muscle, but significantly reduced flesh color score and b* value. Water-holding capacity is another important meat quality indicator, reflecting the muscle' s ability to retain water post-slaughter. Savage et al. found that water loss from muscle leads to loss of protein and soluble flavor compounds, affecting meat quality. Pearce et al. also noted that water content is crucial for muscle physical structure, flavor, and color. Water-holding capacity is typically reflected by drip loss, and this experiment showed that both isoleucine deficiency and excess significantly reduced drip loss in the longissimus dorsi muscle, thereby improving water-holding capacity. These results indicate that while isoleucine deficiency reduced drip loss, it also decreased intramuscular fat content, muscle tenderness, and flesh color score, negatively affecting meat quality. In contrast, excess isoleucine supplementation resulted in the highest intramuscular fat content, lowest shear force, and lowest drip loss, demonstrating relatively better meat quality despite lower flesh color scores.

3.4 Effects of Dietary Isoleucine Level on Serum Physiological and Biochemical Indexes of Finishing Pigs Blood physiological and biochemical indexes reflect physiological function and metabolic status. Serum urea nitrogen is the end product of protein and amino acid metabolism and accurately reflects protein metabolism and amino acid balance, with lower levels indicating better amino acid balance. This experiment found that increasing dietary isoleucine level linearly reduced serum urea nitrogen content, suggesting that the excess isoleucine diet may have provided better amino acid balance under the experimental conditions. Blood lipid content reflects lipid metabolism status. LDL transports endogenous cholesterol synthesized in the liver to extrahepatic tissues to meet cellular cholesterol requirements, while HDL transports cholesterol released from extrahepatic cells to the liver, preventing cholesterol accumulation in blood and atherosclerosis. Sink et al. found that serum TC content positively correlates with body fat deposition and coronary heart disease incidence in humans, and Anderson et al. noted that a 1% increase in serum TC or LDL-C content increases coronary heart disease risk by 2–3%. In this experiment, both isoleucine deficiency and excess significantly reduced serum TC, HDL, and LDL contents, while increasing isoleucine level linearly increased serum TG content and showed a trend toward increased LPS activity. These findings indicate that dietary isoleucine level affects lipid metabolism, which may be related to changes in backfat thickness and intramuscular fat content. Additionally, isoleucine deficiency or excess increased serum glucose content, suggesting an effect on glucose metabolism.

3.5 Effects of Dietary Isoleucine Level on Serum Free Amino Acid Concentrations of Finishing Pigs Serum amino acids primarily originate from tissue protein degradation and intestinal absorption of dietary nutrients. Serum amino acid concentrations 2.5 hours post-feeding are considered to reflect dietary amino acid absorption, while concentrations 8 hours post-feeding may reflect amino acid metabolism status. When dietary amino acids meet animal requirements, further amino acid balance can reduce serum free amino acid concentrations. This experiment found that isoleucine deficiency significantly reduced serum concentrations of free essential amino acids, non-essential amino acids, and total amino acids, specifically decreasing histidine, isoleucine, leucine, lysine, phenylalanine, valine, threonine, cysteine, serine, alanine, proline, glycine, and tyrosine concentrations. Studies on BCAAs often consider the relationship among the three amino acids (leucine, isoleucine, and valine), as their similar structure and shared catabolic enzymes create antagonistic interactions. Excess dietary leucine has been shown to significantly reduce serum isoleucine and valine concentrations, likely by activating hepatic branched-chain keto acid dehydrogenase activity. In this experiment, excess isoleucine supplementation reduced serum leucine and valine concentrations, consistent with Cervantes et al., but isoleucine deficiency also significantly reduced leucine and valine concentrations, possibly due to enhanced metabolism of these amino acids to meet increased requirements when isoleucine is deficient. Cervantes et al. also found that excess isoleucine supplementation increased cationic amino acid transporter 1 (CAT-1) expression and reduced serum threonine concentration. Similarly, this experiment showed that excess isoleucine supplementation significantly reduced serum threonine concentration. These results indicate that isoleucine deficiency reduces the amino acid pool, and its potential effects on protein turnover warrant further investigation.

Conclusions

1. Dietary isoleucine deficiency negatively affects growth performance, carcass traits, and meat quality in finishing pigs. Excess isoleucine supplementation significantly reduces serum urea nitrogen content, shear force, and drip loss of the longissimus dorsi muscle while increasing intramuscular fat content, but at the cost of reduced hot carcass weight and dressing percentage.

2. Dietary isoleucine level affects metabolism of the three major nutrients. Isoleucine deficiency significantly reduces serum concentrations of free essential amino acids, non-essential amino acids, and total amino acids, as well as lipid metabolism-related indexes, while increasing serum glucose content. Excess isoleucine supplementation significantly reduces serum TC, HDL, and LDL contents while increasing serum TG and glucose contents.

References

[1] National Bureau of Statistics. China Statistical Yearbook 2016[M]. Beijing: China Statistics Press, 2016: 12–14.
[2] Yin Jingdong, Li Defa. Molecular mechanisms and nutritional regulation of pork quality formation[J]. Chinese Journal of Animal Nutrition, 2014, 26(10): 2979–2985.
[3] Liu Chunsheng, Zhang Dapeng, Liu Wenkuan, et al. Branched-chain amino acids and their current research status in lactating sow nutrition[J]. Feed Industry, 2006, 27(1): 25–26.
[4] Duan Y H, Duan Y M, Li F N, et al. Effects of supplementation with branched-chain amino acids to low-protein diets on expression of genes related to lipid metabolism in skeletal muscle of growing pigs[J]. Amino Acids, 2016, 48(9): 2131–2144.
[5] Goichon A, Chan P, Lecleire S, et al. An enteral leucine supply modulates human duodenal mucosal proteome and decreases the expression of enzymes involved in fatty acid beta-oxidation[J]. Journal of Proteomics, 2013, 78: 535–544.
[6] Arakawa M, Masaki T, Nishimura J, et al. The effects of branched-chain amino acid granules on the accumulation of tissue triglycerides and uncoupling proteins in diet-induced obese mice[J]. Endocrine Journal, 2011, 58(3): 161–170.
[7] Fu S X, Kendall D C, Fent R W, et al. True ileal digestible (TID) isoleucine:lysine ratio of late-finishing barrows fed corn-blood cell or corn-amino acid diets[J]. Journal of Animal Science, 2005, 82: 67.
[8] Dean D W, Southern L L, Kerr B J, et al. Isoleucine requirement of 80- to 120-kilogram barrows fed corn-soybean meal or corn-blood cell diets[J]. Journal of Animal Science, 2005, 83(11): 2543–2553.

[9] Kendall D C, Kerr B J, Fent R W, et al. Determination of the true ileal digestible isoleucine requirement for 90 kg barrows[J]. Journal of Animal Science, 2004, 82(Suppl. 2): 67.
[10] Zheng Chuntian. Effects of low-protein diets supplemented with isoleucine on protein turnover metabolism and immune function in pigs[D]. Ph.D. Thesis. Beijing: China Agricultural University, 2000: 92–104.
[11] Wiltafsky M K, Bartelt J, Relandeau C, et al. Estimation of the optimum ratio of standardized ileal digestible isoleucine to lysine for eight- to twenty-five-kilogram pigs in diets containing spray-dried blood cells or corn gluten feed as a protein source[J]. Journal of Animal Science, 2009, 87(8): 2554–2564.
[12] Kendall D C. Opportunities and limitations for low-protein diet formulation in swine[D]. Ph.D. Thesis. Columbia: University of Missouri-Columbia, 2004.
[13] Figueroa J L, Lewis A J, Miller P S, et al. Growth, carcass traits, and plasma amino acid concentrations of gilts fed low-protein diets supplemented with amino acids including histidine, isoleucine, and valine[J]. Journal of Animal Science, 2003, 81(6): 1529–1537.
[14] Fernandez X, Monin G, Talmant A, et al. Influence of intramuscular fat content on the quality of pig meat-1. Composition of the lipid fraction and sensory characteristics of m. longissimus lumborum[J]. Meat Science, 1999, 53(1): 59–65.
[15] Font-i-Furnols M, Tous N, Esteve-Garcia E, et al. Do all the consumers accept marbling in the same way? The relationship between eating and visual acceptability of pork with different intramuscular fat content[J]. Meat Science, 2012, 91(4): 448–453.
[16] Khliji S, Van De Ven R, Lamb T A, et al. Relationship between consumer ranking of lamb colour and objective measures of colour[J]. Meat Science, 2010, 85(2): 224–229.
[17] Huff-Lonergan E, Lonergan S M. Mechanisms of water-holding capacity of meat: the role of postmortem biochemical and structural changes[J]. Meat Science, 2005, 71(1): 194–204.
[18] Savage A W J, Warriss P D, Jolley P D. The amount and composition of the proteins in drip from stored pig meat[J]. Meat Science, 1990, 27(4): 289–303.
[19] Pearce K L, Rosenvold K, Andersen H J, et al. Water distribution and mobility in meat during the conversion of muscle to meat and ageing and the impacts on fresh meat quality attributes—A review[J]. Meat Science, 2011, 89(2): 111–124.
[20] Coma J, Zimmerman D R, Carrion D. Relationship of rate of lean tissue growth and urea concentration in plasma of pigs[J]. Journal of Animal Science, 1995, 73(12): 3649–3656.
[21] Ji Cheng. Animal Nutrition[M]. Beijing: Higher Education Press, 2008.
[22] Sink J D, Wilson L L, McCarthy R D, et al. Interrelationships between serum lipids, energy intake, milk-production, growth and body characteristics in Angus-Holstein cows and their progeny[J]. Journal of Animal Science, 1973, 36(2): 313–317.
[23] Anderson J W, Konz E C. Obesity and disease management: effects of

weight loss on comorbid conditions[J]. Obesity Research, 2001, 94(Suppl. 11): 326S–334S.
[24] Adibi S A, Mercer D W. Protein digestion in human intestine as reflected in luminal, mucosal, and plasma amino-acid concentrations after meals[J]. Journal of Clinical Investigation, 1973, 52(7): 1586–1594.
[25] Yen J T, Kerr B J, Easter R A, et al. Difference in rates of net portal absorption between crystalline and protein-bound lysine and threonine in growing pigs fed once daily[J]. Journal of Animal Science, 2004, 82(4): 1079–1090.
[26] Langer S, Fuller M F. Interactions among the branched-chain amino acids and their effects on methionine utilization in growing pigs: effects on nitrogen retention and amino acid utilization[J]. British Journal of Nutrition, 2000, 83(1): 43–48.
[27] Wiltafsky M K, Pfaffl M W, Roth F X. The effects of branched-chain amino acid interactions on growth performance, blood metabolites, enzyme kinetics and transcriptomics in weaned pigs[J]. British Journal of Nutrition, 2010, 103(7): 964–976.
[28] Gatnau R, Zimmerman D R, Nissen S L, et al. Effects of excess dietary leucine and leucine catabolites on growth and immune-responses in weanling pigs[J]. Journal of Animal Science, 1995, 73(1): 159–165.
[29] Cervantes-Ramírez M, Méndez-Trujillo V, Araiza-Piña B A, et al. Supplemental leucine and isoleucine affect expression of cationic amino acid transporters and myosin, serum concentration of amino acids, and growth performance of pigs[J]. Genetics and Molecular Research, 2013, 12(1): 115–126.

Note: Figure translations are in progress. See original paper for figures.