Dietary effect of energy levels on growth performance and carcass characteristics of White Pekin duck over 21 days

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Abstract

This experiment was conducted to determine the maximum dietary energy levels on growth performance and carcass characteristics of White Pekin duck. the Six dietary treatments were formulated based on their apparent metabolizable energy (AME) concentrations from 2,700 to 3,200 kcal/kg with a 100 kcal/kg gap to evaluate the accurate dietary AME requirement to address current knowledge and further issues for fulfilling the genetic potential of meat-type white Pekin ducklings. A total of 432 one-day-old male White Pekin ducklings were randomly allocated into one of six dietary treatments with six replicates (12 birds per pen). The diets were formulated as corn-soybean meal-based diets to meet or exceed the Nutrient Requirement of Poultry specification for meat-type ducks. Growth performance indices (i.e. average daily gain [ADG], average daily feed intake, feed conversion ratio) were measured weekly. Medium body weight (BW) ducklings from each pen were sacrificed to analyze the carcass traits and abdominal fat content on day 21. Obtained data were analyzed to estimate significant effect using the one-way ANOVA of IBM SPSS Statistics (Version, 25). If the *p*-value of the results were significant, differences in means among treatments were separated by Tukey's post hoc test. Significant differences were then analyzed with a linear and quadratic broken model to estimate the accurate concentration of AME. Ducklings fed higher dietary AME diets increased (*p* < 0.05) BW, ADG. Ducklings fed higher AME than 2,900 kcal/kg diets increased abdominal fat accumulation and leg meat portion. The estimated requirement by linear plateau method showed from 3,000.00 kcal/kg to 3,173.03 kcal/kg whereas the requirement by quadratic plateau method indicated from 3,100.00 kcal/kg to 3,306.26 kcal/kg. Collectively, estimated dietary requirements exhibit diverse results based on the measured traits and analysis methods. All the estimated requirements in this experiment present higher than previous research, the maximum requirement for the next diet formulation should be selected by the purpose of the diet.

Keywords: Abdominal fat, Carcass traits, Duck, Energy level, Growth performance

Authors' contributions
Conceptualization: Hong JS, Wickramasuriya SS, Heo JM.
Data curation: Hong JS.
Formal analysis: Hong JS, Wickramasuriya SS.
Methodology: Wickramasuriya SS.
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Ethics approval and consent to participate
The complete experimental procedure was according to the Guidelines of Research Ethics Committee of Chungnam National University (CNU-01176).

INTRODUCTION

In poultry diets, dietary energy-contributing ingredients give a major part of production costs. Thus, the determination of the maximum energy level is important for reducing the overall feed cost per unit. It is known that dietary energy is one of the most contributing factors to the growth performance of poultry. Increasing dietary energy levels could improve the feed conversion rate by reducing feed intake [1–5]. However, up-to-date examination of the effect of energy levels on duck production has been rarely done. Furthermore, published data indicated the energy partitioning of ducks showed completely different patterns compared to the other poultry species (i.e., broiler chicken).

For example, Miclosamu [6] suggested that the dietary energy level from 2,750 kcal/kg to 3,050 kcal/kg exerts no significant changes on the growth performance of Muscovy duck. Similarly, recent research also indicates that dietary energy density continues to play an important role although the growth performance of modern broiler chickens is more responsive to amino acid densities [7]. In this regard, further research on the effect of dietary energy levels on ducks' growth performance is imperative. Additionally, higher dietary energy composed to the standard level caused the deposition of excess abdominal fat or carcass fat in broilers [1,4,8], which could occur an economic loss for poultry producers. It has been determined that abdominal fat deposition resulting in adipogenesis in poultry could be affected by dietary factors such as carbohydrate, protein, and lipid sources [9]. This is of importance, especially with the fact that the White Pekin duck has higher fat levels than other avian species [10]. It is worthy to note that abdominal fat deposition could impact not only consumer choices but also the profitability of duck meat producers. This is because of health concerns the modern consumer has shown a preference for less fatty cut-up parts such as breasts (Pectoralis major).

There is an urgent need to generate up-to-date experimental data on modern duck genotypes because previous studies suggest that duck response to dietary energy [11,12], these experiments were conducted more than 40 years ago. To efficiently utilize the genetic potential of these poultry for specific production goals, it is necessary to determine the nutrient requirements of different poultry types [13]. A previous study evaluates the maximum crude protein levels in White Pekin ducks [14]. Thus, the objective of the current experiment was to investigate the effect of dietary energy levels on the growth performance and carcass traits and estimate the maximum dietary energy level of modern White Pekin ducks from hatch to 21 days.

MATERIALS AND METHODS

Experimental design and environment management
A total of 432 one-day-old male white Pekin ducklings with similar initial body weight were randomly allotted to 24 cages consisting of 6 treatments with 6 replicates. The dietary treatments consisted of a corn and soybean meal-based diet formulated with the nutrients to meet or exceed the National Research Council [15] specification for meat-type duck except for apparent metabolizable energy (AME) level which started from 2,700 kcal/kg to 3,200 kcal/kg with a 100 kcal/kg gap (Table 1). Diets were provided on an ad-libitum basis using a plastic feeder and the birds had free access to fresh clean drinking water via nipple drinkers throughout the experiment. Raised floor pens (120 × 180 cm²) were used to house the birds under the same environmental conditions. The temperature of the cages was maintained at 32 ± 2℃ during week one post-hatch, and then it was gradually lowered leach 25 ± 2℃ until the birds were 3 weeks old. Relative humidity was maintained at 70 ± 5% in the first week, 65 ± 5% in the second week, and 60 ± 5% thereafter.

Table 1. Composition of the experimental diets (%, as-fed basis)

Ingredient (%)	Diets[1]					
	3200	3100	3000	2900	2800	2700
Corn	42.55	38.04	33.53	29.02	24.51	20.00
Wheat HRW	24.00	22.20	20.40	18.60	16.80	15.00
Wheat bran	-	4.90	9.80	14.70	19.60	24.50
SBM (48%)	30.00	29.20	28.40	27.60	26.80	26.00
Oats	-	2.00	4.00	6.00	8.00	10.00
Vegetable oil	0.20	0.41	0.62	0.83	1.04	1.25
Limestone	1.00	1.00	1.00	1.00	1.00	1.00
Monocal phos Biofos	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 premix[2]	0.30	0.30	0.30	0.30	0.30	0.30
DL-methionine	0.15	0.15	0.15	0.15	0.15	0.15
Calculated composition						
ME (kcal/kg)	3,203.0	3,103.2	3,003.4	2,903.6	2,803.8	2,704.0
CP (%)	21.11	21.11	21.11	21.12	21.12	21.12
Lys (%)	1.11	1.11	1.10	1.10	1.09	1.09
Met + Cys (%)	0.85	0.85	0.85	0.86	0.86	0.86

[1]Teatment number indicate dietary AME (kcal/kg).

[2]Vitamin and mineral pre-mixture provided the following nutrients per kg of diet: vitamin A, 24,000 IU; vitamin D_3, 6,000 IU; vitamin E, 30 IU; vitamin K, 4 mg; thiamine, 4 mg; riboflavin, 12 mg; pyridoxine, 4 mg; folacine, 2 mg; biotin, 0.03 mg; vitamin B_8 0.06 mg; niacin, 90 mg; pantothenic acid, 30 mg; Fe, 80 mg (as $FeSO_4 \cdot H_2O$); Zn, 80 mg (as $ZnSO_4 \cdot H_2O$); Mn, 80 mg (as $MnSO_4 \cdot H_2O$); Co, 0.5 mg (as $CoSO_4 \cdot H_2O$); Cu, 10 mg (as $CuSO_4 \cdot H_2O$); Se, 0.2 mg (as Na_2SeO_3); I, 0.9 mg (as Ca $[IO_3] \cdot 2H_2O$).

HRW, hard red winter; SBM, soybean meal; ME, metabolizable energy; CP, crude protein; Met, methionine; Lys, lysine; Cys, cysteine; AME, apparent metabolizable energy.

Furthermore, a continuous lighting regime of 25 lux was practiced during the experimental period.

Growth performance

Body weights (BW) and feed intakes were measured on day 1, 7, 14, 21. Using the BW and feed intake data, average daily gain (ADG), average daily feed intake (ADFI), and feed conversion ratio (FCR) were calculated. Moreover, the daily mortality of birds in each replicate was recorded when the death occurred.

Post-mortem procedure and sample collection

A duck was randomly selected from each pen (six ducks per treatment) on day 21. The individual live body weight of the selected bird was measured and euthanized with cervical dislocation [14]. The carcass was skinned and eviscerated to measure empty body weight. Breast meat, leg meat (with thigh), and abdominal fat were collected to estimate the effects of dietary energy levels on meat (leg and breast muscle) and abdominal fat accumulation.

Statistical analyses

Data were analyzed using the one-way ANOVA technique, a completely randomized design by using the SPSS software package (Version 24, IBM SPSS 2012, Chicago, IL, USA). The pen was used as the experimental unit for all growth performance measurements. Selected individual birds were used as the experimental unit for the carcass measurement. Mean differences were considered significant at $p < 0.05$. Tukey's multiple comparison test was used to determine the significant differences between experimental groups when the mean shows a significant difference. Nutritional response models were analyzed with a broken-line model and quadratic model conducted to

estimate the maximum dietary energy level [16].

RESULTS

All birds remained healthy and performed well; Sudden Death Syndrome (SDS), death from stress, and disease were not noticed.

The data for the growth performance of ducklings fed different dietary AME levels are presented in Table 2. Ducklings fed a 3,200 kcal/kg AME level diet indicate the highest BW. In addition, ducklings fed an AME range of 3,100 kcal/kg to 2,800 kcal/kg, showed medium BW. Whereas ducks fed a 2,700 kcal/kg AME level diet exhibited the lowest ($p < 0.05$) BW on day 21. A similar trend was noted for the ADG over the entire experimental period. Similarly, ducks fed higher dietary AME levels than 2,900 kcal/kg displayed lower FCR ($p < 0.05$) on average during the whole experimental period. Following those results, ducks fed more than 3,200 kcal/kg dietary AME level diet exhibited the highest BW and ADG, and the lowest FCR ($p < 0.05$).

Carcass quality is presented in Table 3. Ducks fed a higher AME level diet had higher ($p < 0.05$) abdominal fat content and leg meat portion. However, no difference ($p > 0.05$) in breast meat portion

Figs. 1 to 6 show linear and quadratic plateau analysis to estimate the maximum requirement level of dietary AME. Fig. 1 shows the linear plateau day 21 BW level to be at 3,000.00 kcal/kg and the quadratic plateau requirement was determined at 3,100.00 kcal/kg. Fig. 2 shows the

Table 2. Comparison of growth performance of six different energy level from hatch to day 21

Period	Diets[1]						SEM	p-value
	3200	3100	3000	2900	2800	2700		
Bodyweight								
Initial	48.48	48.46	48.42	48.48	48.50	48.48	0.089	0.955
Day 7	221.63	211.15	204.93	201.94	201.90	205.32	12.511	0.609
Day 14	716.89	678.50	654.80	657.25	637.60	625.53	35.473	0.190
Day 21	1,387.29^c	1,360.06^{bc}	1,341.76^{abc}	1,246.99^{abc}	1,239.50^{ab}	1,209.65^a	45.663	0.004
Average daily gain								
Day 1–7	24.74	23.24	22.36	21.92	21.91	22.41	1.788	0.610
Day 8–14	70.75	66.76	64.27	65.04	62.24	60.03	3.724	0.130
Day 15–21	88.63	90.22	90.99	84.25	85.99	83.45	5.093	0.584
Day 1–21	63.75^c	62.46^{bc}	61.59^{abc}	57.07^{abc}	56.71^{ab}	55.29^a	2.175	0.004
Average daily feed intake								
Day 1–7	31.47	30.14	29.29	28.71	30.07	31.06	2.310	0.840
Day 8–14	100.18	94.66	97.01	96.60	90.81	95.92	5.311	0.649
Day 15–21	130.55^b	133.34^{ab}	137.60^b	132.79^a	136.38^{ab}	132.79^{ab}	4.724	0.019
Day 1–21	90.91	89.57	91.57	86.03	85.75	86.59^{ab}	3.032	0.205
Feed conversion ratio								
Day 1–7	1.27^a	1.30^b	1.31^b	1.31^b	1.37^c	1.39^d	0.004	0.001
Day 8–14	1.41^a	1.42^a	1.51^{ab}	1.48^{ab}	1.46^{ab}	1.60^b	0.050	0.015
Day 15–21	1.48	1.48	1.51	1.59	1.59	1.59	0.052	0.077
Day 1–21	1.43^a	1.44^a	1.49^{ab}	1.51^{ab}	1.51^b	1.57^b	0.037	0.012

[1]Teatment number indicates dietary AME (kcal/kg).

a–cValues in a row with different superscripts differ significantly ($p < 0.05$).
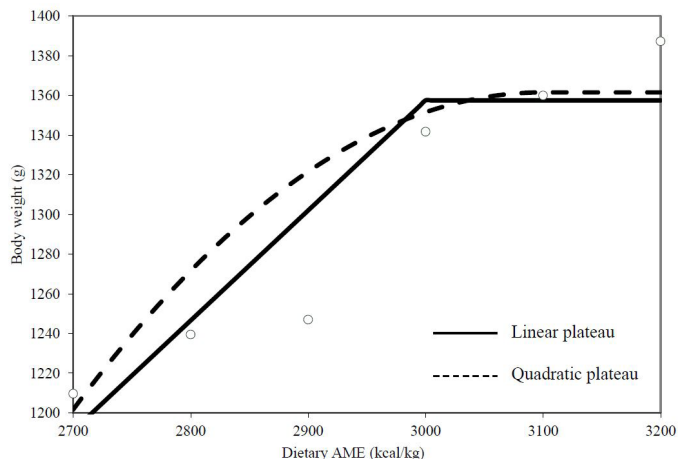
AME, apparent metabolizable energy.

Table 3. Comparison of breast and leg meat yield and abdominal fat accumulation of six different energy level on day 21

Factor	Diets[1]						SEM	*p*-value
	3200	3100	3000	2900	2800	2700		
Abdominal fat (g)	9.94[b]	9.44[ab]	8.93[ab]	7.02[ab]	6.24[ab]	6.19[a]	1.169	0.012
B/EBW (%)	8.36	8.02	8.20	8.12	9.40	8.02	0.520	0.120
L/EBW (%)	17.32[b]	16.90[ab]	17.52[b]	15.28[ab]	15.16[ab]	14.49[a]	0.830	0.006

[1]Teatment number indicate dietary AME (kcal/kg).

[a–c]Values in a row with different superscripts differ significantly (*p* < 0.05).

AME, apparent metabolizable energy; B/EBW, breast meat weight divided by empty body weight; L/EBW, leg meat weight divided by empty body weight.
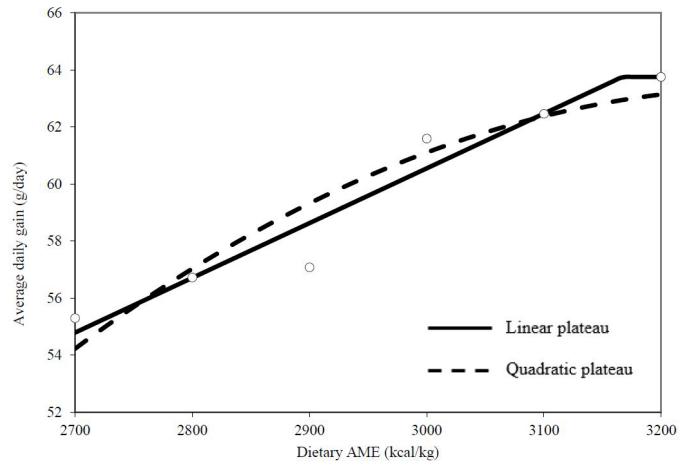

	Requirement (kcal/kg)	R^2 (%)
Linear plateau	3,000.00	83.435
Quadratic plateau	3,100.00	73.079

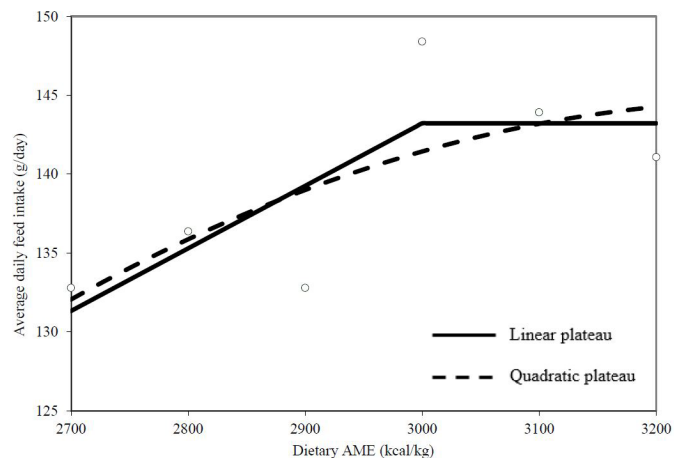**Fig. 1. Linear and quadratic plateau analysis of results of body weight on day 21.** AME, apparent metabolizable energy.
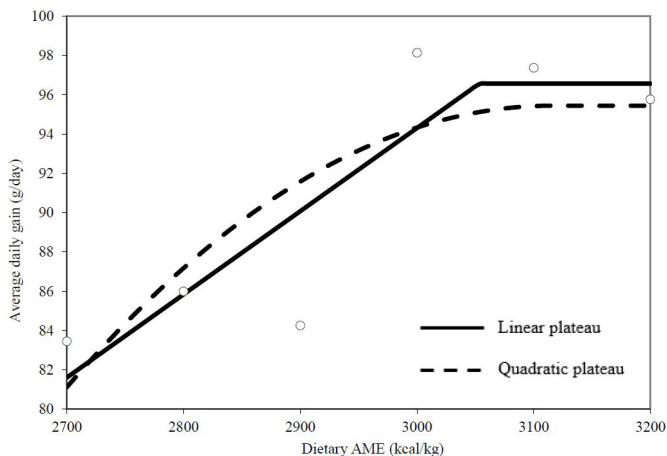
	Requirement (kcal/kg)	R^2 (%)
Linear plateau	3,053.45	77.972
Quadratic plateau	3,115.92	67.333

Fig. 2. Linear and quadratic plateau analysis of results of average daily gain from day 14 to day 21. AME, apparent metabolizable energy.

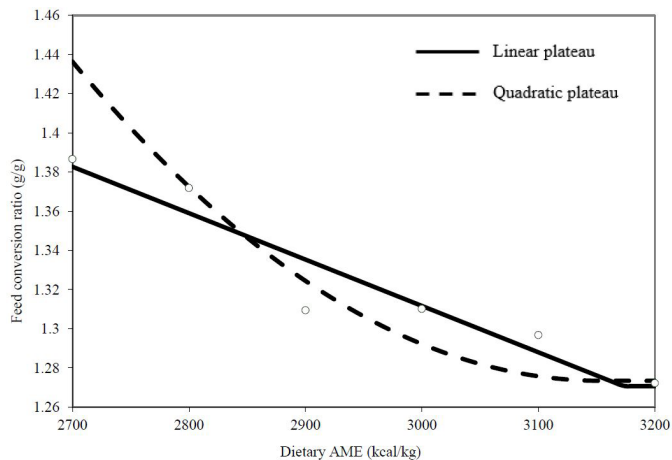|	Requirement (kcal/kg)	R² (%)
Linear plateau	3,167.04	93.991
Quadratic plateau	3,299.72	88.944

Fig. 3. Linear and quadratic plateau analysis of results of average daily gain from day 1 to day 21. AME, apparent metabolizable energy.

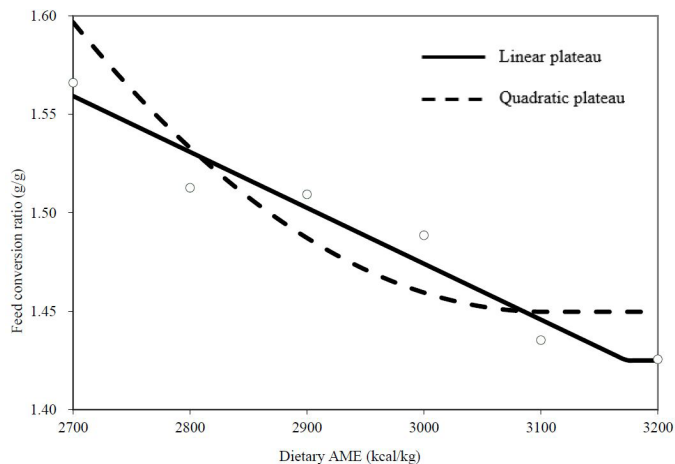|	Requirement (kcal/kg)	R² (%)
Linear plateau	3,000.00	61.591
Quadratic plateau	3,306.26	50.911

Fig. 4. Linear and quadratic plateau analysis of results of average daily feed intake from day 14 to day 21. AME, apparent metabolizable energy.

requirement of ADG from day 14 to 21. The linear plateau level was at 3,053.45 kcal/kg and the quadratic plateau requirement was estimated at 3,115.92 kcal/kg. Fig. 3 shows the requirement of ADG from day 1 to 21, the linear plateau requirement level was at 3,167.04 kcal/kg and the quadratic plateau requirement was estimated to be 3,299.00 kcal/kg. Fig. 4 displays the requirement of ADFI from day 14 to 21 and the linear plateau requirement level was at 3,000.00 kcal/kg whereas the quadratic plateau requirement was at 3,306.26 kcal/kg. Fig. 5 exhibits the FCR requirement from day 1 to 7 and the linear plateau level shows 3,173.03 kcal/kg and the quadratic plateau estimate is at 3,154.17 kcal/kg. Fig. 6 shows the requirement of FCR from day 1 to 21 and

	Requirement (kcal/kg)	R² (%)
Linear plateau	3,173.03	90.705
Quadratic plateau	3,154.17	65.383

Fig. 5. Linear and quadratic plateau analysis of results of feed conversion ratio from day 1 to day 7. AME, apparent metabolizable energy.

	Requirement (kcal/kg)	R² (%)
Linear plateau	3,173.00	94.630
Quadratic plateau	3,104.14	74.797

Fig. 6. Linear and quadratic plateau analysis of results of feed conversion ratio from day 1 to day 21. AME, apparent metabolizable energy.

the linear plateau level is shown at 3,173.00 kcal/kg while the quadratic plateau requirement was gauged at 3,104.14 kcal/kg.

DISCUSSION

The dietary AME level is a critical issue in the animal production field. This is because the optimization of the nutrient requirement is a really important step to cut down on the production

cost while maximizing productivity. Following previously published data, feeding a higher dietary AME level diet could improve growth performance parameters such as BW, ADG, ADFI, and FCR [1–5]. In this study, the growth performance and carcass traits data obtained agree with previous studies that showed that starter Pekin ducklings fed a lower energy diet recorded higher feed intake and thus increased feed conversion [11,12,17,18]. This could be because a lower dietary AME diet makes animals consume more to reach the required energy level. The current data also supports the theory that the effect of dietary energy level on the performance of growing birds is dependent on the birds' capacity to alter feed intake to meet changing demands for calories [19,20]. As a result, birds fed a higher dietary AME diet showed improved feed efficiency [1–4].

Dietary AME levels could also influence the carcass traits. Previous research suggested that dietary energy causes the deposition of excess abdominal fat or carcass fat in broilers [1,4,8,21], and ducks fed a high dietary AME level diet can accumulate larger amounts of abdominal fat [11,18,22]. The high abdominal fat accumulation trait could negatively affect the consumers' choices [23,24].

Increasing dietary AME shows no differences ($p > 0.05$) in breast meat yield while leg meat yield is increasing in broilers [3,8,17,21].

Looking at the concept of broken line analysis as suggested by Whittemore and Fawcett [25] states that when the dietary nutrient is over the threshold, then the performance nearly keeps staying on the most improved side. That overlapped point between the highest performance graph and regression graph is called the broken point and can be regarded as the maximum dietary requirement. Figs. 1 to 6 present the requirement of linear and quadratic plateau analysis results. The requirement of linear plateau shows from 3,000.00 kcal/kg to 3,173.03 kcal/kg whereas the requirement of quadratic plateau ranges from 3,100.00 kcal/kg to 3,306.26 kcal/kg. Those gaps between linear and quadratic plateau requirements came from the characteristic of the regression graph. Some research [26] suggests that estimation by quadratic regressions can be overestimated when the requirement was not centered in the experimental nutrient. Therefore, the linear plateau requirement could be a more accurate maximum dietary AME level. Previous study suggested that the dietary AME requirement level is nearly 2,755.75 kcal/kg [11], which is lower than the estimated maximum AME level. The currently estimated requirement based on growth performance is much higher than that of the previous experiment because of the improved genetic performance of the modern White Pekin duck. Maximum dietary AME level should be selected based on the purpose of the diet formulation and the balance of the growth performance and abdominal fat accumulation.

REFERENCES

1. Jackson S, Summers JD, Leeson S. Effect of dietary protein and energy on broiler carcass composition and efficiency of nutrient utilization. Poult Sci. 1982;61:2224-31. https://doi.org/10.3382/ps.0612224

2. Dozier WA 3rd, Corzo A, Kidd MT, Branton SL. Dietary apparent metabolizable energy and amino acid density effects on growth and carcass traits of heavy broilers. J Appl Poult Res. 2007;16:192-205. https://doi.org/10.1093/japr/16.2.192

3. Dozier WA 3rd, Price CJ, Kidd MT, Corzo A, Anderson J, Branton SL. Growth performance, meat yield, and economic responses of broilers fed diets varying in metabolizable energy from thirty to fifty-nine days of age. J Appl Poult Res. 2006;15:367-82. https://doi.org/10.1093/japr/15.3.367

4. Ghaffari M, Shivazad M, Zaghari M, Taherkhani R. Effects of different levels of metabolizable

energy and formulation of diet based on digestible and total amino acid requirements on performance of male broiler. Int J Poult Sci. 2007;6:276-9. https://doi.org/10.3923/ijps.2007.276.279

5. Wen ZG, Rasolofomanana TJ, Tang J, Jiang Y, Xie M, Yang PL, et al. Effects of dietary energy and lysine levels on growth performance and carcass yields of Pekin ducks from hatch to 21 days of age. Poult Sci. 2017;96:3361-6. https://doi.org/10.3382/ps/pex122

6. Miclosanu EP, Roibu C. Research on dietary energy influence on the growth performance and meat quality in the Muscovy ducks. 1. Effects of high and medium levels of metabolic energy. Arch Zootech. 2001;6:125-32.

7. Liu SY, Naranjo VD, Chrystal PV, Buyse J, Selle PH. Box-Behnken optimisation of growth performance, plasma metabolites and carcass traits as influenced by dietary energy, amino acid and starch to lipid ratios in broiler chickens. PLOS ONE. 2019;14:e0213875. https://doi.org/10.1371/journal.pone.0213875

8. Summers JD, Spratt D, Atkinson JL. Broiler weight gain and carcass composition when fed diets varying in amino acid balance, dietary energy, and protein level. Poult Sci. 1992;71:263-73. https://doi.org/10.3382/ps.0710263

9. Wang G, Kim WK, Cline MA, Gilbert ER. Factors affecting adipose tissue development in chickens: a review. Poult Sci. 2017;96:3687-99. https://doi.org/10.3382/ps/pex184

10. Baeza E, Dessay C, Wacrenier N, Marche G, Listrat A. Effect of selection for improved body weight and composition on muscle and meat characteristics in Muscovy duck. Br Poult Sci. 2002;43:560-8. https://doi.org/10.1080/0007166022000004471

11. Scott ML, Hill FW, Parsons EH Jr, Bruckner JH, Dougherty E 3rd. Studies on duck nutrition: 7. effect of dietary energy: protein relationships upon growth, feed utilization and carcass composition in market ducklings. Poult Sci. 1959;38:497-507. https://doi.org/10.3382/ps.0380497

12. Wilson BJ. The performance of male ducklings given starter diets with different concentrations of energy and protein. Br Poult Sci. 1975;16:617-25. https://doi.org/10.1080/00071667508416237

13. Crowford RD. Nutritional genetics poultry breeding and genetics. Amsterdam: Elsevier; 1990. p. 847-76.

14. Cho HM, Wickramasuriya SS, Macelline SP, Hong JS, Lee B, Heo JM. Evaluation of crude protein levels in White Pekin duck diet for 21 days after hatching. J Anim Sci Technol. 2020;62:628-37. https://doi.org/10.5187/jast.2020.62.5.628

15. National Research Council. Nutrient requirements of poultry. 9th rev. ed. Washington, DC: The National Academies Press; 1994.

16. Robbins KR. A method, SAS program, and example for fitting the broken-line to growth data. Knoxville, TN: University of Tennessee Agricultural Experiment Station; 1986. Research Report 86-09.

17. Xie M, Zhao JN, Hou SS, Huang W. The apparent metabolizable energy requirement of White Pekin ducklings from hatch to 3 weeks of age. Anim Feed Sci Technol. 2010;157:95-8. https://doi.org/10.1016/j.anifeedsci.2010.01.011

18. Fan HP, Xie M, Wang WW, Hou SS, Huang W. Effects of dietary energy on growth performance and carcass quality of white growing Pekin ducks from two to six weeks of age. Poult Sci. 2008;87:1162-4. https://doi.org/10.3382/ps.2007-00460

19. Plavnik I, Wax E, Sklan D, Bartov I, Hurwitz S. The response of broiler chickens and turkey poults to dietary energy supplied either by fat or carbohydrates. Poult Sci. 1997;76:1000-5. https://doi.org/10.1093/ps/76.7.1000

20. Nahashon SN, Adefope N, Amenyenu A, Wright D. Effects of dietary metabolizable energy and crude protein concentrations on growth performance and carcass characteristics of French guinea broilers. Poult Sci. 2005;84:337-44. https://doi.org/10.1093/ps/84.2.337

21. Tang MY, Ma QG, Chen XD, Ji C. Effects of dietary metabolizable energy and lysine on carcass characteristics and meat quality in Arbor Acres broilers. Asian-Australas J Anim Sci. 2007;20:1865-73. https://doi.org/10.5713/ajas.2007.1865

22. Yuan L, Lin H, Jiang KJ, Jiao HC, Song ZG. Corticosterone administration and high-energy feed results in enhanced fat accumulation and insulin resistance in broiler chickens. Br Poult Sci. 2008;49:487-95. https://doi.org/10.1080/00071660802251731

23. Anders S, Mőser A. Consumer choice and health: the importance of health attributes for retail meat demand in Canada. Can J Agric Econ. 2010;58:249-71. https://doi.org/10.1111/j.1744-7976.2010.01183.x

24. Resurreccion AVA. Sensory aspects of consumer choices for meat and meat products. Meat Sci. 2004;66:11-20. https://doi.org/10.1016/S0309-1740(03)00021-4

25. Whittemore CT, Fawcett RH. Theoretical aspects of a flexible model to stimulate protein and lipid growth in pigs. Anim Sci. 1976;22:87-96. https://doi.org/10.1017/S0003356100035455

26. Lamberson WR, Firman JD. A comparison of quadratic versus segmented regression procedures for estimating nutrient requirements. Poult Sci. 2002;81:481-4. https://doi.org/10.1093/ps/81.4.481