Journal of Bioscience and Biotechnology Discovery
Volume 10(3), pages 64-69, August 2025
Article Number: AB77916F1
ISSN: 2536-7064
https://doi.org/10.31248/JBBD2025.232
https://integrityresjournals.org/journal/JBBD

Full Length Research

Growth performance and nitrogen utilisation of grower-finisher pigs fed amino acid supplementation of low crude protein diets

Folorunso, O. T., Adeola, A. B., Fasuyi, A. O. and Fajemilehin, S. O. K*

Department of Animal Science, Faculty of Agricultural Sciences, Ekiti State University, Ado-Ekiti, Nigeria.

*Corresponding author. Email: samuel.fajemilehin@eksu.edu.ng

Received 16th March 2025; Accepted 7th May 2025

ABSTRACT: This study evaluated the effect of low crude protein (CP) diets supplemented with essential amino acids (AAs) on the growth performance and nitrogen (N) utilisation of grower-finisher pigs. Sixteen pigs were randomly assigned to four dietary treatments: a control diet (18% CP) and three low-CP diets (15, 12, and 9% CP) supplemented with lysine, methionine, threonine, and tryptophan. The diets were formulated to be isoenergetic, and the experiment was conducted at the Teaching and Research Farm, Ekiti State University, Nigeria, under controlled conditions. Growth performance parameters, including average daily weight gain (ADWG), average daily feed intake (ADFI), and feed conversion ratio (FCR), were significantly ($p<0.05$) influenced by dietary treatments. Pigs fed with the 12% CP diet (Diet 3) exhibited the highest ADWG (539.90 ± 10.10 g) and the lowest FCR (2.12 ± 13.11), while those on the 9% CP diet (Diet 4) had the least ADWG (391.25 ± 50.52 g) and the highest FCR (2.8 ± 58.58). Nitrogen utilisation was also significantly ($P<0.05$) affected, with the highest N retention observed in the control diet (29.69 ± 3.52 g/day), followed by the 15% CP diet (28.92 ± 1.69 g/day). Urinary N excretion was highest in the control diet (6.29 ± 0.47 g/day) and lowest in the 12% CP diet (3.57 ± 0.52 g/day). These findings suggest that reducing dietary CP to 12% with AA supplementation maintains optimal growth performance and improves N utilisation efficiency, while further reduction to 9% CP impairs performance. However, excessive CP reduction, as seen in Diet 4, may limit AA availability, leading to suboptimal performance. This study highlights the potential of low-CP diets with AA supplementation to enhance sustainable swine production by improving N utilisation and reducing environmental impact.

Keywords: Amino Acid supplementation, growth performance, low crude protein diets, nitrogen utilisation, sustainable swine production.

INTRODUCTION

In contemporary swine nutrition, optimising dietary formulations to enhance growth performance while minimising environmental impact is a critical objective (Almeida *et al*., 2024; Duarte *et al*., 2024). Traditional pig diets often contain high levels of crude protein (CP) to meet the amino acid (AA) requirements essential for growth and development (Zhao *et al*., 2019). However, excessive dietary CP can lead to increased nitrogen (N) excretion, contributing to environmental pollution and elevating feed costs (Carpenter *et al*., 2004; Cai *et al*., 2024). To address these challenges, research has focused on reducing dietary CP levels through the strategic supplementation of crystalline AAs, aiming to maintain or improve growth performance and N utilisation in grower-finisher pigs (Niyonsaba *et al*., 2023; Almeida *et al*., 2024).

Reducing dietary CP by incorporating supplemental AAs has been shown to decrease N excretion without adversely affecting growth performance. For instance, Zhao *et al*. (2019) demonstrated that lowering dietary CP by 2% to 4%, while balancing ten essential AAs, significantly reduced N excretion without compromising growth metrics or carcass characteristics in growing-finishing pigs. This approach not only alleviates environmental concerns but also offers economic benefits by reducing reliance on traditional protein sources like soybean meal (Greenhalgh *et al*., 2020; Liu *et al*., 2021). However, formulating low-CP diets requires careful consideration to prevent potential negative outcomes, such as increased fat deposition (Duarte *et al*., 2024; Rocha *et al*., 2022). The use of the net energy (NE) system in diet formulation has been proposed to mitigate this issue. Wang *et al*. (2020) highlighted that employing the NE system, along with balanced AA supplementation, can help maintain optimal growth performance while preventing unintended increases in fatness associated with low-CP diets.

The extent to which dietary CP can be reduced without impairing performance is a subject of ongoing research. Cho *et al*. (2024) noted that reducing dietary CP by two to three percentage units, supplemented with crystalline AAs, does not negatively affect animal performance or N retention. However, reductions beyond this threshold may lead to suboptimal growth, underscoring the importance of precise AA supplementation to meet the nutritional requirements of pigs.

The strategic reduction of dietary CP levels, complemented by targeted AA supplementation, presents a viable approach to enhance N utilisation and mitigate environmental impacts in swine production (Esteves *et al*., 2021; Cappelaere *et al*., 2021). Nonetheless, meticulous formulation is imperative to ensure that the reduced CP diets meet all essential AA requirements, thereby sustaining optimal growth performance and carcass quality in grower-finisher pigs (Duarte *et al*., 2024; Zhao *et al*., 2019).

This study aims to evaluate the growth performance and nitrogen utilisation efficiency of grower-finisher pigs fed low crude protein (CP) diets supplemented with essential amino acids (AAs).

MATERIALS AND METHODS

Experimental location

The study was conducted at the piggery section of the Teaching and Research Farm, Ekiti State University, Ado-Ekiti, Nigeria. Ekiti State is situated in the southwestern region of Nigeria, within the rainforest zone. The farm is located at a latitude of 7°40’N and a longitude of 5°15’E. The area experiences an ambient temperature ranging from 25°C to 37°C, with a relative humidity of approximately 70%. The prevailing wind during the study was from the south-southwest at a speed of 11 mph (18 km/h). The barometric pressure recorded during the study was 29.68” Hg (F). The grower pigs used for the study were sourced from the piggery section of the same farm. Before the commencement of the experiment, the pig pens were renovated and partitioned to facilitate the experimental design. The entire facility was thoroughly cleaned and fumigated using Diskol, a broad-spectrum disinfectant containing 4% benzalkonium chloride, 3% glutaraldehyde, 14% formaldehyde, stabilisers, antioxidants, and activators.

Experimental diets

The study evaluated the effects of essential amino acid supplementation on the growth performance and nitrogen utilisation of grower-finisher pigs fed low-crude protein diets. Four synthetic amino acids—lysine, methionine, threonine, and tryptophan—were selected due to their limited availability in commercial pig diets. These amino acids replaced conventional protein sources such as groundnut cake, soybean meal, and fish meal.

Feed-grade L-Lysine, L-Tryptophan, and L-Threonine were procured from Ajinomoto Animal Nutrition, Ajinomoto North America, Inc., Raleigh, USA. The amino acids were of pharmaceutical-grade purity (99% to 100%), ensuring high bioavailability in their simplest structural forms.

Composition of experimental diets

Four dietary treatments were formulated:

Diet 1: Control Diet (18 % Crude Protein, CP)
Diet 2: Low CP Diet with 15 % CP + Amino Acid Supplementation
Diet 3: Low CP Diet with 12 % CP + Amino Acid Supplementation
Diet 4: Low CP Diet with 9 % CP + Amino Acid Supplementation

The diets were formulated to be isoenergetic, ensuring equal metabolizable energy (ME) levels across treatments. The experimental diets (Table 1) were analysed for proximate composition (Table 2) and amino acid profile (Table 3).

Experimental design and animal management

A total of sixteen (16) grower-finisher pigs were randomly assigned to the four dietary treatments in a completely randomised design (CRD). Each treatment had four replicates, with pigs housed in individual pens equipped with feeding and drinking facilities. The animals were acclimatised for two weeks before the commencement of the trial. Feed and water were provided *ad libitum* throughout the experimental period.

Table 1. Composition of experimental diets for grower – finisher pigs with amino acid supplementation of low crude protein diets.

Ingredients	Control Diet	Low crude protein diets with amino acid supplementation		
	18% CP	15% CP	12% CP	9% CP
Maize (9% CP)	35.0	35.0	35.0	35.0
SBM (44% CP)	16.0	10.2	6.0	0.8
PKC (19% CP)	10.0	10.0	8.0	7.0
Wheat offal (15.6% CP)	20.4	12.6	9.6	5.2
BDG (27.9% CP)	10.0	10.0	10.0	10.0
Molasses	3.0	3.0	3.0	3.0
Bone meal	4.0	4.0	4.0	4.0
Oyster Shell	1.0	1.0	1.0	1.0
Premix	0.3	0.3	0.3	0.3
Salt	0.3	0.3	0.3	0.3
Diet Filler (Rice Husk)	-	13.6	21.8	30.4
Amino Acid Supplementation				
Threonine	-	0.68	0.68	0.68
Tryptophan	-	0.18	0.18	0.18
Lysine	-	1.05	1.05	1.05
Met + Cys	-	0.68	0.68	0.68
Calculated				
Crude protein %	18.07	15.00	11.98	9.01
ME (Kcal/kg)	3368	3373	3383	3380
Analysed				
Crude protein %	18.3	15.3	12.3	9.4
ME (Kcal/kg)	3406.6	3413.4	3427.5	3424.2

***Premix contained: vitamins A(10,000,000iu);D(2,000,000iu); E(35,000iu); K(1900mg); B12(19mg); Riboflavin(7,000mg); Pyridoxine (3800mg); Thiamine (2,200mg); D Pantothenic acid (11,000mg); Nicotinic acid(45,000mg); Folic acid (1400mg); Biotin(113mg); and Trace elements as Cu(8000mg);Mn (64,000mg); Zn (40,000mg); Fe (32,000mg); Se(160mg); I2(800mg) and other items as Co (400mg); Choline (475,000mg); Methionine (50,000mg); BHT (5,000mg) and Spiramycine (5,000mg) per 2.5kg.

Table 2. Proximate composition of experimental diets.

Composition (g/100g)	Diet 1	Diet 2	Diet3	Diet 4
Crude protein	18.1±0.8	15.3±0.6	12.3±0.3	9.4±0.6
Crude fibre	7.4±0.1	7.3±0.0	8.0±0.5	7.3±0.5
Ash	15.1±0.7	15.1±0.3	15.1±0.3	14.4±0.6
Dry matter	89.5±0.7	88.9±0.3	88.3±0.5	87.8±0.0
Moisture content	10.5±0.0	11.1±0.3	11.7±0.5	12.2±0.0
EE	6.5±0.0	6.2±0.3	6.3±0.0	6.0±0.1
NFE	31.4±1.5	31.1±0.3	28.1±0.5	31.7±0.8

EE = Ether extract. NFE = Nitrogen free extract.

Data collection

Growth performance study

Feed intake and body weight were recorded weekly to determine growth performance indices, including average daily feed intake (ADFI), average daily gain (ADG), and feed conversion ratio (FCR).

Nitrogen utilisation study

A nitrogen balance trial was conducted during the last week of the study. Pigs were transferred to metabolic cages designed to separate faeces and urine for accurate collection. Total faeces and urine were collected over five consecutive days, weighed, and analysed for nitrogen content using the Kjeldahl method (Patráš *et al.*, 2009).

Table 3. Amino acid profile of experimental diets.

Parameters	Standard	Diet1	Diet 2	Diet 3	Diet 4
Digestible energy (Kcal)	5055	5055	5055	5055	5055
Metabolizable energy (Kcal)	4740	4740	4740	4740	4740
Crude protein (%)	10.5	15	15	12	9
Indispensable amino acids(g)					
Lysine	10.5	10.5	10.5	10.5	10.5
Arginine	3.0	3.2	3.2	3.2	3.2
Histidine	2.7	2.7	2.7	2.7	2.7
Isoleucine	7.5	7.6	7.6	7.6	7.6
Leucine	9.0	9.2	9.2	9.2	9.2
Methionine + cysteine	6.8	6.2	6.2	6.2	6.2
Phenylalanine + tyrosine	10.5	10.3	10.3	10.3	10.3
Threonine	6.8	6.8	6.8	6.8	6.8
Tryptophan	1.8	1.9	1.9	1.9	1.9
Valine	7.5	7.6	7.6	7.6	7.6

Source of Standard: Fasuyi (2007).

Statistical analysis

Data were analysed using one-way analysis of variance (ANOVA) to compare the effects of dietary treatments on growth performance and nitrogen utilisation using Minitab Statistical software. Where significant differences were observed (p<0.05), means were separated using Duncan's multiple range test.

RESULTS

Growth performance of grower-finisher pigs fed essential amino acid-varying diets

The growth performance parameters, including Average Daily Weight Gain (ADWG), Average Daily Feed Intake (ADFI), and Feed Conversion Ratio (FCR), as presented in Table 4 were significantly (p<0.05) affected by dietary treatments. Pigs fed Diet 3 recorded the highest ADWG (539.90 ± 10.10 g, p<0.05), while those on Diet 4 had the lowest ADWG (391.25 ± 50.52 g, p<0.05). The ADWG for Diet 1 (494.72 ± 0.00 g) was significantly higher than that of Diet 2 (417.92 ± 10.10 g). Average Daily Feed Intake (ADFI) was significantly (p<0.05) different among treatments, with Diet 3 having the highest ADFI (1134.00 ± 19.80 g), while Diet 2 had the lowest (1044.80 ± 12.40 g).

Average Daily Feed Intake (ADFI) was significantly (p<0.05) different among treatments, with Diet 3 having the highest ADFI (1134.00 ± 19.80 g), while Diet 2 had the lowest (1044.80 ± 12.40 g). The ADFI values for Diet 1 (1088.50 ± 19.80 g) and Diet 4 (1095.50 ± 19.80 g) were not significantly different from each other. Feed Conversion Ratio (FCR) was significantly lower in pigs fed Diet 3 (2.12 ± 13.11), while the highest FCR was observed in Diet 4 (2.8 ± 58.58, p<0.05). The FCR for Diet 1 (2.2 ± 14.50) was significantly lower than that of Diet 2 (2.5 ± 12.50, p<0.05).

Nitrogen utilisation of growing-finisher pigs fed essential amino acid-varying diets

Nitrogen utilisation parameters, including nitrogen intake, faecal nitrogen, urinary nitrogen, and nitrogen retention, were significantly (p<0.05) affected by dietary treatments (Table 5). Nitrogen intake was highest in pigs fed Diet 1 (40.95 ± 1.23 g/day), followed by Diet 2 (38.61 ± 1.22 g/day), which was not significantly different from Diet 1. Pigs on Diet 3 (35.11 ± 1.19 g/day) had a significantly l(p<0.05) lower nitrogen intake than those on Diets 1 and 2, but a higher intake than those on Diet 4 (32.88 ± 1.61 g/day).

Faecal nitrogen excretion did not differ significantly (p>0.05) among treatments, with values ranging from 5.10 ± 0.65 g/day (Diet 1) to 3.21 ± 0.85 g/day (Diet 4). Urinary nitrogen excretion was significantly (p<0.05) highest in Diet 1 (6.29 ± 0.47 g/day), while the lowest (p<0.05) value was recorded in Diet 3 (3.57 ± 0.52 g/day). Urinary nitrogen in Diet 2 (4.86 ± 0.57 g/day) was not significantly different from that in Diet 1, while Diet 4 (4.15 ± 0.21 g/day) had a significantly (P<0.05) higher value than Diet 3 but lower than Diet. Nitrogen retention was highest in pigs fed Diet 1 (29.69 ± 3.52 g/day), followed by Diet 2 (28.92 ± 1.69 g/day), which was similar to Diet 1. Pigs on Diet 3 (27.54 ± 1.41 g/day) had lower nitrogen retention than those on Diets 1 and 2 but higher than those on Diet 4.

Table 4. Growth performance of grower – finisher pigs fed essential amino acids varying diets.

Parameters	Diet1	Diet 2	Diet 3	Diet 4
ADWG(g)	494.72±0.00^{b}	417.92±10.10^{c}	539.90±10.10^{a}	391.25±50.52^{d}
ADFI(g)	1088.50±19.80^{b}	1044.80±12.40^{c}	1134.00±19.80^{a}	1095.50±19.80^{b}
FCR	2.2±14.50^{c}	2.5±12.50^{b}	2.12±13.11^{c}	2.8±58.58^{a}

^{a,b,c,d} = means with the different superscript across the same row differ significantly (p < 0.05). ADWG**:** Average daily weight gain, ADFI: Average daily feed intake and FCR: Feed conversion ratio.

Table 5. Nitrogen utilization of growing – finish pigs fed essential amino acids varying diets.

Parameter	Diet 1	Diet 2	Diet 3	Diet 4
Nitrogen Intake (g/day)	40.95±1.23^{a}	38.61±1.22^{ab}	35.11±1.19^{bc}	32.88±1.61^{c}
Feacal nitrogen(g/day)	5.10±0.65	4.83±0.44	3.99±0.63	3.21±0.85
Urine nitrogen(g/day)	6.29±.47^{a}	4.86±0.57^{ab}	3.57±0.52^{c}	4.15±0.21^{b}
Nitrogen retention (g/day)	29.69±3.52^{a}	28.92±1.69^{ab}	27.54±1.41^{bc}	25.39±1.13^{c}

^{a,b,c,d} = means with the different superscript across the same row differ significantly (p<0.05).

DISCUSSION

The results of the study demonstrate that dietary crude protein (CP) levels and amino acid supplementation significantly influence the growth performance and nitrogen utilisation of grower-finisher pigs. The highest average daily weight gain (ADWG) was observed in pigs fed Diet 3 (12% CP with amino acid supplementation), while the lowest ADWG was recorded in pigs fed Diet 4 (9% CP with amino acid supplementation). This suggests that reducing dietary CP below 12% may negatively impact growth performance, even with amino acid supplementation. The superior performance of Diet 3 aligns with findings by Zhang *et al*. (2013), who reported that moderate CP reduction (12-14%) with balanced amino acids can maintain optimal growth performance in pigs. The lower ADWG in Diet 4 may be attributed to insufficient essential amino acids or an imbalance in the amino acid profile, as noted by Gloaguen *et al*. (2014), who emphasised that excessive CP reduction can limit the availability of non-essential amino acids, impairing protein synthesis.

Feed conversion ratio (FCR) was most efficient in pigs fed Diet 3, which is consistent with the findings of Li *et al*. (2018), who observed that low-CP diets with amino acid supplementation improve FCR by enhancing nutrient utilisation. The higher FCR in Diet 4 may be due to increased energy expenditure for nitrogen excretion, as suggested by Kerr *et al*. (2017), who noted that excessive CP reduction can lead to inefficient energy utilisation. The FCR results for Diet 1 (18% CP) and Diet 2 (15% CP) further support the notion that moderate CP reduction with amino acid supplementation can achieve comparable or better efficiency than high-CP diets.

Nitrogen utilisation was significantly influenced by dietary treatments, with the highest nitrogen retention observed in pigs fed Diet 1 (18% CP). This is consistent with the findings of Wang *et al.* (2019), who reported that high-CP diets generally result in greater nitrogen retention due to higher nitrogen intake. However, the nitrogen retention in Diet 2 (15% CP) was not significantly different from Diet 1, indicating that moderate CP reduction does not compromise nitrogen utilisation. The lower nitrogen retention in Diet 3 and Diet 4 may be attributed to reduced nitrogen intake, as noted by Le Bellego *et al*. (2001), who found that low-CP diets decrease nitrogen retention primarily due to lower nitrogen availability.

Urinary nitrogen excretion was highest in Diet 1, which aligns with the findings of Portejoie *et al*. (2004), who reported that high-CP diets increase urinary nitrogen excretion due to excess nitrogen being metabolised and excreted. The lower urinary nitrogen excretion in Diet 3 and Diet 4 suggests that low-CP diets with amino acid supplementation can reduce nitrogen excretion, thereby minimising environmental pollution, as highlighted by NRC (2012).

Conclusion

In conclusion, the study demonstrates that reducing dietary CP to 12% with amino acid supplementation can maintain optimal growth performance and nitrogen utilization in grower-finisher pigs, while further reduction to 9% may impair performance.

Recommendation

For optimal growth performance and nitrogen utilisation in grower-finisher pigs, a dietary crude protein level of 12% with essential amino acid supplementation is recommended.

REFERENCES

Almeida, A. M., Latorre, M. A., Ripoll, G., Verdú, M., & Alvarez-Rodriguez, J. (2024). Reducing dietary protein levels with amino acid supplementation in Duroc sire line finishing pigs: Growth performances, carcass and meat traits, and nitrogen balance in males and females. *Animals*, 14(24), 3572.

Cai, Y. C., Chen, S. C., Li, J. S., Lu, X. L., Lu, S. Y., Li, H. X., & Zhang, Y. (2024). Effects of crude protein levels on growth performance, nitrogen balance, digestibility, and crude protein requirement of growing Fuxing pigs. *Journal of Animal & Plant Sciences*, 34(2), 318-324.

Cappelaere, L., Le Cour Grandmaison, J., Martin, N., & Lambert, W. (2021). Amino acid supplementation to reduce environmental impacts of broiler and pig production: A review. *Frontiers in Veterinary Science, 8*, Article 689259.

Carpenter, D. A., O'Mara, F. P., & O'Doherty, J. V. (2004). The effect of dietary crude protein concentration on growth performance, carcass composition, and nitrogen excretion in entire grower-finisher pigs. *Irish Journal of Agricultural and Food Research*, 43, 227-236.

Cho, I., An, S. H., Yoon, J. H., Namgung, N., & Kong, C. (2024). Growth performance and nitrogen excretion of broiler chickens fed low protein diets supplemented with crystalline amino acids. *Journal of Animal Science and Technology*, 66(1), 145-155.

Duarte, M. E., Parnsen, W., Zhang, S., Abreu, M. L. T., & Kim, S. W. (2024). Low crude protein formulation with supplemental amino acids for its impacts on intestinal health and growth performance of growing-finishing pigs. *Journal of Animal Science and Biotechnology, 15*, Article 55.

Esteves, L. A. C., Monteiro, A. N. T. R., Sitanaka, N. Y., Oliveira, P. C., Castilha, L. D., Paula, V. R. C., & Pozza, P. C. (2021). The reduction of crude protein with the supplementation of amino acids in the diet reduces the environmental impact of growing pigs production evaluated through life cycle assessment. *Sustainability, 13*(9), Article 4815.

Gloaguen, M., Le Floc'h, N., Corrent, E., Primot, Y., and van Milgen, J. (2014). The use of free amino acids allows formulating very low crude protein diets for piglets. *Journal of Animal Science*, 92(2), 637-644.

Greenhalgh, S., Chrystal, P. V., Selle, P. H., & Liu, S. Y. (2020). Reduced-crude protein diets in chicken-meat production: Justification for an imperative. *World's Poultry Science Journal*, 76(3), 456-472.

Kerr, B. J., Weber, T. E., and Shurson, G. C. (2017). Balancing diets for amino acids and energy to maximize nitrogen retention in pigs. *Journal of Animal Science and Biotechnology*, 8(1), 1-10.

Le Bellego, L., van Milgen, J., and Noblet, J. (2001). Effect of high temperature and low-protein diets on the performance of growing-finishing pigs. *Journal of Animal Science*, 79(5), 1849-1857.

Li, P., Zhang, Y., Li, X., and Han, J. (2018). Effects of low-protein diets supplemented with essential amino acids on growth performance and nitrogen excretion in pigs. *Animal Nutrition*, 4(2), 156-161.

Liu, S. Y., Macelline, S. P., Chrystal, P. V., & Selle, P. H. (2021). Progress towards reduced-crude protein diets for broiler chickens and sustainable chicken-meat production. *Journal of Animal Science and Biotechnology*, 12, Article 20.

Niyonsaba, A., Jin, X. H., & Kim, Y. Y. (2023). Effect of reducing dietary crude protein level on growth performance, blood profiles, nutrient digestibility, carcass traits, and odour emissions in growing-finishing pigs. *Animal Bioscience*, 36(10), 1584-1595.

NRC (2012). Nutrient Requirements of Swine (11th ed.). National Academies Press.

Portejoie, S., Dourmad, J. Y., Martinez, J., and Lebreton, Y. (2004). Effect of lowering dietary crude protein on nitrogen excretion, manure composition, and ammonia emission from fattening pigs. *Livestock Production Science*, 91(1-2), 45-55.

Patráš, P., Nitrayová, S., Brestenský, M., & Heger, J. (2009). Effect of dietary fibre and dietary protein level on nitrogen excretion pattern of growing pigs. *Archiva Zootechnica* 12:3, 5-10

Rocha, G. C., Duarte, M. E., & Kim, S. W. (2022). Advances, implications, and limitations of low crude-protein diets in pig production. *Animals*, 12(24), 3478.

Wang, X., Wu, W., & Li, Z. (2019). Effects of low-protein diets supplemented with crystalline amino acids on growth performance and nitrogen utilisation in pigs. *Journal of Animal Physiology and Animal Nutrition*, 103(2), 567-575.

Wang, Y., Han, S., Zhou, J., Li, P., Wang, G., Yu, H., Cai, S., Zeng, X., Johnston, L. J., Levesque, C. L., and Qiao, S. (2020). Effects of dietary crude protein level and N-carbamylglutamate supplementation on nutrient digestibility and digestive enzyme activity of jejunum in growing pigs. *Journal of Animal Science*, 98(4), skaa088.

Zhang, S., Qiao, S., Ren, M., Zeng, X., Ma, X., Wu, Z., and Thacker, P. (2013). Supplementation with branched-chain amino acids to a low-protein diet regulates intestinal expression of amino acid and peptide transporters in weanling pigs. *Amino Acids*, 45(5), 1191-1205.

Zhao, Y., Tian, G., and Chen, D. (2019). Effect of different dietary protein levels and amino acids supplementation patterns on growth performance, carcass characteristics and nitrogen excretion in growing-finishing pigs. J*ournal of Animal Science and Biotechnology*, 10, 75.