JAST (Journal of Animal Science and Technology) TITLE PAGE

Upload this completed form to website with submission

ARTICLE INFORMATION	Fill in information in each box below
Article Type	Research article
Article Title (within 20 words without abbreviations)	Standardized ileal digestible lysine requirements based on growth performance of White Pekin ducks for 21 days after hatch
Running Title (within 10 words)	Standardized ileal digestible lysine requirement for White Pekin ducks
Author	Myunghwan Yu, Yu Bin Kim, Hyun Min Cho, Jun Seon Hong, Shan Randima Nawarathne, Elijah Ogola Oketch, Jung Min Heo
Affiliation	Department of Animal Science and Biotechnology, Chungnam National University, Daejeon 34134, Korea
ORCID (for more information, please visit https://orcid.org)	Myunghwan Yu (https://orcid.org/0000-0003-4479-4677) Yu Bin Kim (https://orcid.org/0000-0001-7720-128X) Hyun Min Cho (https://orcid.org/0000-0002-9329-8824) Jun Seon Hong (https://orcid.org/0000-0003-2142-9888) Shan Randima Nawarathne (https://orcid.org/0000-0001-9055-9155) Elijah Ogola Oketch (https://orcid.org/0000-0003-4364-460X) Jung Min Heo (https://orcid.org/0000-0002-3693-1320)
Competing interests	No potential conflict of interest relevant to this article was reported.
Funding sources State funding sources (grants, funding sources, equipment, and supplies). Include name and number of grant if available.	This work was supported by “Regional Innovation Strategy (RIS)” through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (MOE) (2021RIS-004).
Acknowledgements	This research was supported by “Regional Innovation Strategy (RIS)” through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (MOE) (2021RIS-004).
Availability of data and material	Upon reasonable request, the datasets of this study can be available from the corresponding author.
Authors' contributions Please specify the authors’ role using this form.	Conceptualization: Yu M, Kim YB, Heo JM. Data curation: Yu M. Formal analysis: Yu M. Methodology: Yu M, Kim YB Software: Yu M, Hong JS. Validation: Cho HM, Heo JM. Investigation: Yu M, Kim YB, Nawarathne SR, Oketch EO. Writing - original draft: Yu M. Writing - review & editing: Yu M, Kim YB, Cho HM, Hong JS, Nawarathne SR, Oketch EO, Heo JM.
Ethics approval and consent to participate	The Animal Ethics Committee of Chungnam National University, Daejeon, Republic of Korea, approved the protocols used in this experiment (approval number: 202109A-CNU-114).

CORRESPONDING AUTHOR CONTACT INFORMATION

For the corresponding author (responsible for correspondence, proofreading, and reprints)	Fill in information in each box below
First name, middle initial, last name	Jung Min Heo
Email address – this is where your proofs will be sent	jmheo@cnu.ac.kr
Secondary Email address	None
Address	Department of Animal Science and Biotechnology, Chungnam National University, Daejeon 34134, Korea.
Cell phone number	+82 42-821-5777
Office phone number	None
Fax number	None

Abstract

The purpose of this study was to assess the optimal standardized ileal digestible (SID) lysine (Lys) requirement for male White Pekin ducklings with a specific focus on growth performance for the 3 weeks following hatching. A total of 384 one-day-old male White Pekin ducklings were allocated to six different dietary treatments, each containing varying levels of digestible Lys content ranging from 0.72% to 1.12%. All amino acids in the diets remained consistent except for Lys. The ducklings were randomly distributed into 24-floor pens, with each treatment group comprising eight pens, and each pen housing eight ducklings. The diets were offered *ad-libitum* throughout the study. Weekly measurements of body weight and feed intake were recorded to calculate the feed conversion ratio. The SID Lys requirement was determined by analyzing the data using both linear-plateau and quadratic-plateau models and calculating the mean value. The results demonstrated a significant linear ($P < 0.001$) and quadratic ($P < 0.001$) improvement in body weight gain and feed efficiency with increasing SID Lys content in the diet. According to the linear-plateau regression analysis, the estimated SID Lys requirements for final body weight, weight gain, and feed efficiency were 1.00%, 1.00%, and 0.98%, respectively. Conversely, the quadratic-plateau regression analysis yielded estimated SID Lys requirements of 1.11%, 1.11%, and 1.10%, respectively, for the same parameters. In summary, this study established that the recommended SID Lys levels for White Pekin ducklings for the 3 wk period after hatching were found to be 1.05%, 1.05%, and 1.04% for achieving the finest final body weight, daily gain, and feed efficiency, respectively.

Keywords: linear-plateau model, lysine requirement, quadratic-plateau model, standardized ileal digestible lysine, White Pekin duck

Introduction

As the second limiting amino acid (AA) in corn and soybean meal diets for poultry, lysine (Lys) is commonly utilized as a reference AA to establish the ideal amino acid ratios [1, 2]. Lys plays a central role in supporting the growth performance of poultry by promoting nutrient utilization and muscle development as well as protein synthesis and production of enzymes, hormones, and antibodies [3, 4]. Accordingly, determining the optimal dietary Lys content is necessary for achieving efficient duck production.

Based on observations in the marketing of various poultry species, it is evident that the industry has made significant strides in the development of cut and processed duck products. This progress can be attributed to the implementation of genetic selection and advancements in duck management, particularly in the realm of nutrition. As a result, the meat yield of ducks has experienced a notable increase, while carcass fatness has concurrently decreased [5, 6]. Hence, it becomes imperative to formulate updated nutrient requirements to meet the evolving demands of genetic enhancements in meat-type ducks.

Numerous investigations have been carried out to ascertain the Lys requirement for White Pekin ducks [7-9]. However, there is the suggestion that using standardized ileal digestible (SID) AA could offer a more accurate means of determining these requirements in animals, as it accounts for the bioavailability of AA from various feed ingredients [10, 11]. This method assesses the disappearance of AA in the small intestine, providing a more reliable indicator of AA digestibility without disrupting the hindgut [12]. Despite this rationale, limited attention has been given to recent studies that focus on estimating the SID Lys requirements during the starter period (up to 21 days of age) in White Pekin ducks. Moreover, a range of regression models, such as the linear broken line and the quadratic broken line can be effectively employed to estimate the digestible Lys requirements for ducks, as demonstrated by the research conducted by [13]. The utilization of distinct estimation models provides diverse dietary Lys requirements, facilitating the determination of optimal nutritional Lys concentrations for enhancing animal breeding practices [14, 15]. Therefore, this study aims to determine the SID Lys requirement for ducks from hatch to 21 days of age, utilizing both the linear broken-line and quadratic line models.

Materials and Methods

Animal ethics

The Animal Ethics Committee of Chungnam National University, Daejeon, Republic of Korea, approved the protocols used in this experiment (approval number: 202109A-CNU-114).

Experimental diets

The experimental diets (detailed in Table 1) comprised six variations with progressively increasing SID Lys concentrations. SID values for AA in corn, soybean meal, and corn distillers' dried grains with solubles (DDGS) were sourced from a prior investigation [16]. These dietary formulations encompassed SID Lys concentrations ranging from 0.72% to 1.12%, incremented by every 8 points. Each experimental diet was meticulously crafted to either meet or surpass recommended specifications [17], except for Lys, which was adjusted to align with the requirements of ducklings at 3 weeks of age. Indispensable AA concentrations, excluding Lys, were calibrated based on ideal AA ratios to avert deficiencies. The experimental diets were provided in crumble form.

Birds and housing

The experiment was carried out in two consecutive periods, with 192 birds in each period, within the same research facility due to space constraints. Consistent procedures and environmental conditions were maintained throughout. The experiment was conducted using 384 male White Pekin ducklings from hatch to 3 weeks of age. One-day-old male White Pekin ducklings were obtained from a local hatchery (Charmfree Co., Jincheon, Republic of Korea) for the experiment. Upon arrival, the ducklings were weighed and randomly allocated to one of the six dietary treatments with varying digestible Lys levels. Each pen, measuring 1.7 m × 1.3 m × 1.0 m, housed eight birds with a mean body weight (BW) of 53.05 ± 0.201 g (mean ± SEM). The floor pens were lined with rice husk as litter, following the recommendation of a previous study we conducted [18], and each pen was equipped with tree nipple drinkers and a feeder. The ducklings had *ad-libitum* access to the experimental diets and fresh water for 21 days. Continuous lighting was provided for 24 h, and the ambient temperature was maintained at 30-32 ℃ for the first week, gradually decreasing to 25 ℃ until 21 days of age.

Performance measurements and chemical analysis

The initial BW of the birds was recorded upon arrival, and subsequent BW and feed consumption were measured weekly (on days 7, 14, and 21) throughout the experiment. Based on these measurements, the average daily gain (ADG), mortality-corrected average daily feed intake (ADFI), and feed conversion ratio (FCR) were calculated for each cage during each respective week. The AA composition of the experimental diets was determined using standard procedures (AOAC method 982.30 E) [19]. The analyzed AA content of the experimental diets is shown in Table 2.

Statistical analysis

The collected data were analyzed according to a completely randomized design using the general linear model procedure for the one-way ANOVA using SPSS software (Version 26; IBM SPSS 2019). Each pen served as the experimental unit for all growth performance measurements. Orthogonal polynomial contrasts were conducted to assess the significance of linear or quadratic effects of SID Lys levels on all measurements. When significant treatment effects were observed ($P < 0.05$), means were separated using Tukey's multiple range test in SPSS software. Linear-plateau and quadratic-plateau regression analysis, performed with the Nutritional Responses Model version 1.3 [13], were used to estimate the SID Lys requirements.

Results

Throughout the entire 3 weeks experiment, the ducklings remained in good health and performed well. Different levels of dietary SID Lys ranging from 0.72% to 1.12% across 6 treatments in the experimental diets resulted in notable enhancements ($P < 0.001$) in BW, ADG, and feed efficiency for 3 weeks after hatching, with linear and quadratic manners (Table 3). Standardized ileal digestible Lys requirements for White Pekin ducks during the 3 weeks after hatch were estimated (Table 4) using two different response models. When data were analyzed using a linear-plateau model, the estimated requirements were 1.00% and 1.00% for maximum final BW and ADG, respectively, while the requirement for minimum FCR was 0.98% (Fig. 1 to 3). On the other hand, the quadratic-plateau model yielded estimates of 1.11% and 1.11% for maximum final BW and ADG respectively, and 1.10% for minimum FCR (Fig. 1 to 3). By averaging the values obtained from both response models, the recommended SID Lys requirements for White Pekin ducks during the 2 wk after hatching were determined as 1.05%, 1.05%, and 1.04% for maximum final BW, ADG, and minimum FCR, respectively.

Discussion

Our study aimed to assess the SID Lys requirement for achieving the ideal growth performance during 3 wk after the hatch in White Pekin ducks. Although numerous studies have investigated the SID Lys values in feed formulations to determine the ideal lysine requirements for broiler chickens [15, 20, 21], there exists a notable scarcity of published data specific to White Pekin ducks in this regard.

A comparative analysis of AA digestibility was conducted between broiler chickens and Pekin ducks [22]. The findings strongly indicate that utilizing values derived from feedstuffs formulated for broiler chickens should be avoided when formulating diets specifically for ducks. This recommendation is primarily attributed to the higher levels of basal endogenous AA losses observed in ducks in comparison to broiler chickens. As a result, it is imperative to consider these contrasting factors in diet formulation to ensure the best nutrient utilization for ducks. For these reasons, the formulation of experimental diets was based on the consideration of SID AA content in this study. The utilization of SID AA content as a measure is considered more precise compared to total or dietary AA content, as it reflects the nutrient availability for birds [23]. The SID AA values for the diets were determined by incorporating digestible coefficients specific to ducks [12], as well as the total AA content of the ingredients.

The present study observed increasing the SID Lys level had a non-linear impact on various performance parameters, including BW, ADG, ADFI, and feed efficiency. This finding aligns with previous research by [7, 9], which also demonstrated a non-linear improvement in performance indicators of male White Pekin ducks with increasing lysine levels.

Precise identification of an appropriate statistical model holds paramount importance in accurately estimating nutrient requirements, as the choice of model can significantly influence the derived requirement values [24]. The variation in nutrient recommendations can arise due to the application of different estimation models, which is a common practice observed in similar experiments [13]. This highlights the need for careful consideration when selecting an appropriate model to derive accurate and consistent nutrient requirement estimations. The linear plateau model, although it may exhibit a satisfactory statistical fit, has a tendency to underestimate the optimal nutrient requirements of the animal groups studied due to their failure to consider the physiological variances present within the population [25]. Conversely, the quadratic plateau model estimates higher nutritional requirements compared to the linear plateau model [26]. Therefore, a combined approach, averaging the results of the linear plateau and quadratic plateau models, was employed to estimate Lys requirements for White Pekin ducks during the critical 21 d period after hatching.

In the current investigation, the linear plateau and quadratic-plateau regression analyses determined that the minimum requirement of SID Lys for achieving maximum BW and ADG was determined to be 1.05%, while the minimum requirement for attaining optimal FCR was found to be 1.04%. These findings align with the study conducted by [7], which indicated that reaching 95% of the asymptote in ADG for White Pekin ducks occurred at a total lysine concentration of 1.17% (day 1 to 21). Additionally, for efficient FCR, male Pekin ducks required a 1.06% Lys concentration from day 1 to 21. Similarly, [9] reported Lys requirements of 0.84% for ADG and 0.90% for feed conversion efficiency of male White Pekin ducklings from day 7 to 21, both of which exceeded the recommendations of [17]. These differences in Lys requirements can be attributed to variations in response criteria, research methodologies (including experimental diets based on digestible amino acids), and the enhanced growth potential resulting from the genetic selection of Pekin ducks [27]. Furthermore, it is worth noting that the response to Lys may be affected by the concentrations of other AA in the diet [28]. Furthermore, the selection of an appropriate mathematical model can have a significant impact on the estimation process [29].

Conclusion

The findings of this research demonstrate that augmenting the SID Lys content has a positive impact on ADG and feed efficiency during the 3 weeks after hatching in White Pekin ducks. By employing both linear- and quadratic-plateau models, it was determined that the recommended SID Lys levels for optimal final BW, ADG, and feed efficiency in White Pekin ducks from hatch to 21 d are 1.05%, 1.05%, and 1.04%, respectively.

Funding sources

This research was supported by "Regional Innovation Strategy (RIS)" through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (MOE) (2021RIS-004).

References

1. Ruan D, Fouad A, Zhang Y, Wang S, Chen W, Xia W, et al. Effects of dietary lysine on productivity, reproductive performance, protein and lipid metabolism-related gene expression in laying duck breeders. Poultry science. 2019;98(11):5734-45. https://doi.org/10.3382/ps/pez361

2. Kim E, Wickramasuriya SS, Shin TK, Cho HM, Kim HB, Heo JM. Estimating total lysine requirement for optimised egg production of broiler breeder hens during the early-laying period. Journal of Animal Science and Technology. 2020;62(4):521. https://doi.org/10.5187/jast.2020.62.4.521

3. Fouad AM, Chen W, Ruan D, Wang S, Xia W, Zheng C. Effects of dietary lysine supplementation on performance, egg quality, and development of reproductive system in egg-laying ducks. Journal of Applied Animal Research. 2018;46(1):386-91. https://doi.org/10.1080/09712119.2017.1308868

4. Linh N, Dong N, Thu N. Effect of dietary lysine and energy levels on apparent nutrient, nitrogen, and amino acids digestibility of local Muscovy ducks. Adv Anim Vet Sci. 2022;10(2):253-62. http://dx.doi.org/10.17582/journal.aavs/2022/10.2.253.262

5. Baéza E. Nutritional requirements and feed management of meat type ducks. World's Poultry Science Journal. 2016;72(1):5-20. https://doi.org/10.1017/S004393391500272X

6. Zhou Z, Li M, Cheng H, Fan W, Yuan Z, Gao Q, et al. An intercross population study reveals genes associated with body size and plumage color in ducks. Nature communications. 2018;9(1):2648. https://doi.org/10.1038/s41467-018-04868-4

7. Bons A, Timmler R, Jeroch H. Lysine requirement of growing male Pekin ducks. British Poultry Science. 2002;43(5):677-86. https://doi.org/10.1080/0007166021000025073

8. Adeola O. Review of research in duck nutrient utilization. International Journal of Poultry Science. 2006;5(3):201-18. https://doi.org/10.3923/ijps.2006.201.218

9. Xie M, Guo Y, Zhang T, Hou S, Huang W. Lysine requirement of male white pekin ducklings from seven to twenty-one days of age. Asian-Australasian Journal of Animal Sciences. 2009;22(10):1386-90. https://doi.org/10.5713/ajas.2009.90142

10. Tansil F, Pezzali JG, Cargo-Froom C, Huber L-A, Kiarie EG, Courtney-Martin G, et al. Evaluation of standardized ileal digestibility of amino acids and metabolic availability of methionine, using the indicator amino acid oxidation method, in black soldier fly larvae

(Hermetia illucens) meal fed to growing pigs. Journal of Animal Science. 2023;101:skac420. https://doi.org/10.1093/jas/skac420

11. An SH, Kong C. Influence of age and type of feed ingredients on apparent and standardized ileal amino acid digestibility in broiler chickens. Journal of Animal Science and Technology. 2022;64(4):740. https://doi.org/10.5187/jast.2022.e43

12. Kong C, Adeola O. Apparent ileal digestibility of amino acids in feedstuffs for White Pekin ducks. Poultry science. 2010;89(3):545-50. https://doi.org/10.3382/ps.2009-00485

13. Wickramasuriya S, Yi Y, Yoo J, Kim J, Heo K, Heo J. Lysine requirements of Korean native ducklings for three weeks after hatch. Journal of Applied Poultry Research. 2016;25(4):464-73. https://doi.org/10.3382/japr/pfw019

14. Cemin HS, Vieira SL, Stefanello C, Kipper M, Kindlein L, Helmbrecht A. Digestible lysine requirements of male broilers from 1 to 42 days of age reassessed. PLoS One. 2017;12(6):e0179665. https://doi.org/10.1371/journal.pone.0179665

15. An SH, Kang H-K, Kong C. Standardized ileal digestible lysine requirements of 21–28 days old male broilers. Animal Feed Science and Technology. 2022;292:115409. https://doi.org/10.1016/j.anifeedsci.2022.115409

16. Oketch EO, Kim YB, Yu M, Cho HM, Hong JS, Nawarathne SR, et al. Research Note: Evaluation of standardized ileal amino acid digestibility in feed ingredients for Pekin ducks. Poultry Science. 2023:102899. https://doi.org/10.1016/j.psj.2023.102899

17. NRC [National Research Council]. Nutrient requirements of poultry. 9th ed. Washington, DC: National Academies Press; 1994.

18. Oketch EO, Kim YB, Yu M, Hong JS, Nawarathne SR, Heo JM. Differences in bedding material could alter the growth performance of White Pekin ducks raised for 42 days. Journal of Animal Science and Technology. 2023;65(2):377. https://doi.org/10.5187/jast.2022.e116

19. AOAC [Association of Official Analytical Chemists] International. Official methods of analysis of AOAC International. 18th ed. Washington, DC: AOAC International; 2006.

20. Lee J, Sung Y, Kong C. Standardized ileal digestible lysine requirement of male broilers at the age of 0–10 days. Animal Feed Science and Technology. 2018;241:55-62. https://doi.org/10.1016/j.anifeedsci.2018.04.016

21. An SH, Lee B, Choi YM, Kong C. Standardized ileal digestible lysine requirements based on growth performance and histochemical characteristics of male broilers from 10 to 21 d of age. Animal Nutrition. 2023;12:145-50. https://doi.org/10.1016/j.aninu.2022.09.012

22. Kong C, Adeola O. Comparative amino acid digestibility for broiler chickens and White Pekin ducks. Poultry Science. 2013;92(9):2367-74. https://doi.org/10.3382/ps.2013-03042

23. Lemme A, Ravindran V, Bryden W. Ileal digestibility of amino acids in feed ingredients for broilers. World's Poultry Science Journal. 2004;60(4):423-38. https://doi.org/10.1079/WPS200426

24. Nørgaard J, Pedersen T, Soumeh E, Blaabjerg K, Canibe N, Jensen B, et al. Optimum standardized ileal digestible tryptophan to lysine ratio for pigs weighing 7–14 kg. Livestock science. 2015;175:90-5. https://doi.org/10.1016/j.livsci.2015.02.012

25. Pomar C, Pomar J, Rivest J, Cloutier L, Letourneau-Montminy M, Andretta I, et al. Estimating real-time individual amino acid requirements in growing-finishing pigs: towards a new definition of nutrient requirements in growing-finishing pigs? Nutritional modelling for pigs and poultry: CABI Wallingford UK; 2015. p. 157-74. https://doi.org/10.1079/9781780644110.0157

26. Heger J, Krizova L, Sustala M, Nitrayová S, Patras P, Hampel D. Assessment of statistical models describing individual and group response of pigs to threonine intake. Journal of Animal and Feed Sciences. 2007;16(3):420. https://doi.org/10.22358/jafs/66798/2007

27. Zhou Y, Liu Y, Wei H, Peng J. Estimation of the optimum digestible lysine level for Cherry Valley ducks. Poultry Science. 2017;96(4):838-43. https://doi.org/10.3382/ps/pew306

28. Hickling D, Guenter W, Jackson M. The effects of dietary methionine and lysine on broiler chicken performance and breast meat yield. Canadian Journal of Animal Science. 1990;70(2):673-8. https://doi.org/10.4141/cjas90-079

29. Liu S, Rochell S, Maynard C, Caldas J, Kidd M. Digestible lysine concentrations and amino acid densities influence growth performance and carcass traits in broiler chickens from 14 to 35 days post-hatch. Animal Feed Science and Technology. 2019;255:114216. https://doi.org/10.1016/j.anifeedsci.2019.114216

Tables and Figures

Table 1. Ingredients and chemical compositions of the experimental diets (as-fed basis, %).

Item	Standardized ileal digestible lysine concentrations (%)					
	0.72	0.80	0.88	0.96	1.04	1.12
Corn	41.67	41.58	41.47	41.36	41.26	41.16
Corn DDGS	38.53	38.53	38.53	38.53	38.53	38.53
Soybean meal	16.70	16.70	16.70	16.70	16.70	16.70
Limestone	1.00	1.00	1.00	1.00	1.00	1.00
Dicalcium-phosphate	1.50	1.50	1.50	1.50	1.50	1.50
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin-mineral premix[1]	0.30	0.30	0.30	0.30	0.30	0.30
L-Lysine-HCl	0.00	0.10	0.21	0.31	0.41	0.51
Calculated values						
ME (kcal/kg)	2,872	2,873	2,875	2,876	2,877	2,878
Crude protein	21.95	22.03	22.13	22.22	22.31	22.39
Calcium	0.88	0.88	0.88	0.88	0.88	0.88
Non-phytate phosphorus	0.52	0.52	0.52	0.52	0.52	0.52
Total lysine	0.90	0.98	1.06	1.14	1.22	1.30
Standardized ileal digestible amino acids (%)						
Arginine	1.01	1.01	1.01	1.01	1.01	1.01
Histidine	0.49	0.49	0.49	0.49	0.49	0.49
Isoleucine	0.72	0.72	0.72	0.72	0.72	0.72
Leucine	1.98	1.98	1.98	1.98	1.98	1.98
Lysine	0.72	0.80	0.88	0.96	1.04	1.12
Methionine	0.35	0.35	0.35	0.35	0.35	0.35
Cysteine	0.28	0.28	0.28	0.28	0.28	0.28
Phenylalanine	0.92	0.92	0.92	0.92	0.92	0.92
Threonine	0.63	0.63	0.63	0.63	0.63	0.63
Tryptophan	0.17	0.17	0.17	0.17	0.17	0.17
Valine	0.87	0.87	0.87	0.87	0.87	0.87

[1]Provided per kilogram of diet: vitamin A, 12,000 IU; vitamin D_3, 2,500 IU; vitamin E, 30 IU; vitamin K_3, 3 mg; D-pantothenic acid, 15 mg; nicotinic acid, 40 mg; choline, 400 mg; and vitamin B_{12}, 12 μg; Fe, 90 mg from iron sulfate; Cu, 8.8 mg from copper sulfate; Zn, 100 mg from zinc oxide; Mn, 54 mg from manganese oxide; I, 0.35 mg from potassium iodine; Se, 0.30 mg from sodium selenite.

DDGS, Distiller's Dried Grains with soluble

Table 2. Analyzed amino acid composition of the experimental diets containing 6 concentrations of standardized ileal digestible lysine (as-fed basis, %)

Item	Standardized ileal digestible lysine concentrations (%)					
	0.72	0.80	0.88	0.96	1.04	1.12
Indispensable amino acids (%)						
Arginine	1.04	1.07	0.98	0.96	1.06	1.01
Histidine	0.46	0.45	0.45	0.45	0.49	0.46
Isoleucine	0.69	0.73	0.69	0.67	0.75	0.73
Leucine	1.85	1.90	1.81	1.81	1.95	1.88
Lysine	0.66	0.77	0.80	0.89	1.03	1.12
Methionine	0.36	0.34	0.32	0.33	0.38	0.38
Phenylalanine	0.85	0.87	0.82	0.82	0.90	0.85
Threonine	0.54	0.56	0.52	0.50	0.57	0.55
Tryptophan	0.17	0.16	0.18	0.17	0.17	0.18
Valine	0.80	0.82	0.80	0.77	0.86	0.83

Table 3. Growth performance of White Pekin ducks from 1 to 21 days of age fed diets containing different dietary standardized ileal digestible lysine concentrations[1].

Item	Standardized ileal digestible lysine concentrations (%)						SEM[2]	*P*-value	Polynomial contrast[3]	
	0.72	0.80	0.88	0.96	1.04	1.12			Lin	Quad
BW (g)										
Day 1	52.73	53.11	53.03	53.47	53.04	52.91	0.201	0.937	0.778	0.639
Day 7	173.92^{a}	174.05^{a}	174.56^{a}	189.25^{b}	189.31^{b}	182.69^{ab}	1.049	<0.001	<0.001	<0.001
Day 14	494.42^{ab}	474.06^{a}	540.58^{bc}	573.17^{c}	580.56^{c}	549.72^{c}	4.532	<0.001	<0.001	<0.001
Day 21	1039.75^{ab}	1021.06^{a}	1106.34^{bc}	1168.49^{c}	1180.88^{c}	1170.50^{c}	7.616	<0.001	<0.001	<0.001
ADG (g/bird/d)										
Day 7	17.31^{a}	17.28^{a}	17.36^{a}	19.40^{b}	19.47^{b}	18.54^{ab}	0.148	<0.001	<0.001	<0.001
Day 14	45.79^{ab}	42.86^{a}	52.29^{bc}	54.29^{c}	55.89^{c}	52.43^{bc}	0.656	<0.001	<0.001	<0.001
Day 21	77.90^{a}	78.14^{a}	80.82^{ab}	85.05^{ab}	85.76^{ab}	88.68^{b}	0.856	0.002	<0.001	<0.001
Day 1-21	47.00^{ab}	46.09^{a}	50.16^{bc}	53.10^{c}	53.71^{c}	53.22^{c}	0.357	<0.001	<0.001	<0.001
ADFI (g/bird/d)										
Day 7	26.78	26.56	26.51	26.73	26.64	26.47	0.045	0.304	0.244	0.510
Day 14	79.06	75.08	78.03	77.32	74.65	77.76	0.634	0.299	0.525	0.553
Day 21	141.14	134.54	134.47	137.72	134.51	137.72	1.161	0.493	0.561	0.318
Day 1-21	82.33	78.73	79.67	80.59	78.60	80.65	0.521	0.323	0.473	0.295
FCR (g/g)										
Day 7	1.55^{b}	1.54^{b}	1.53^{b}	1.39^{a}	1.37^{a}	1.43^{ab}	0.011	<0.001	<0.001	<0.001
Day 14	1.74^{b}	1.76^{b}	1.50^{a}	1.41^{a}	1.34^{a}	1.50^{a}	0.018	<0.001	<0.001	<0.001
Day 21	1.82^{b}	1.73^{ab}	1.68^{ab}	1.62^{ab}	1.59^{ab}	1.55^{a}	0.023	0.021	<0.001	0.001
Day 1-21	1.76^{c}	1.71^{bc}	1.59^{ab}	1.52^{a}	1.47^{a}	1.52^{a}	0.014	<0.001	<0.001	<0.001

[1]Values are the mean of eight replicates per treatment.
[2]Pooled standard error of the mean.
[3]Orthogonal polynomial contrast coefficients were used to determine linear (Lin) and quadratic (Quad) effects of increasing digestible lysine.
[a-c]Values in a row with different superscripts differ significantly ($P < 0.05$)
ADFI, average daily feed intake; ADG, average daily gain; BW, body weight; FCR, Feed conversion ratio.

Table 4. Estimated standardized ileal digestible lysine requirements and recommendations for White Pekin ducks from hatch to 21 days of age based on linear-plateau and quadratic-plateau regression analysis[1].

Item	Requirement (%)[2]	SE	R^2	*P*-value	Recommendation (%)[3]
Final BW (g)					
LP	1.00	0.060	0.90	<0.001	1.05
QP	1.11	0.176	0.84	0.008	
ADG (g/bird/day)					
LP	1.00	0.061	0.90	<0.001	1.05
QP	1.11	0.181	0.84	0.009	
FCR (g/g)					
LP	0.98	0.029	0.97	<0.001	1.04
QP	1.10	0.097	0.95	0.002	

[1]LP; Linear-plateau regression analysis, QP; Quadratic-plateau regression analysis, SE; Standard error.
[2]Standardized ileal digestible lysine requirement based on regression analysis.
[3]Standardized ileal digestible lysine recommendation for each parameter based on both regression analyses.
ADG, average daily gain; BW, body weight; FCR, Feed conversion ratio.

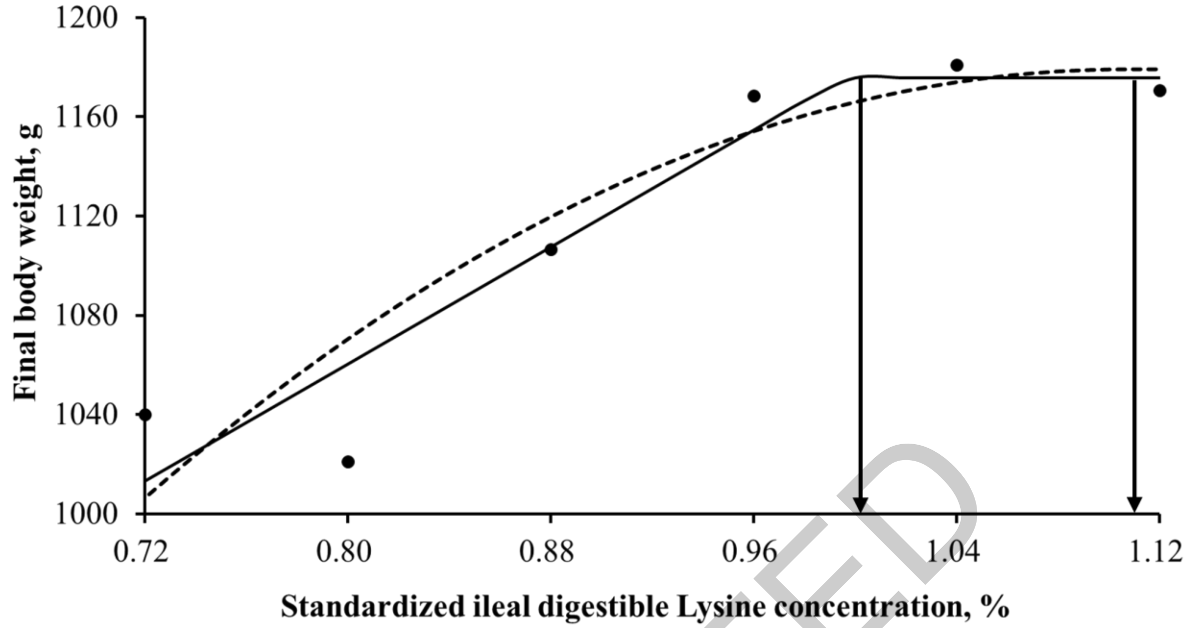

Figure 1. Standardized ileal digestible lysine requirements of White Pekin ducks from hatch to 21 days of age for final body weight determined by a quadratic-plateau model was 1.11 [Y = 1179.14-1152.68(1.11-x)^2, R^2 = 0.84] (open line), and by a linear-plateau model was 1.00 [Y = 1175.69-589.38(1.00-x), R^2 = 0.90] (closed line). Data points (●) represent least squares means of dietary treatment (n = 8).

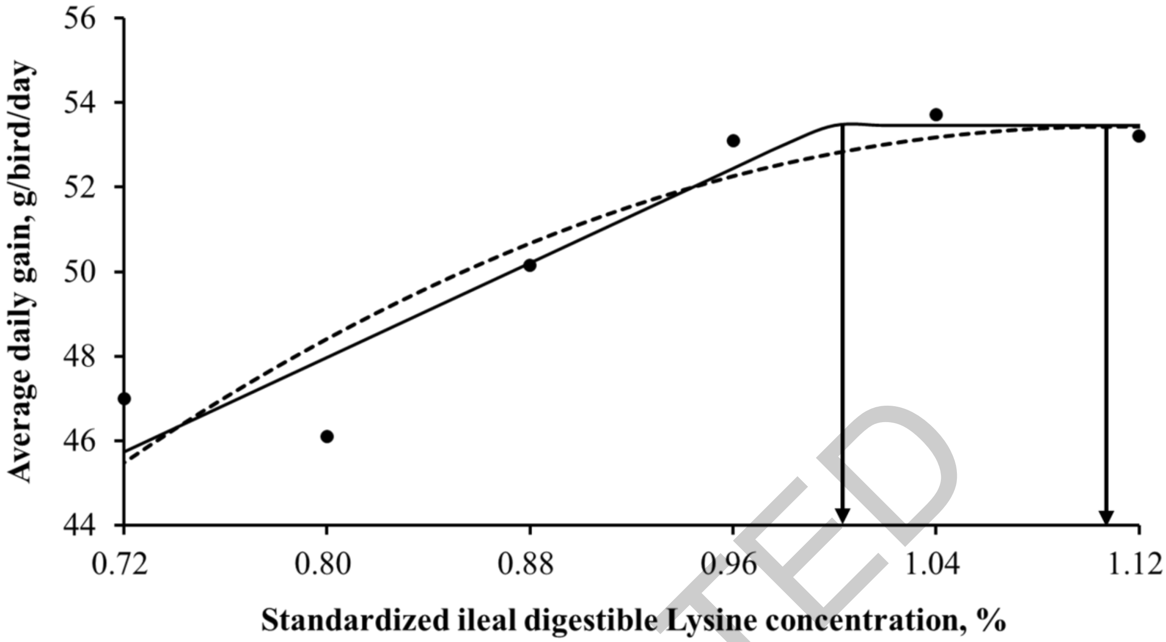

Figure 2. Standardized ileal digestible lysine requirements of White Pekin ducks from hatch to 21 days of age for average daily gain determined by a quadratic-plateau model was 1.11 [Y = 53.43-52.41(1.11-x)^2, R^2 = 0.84] (open line), and by a linear-plateau model was 1.00 [Y = 53.46-27.96(1.00-x), R^2 = 0.90] (closed line). Data points (●) represent least squares means of dietary treatment (n = 8).

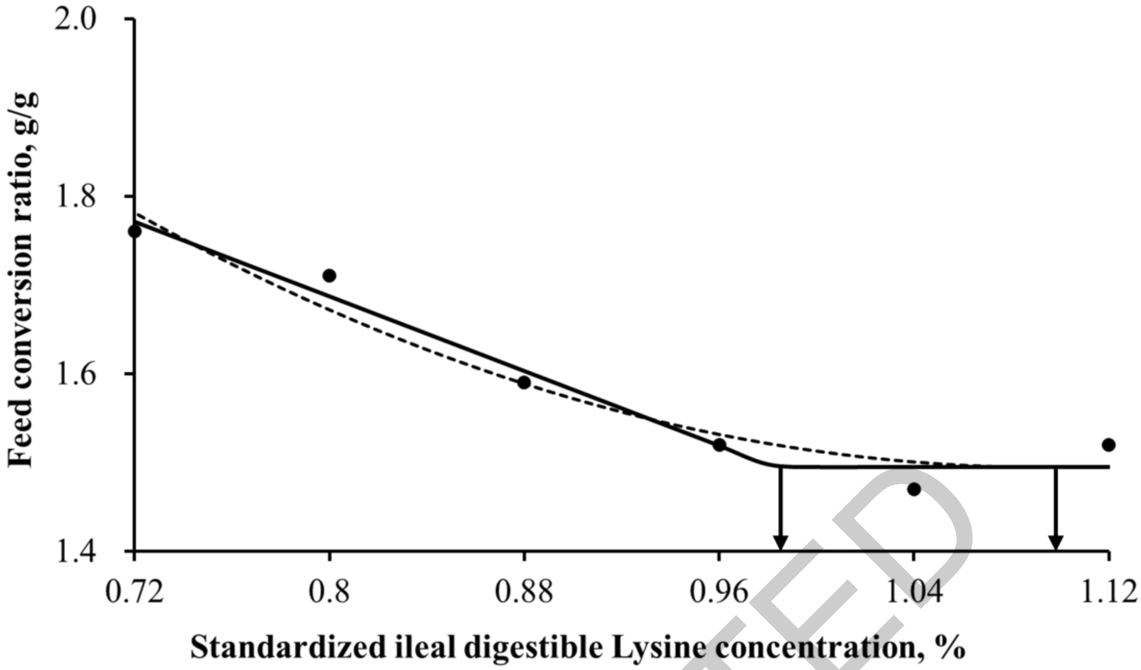

Figure 3. Standardized ileal digestible lysine requirements of White Pekin ducks from hatch to 21 days of age for feed conversion ratio determined by a quadratic-plateau model was 1.10 [Y = 1.49+2.04(1.10-x)^2, R^2 = 0.95] (open line), and by a linear-plateau model was 0.98 [Y = 1.50+1.05(0.98-x), R^2 = 0.97] (closed line). Data points (●) represent least squares means of dietary treatment (n = 8).