

JAST (Journal of Animal Science and Technology) TITLE PAGE

ARTICLE INFORMATION	Fill in information in each box below
Article Type	Research article
Article Title (within 20 words without abbreviations)	Dietary effect of energy levels on growth performance and carcass characteristics of White Pekin duck over 21 days
Running Title (within 10 words)	The maximum dietary energy level on performance of White Pekin duck
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Competing interests	No potential conflicts 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 paper was financially supported by the research fund of National Institute of Animal Science (PJ01692006).
Acknowledgements	The authors greatly appreciate the financial and material support provided by National Institute of Animal Science.
Availability of data and material	Upon reasonable request, the datasets of this study can be made available from the corresponding author.
Authors' contributions Please specify the authors' role using this form.	Conceptualization: Hong JS, Samiru SW, Heo JM Data curation: Hong JS Formal analysis: Hong JS, Samiru SW Methodology: Samiru SW Software: Shemil PM Validation: Samiru SW, Heo JM Investigation: Hong JS, Yoo J, Hyun Min Cho, Shemil PM Writing - original draft: JS Hong Writing - review & editing: JS Hong, Yoo J, Hyun Min Cho, Samiru SW, Shemil PM, Heo JM

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)
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2 Running title: Dietary energy level on performance of White Pekin duck

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4 **Determination of the maximum dietary effect of energy levels on growth**
5 **performance and carcass characteristics of White Pekin duck**

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Abstract

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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 (1994) specification for meat-type ducks. Growth performance indices (i.e. average daily gain, average daily feed intake, feed conversion ratio) were measured weekly. Medium body weight 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 3000.00 kcal/kg to 3173.03 kcal/kg whereas the requirement by quadratic plateau method indicated from 3100.00 kcal/kg to 3306.26 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

41 previous research, the maximum requirement for the next diet formulation should be selected by
42 the purpose of the diet.

43 **Keywords:** abdominal fat, carcass traits, duck, energy level, growth performance

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Introduction

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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 2750 kcal/kg to 3050 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*).

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

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Materials and Methods

77 **Experimental design and environment management**

78 A total of 432 one-day-old male white Pekin ducklings with similar initial body weight
79 were randomly allotted to 24 cages consisting of 6 treatments with 6 replicates. The dietary
80 treatments consisted of a corn and soybean meal-based diet formulated with the nutrients to meet
81 or exceed the Nutrient Requirement of Poultry [15] specification for meat-type duck except for
82 AME level which started from 2,700 kcal/kg to 3,200 kcal/kg with a 100 kcal/kg gap. Diets were
83 provided on an ad-libitum basis using a plastic feeder and the birds had free access to fresh clean
84 drinking water via nipple drinkers throughout the experiment. Raised floor pens ($120 \times 180 \text{ cm}^2$)
85 were used to house the birds under the same environmental conditions. The temperature of the
86 cages was maintained at $32 \pm 2^\circ\text{C}$ during week one post-hatch, and then it was gradually lowered
87 leach $25 \pm 2^\circ\text{C}$ until the birds were 3 weeks old. Relative humidity was maintained at $70 \pm 5\%$ in
88 the first week, $65 \pm 5\%$ in the second week, and $60 \pm 5\%$ thereafter. Furthermore, a continuous
89 lighting regime of 25 lux was practiced during the experimental period.

90 **Growth performance**

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

95 **Post-mortem procedure and sample collection**

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

101 **Statistical analyses**

102 Data were analyzed using the one-way ANOVA technique, a completely randomized
103 design by using the SPSS software package (Version 24; IBM SPSS 2012, Chicago, IL, USA).
104 The pen was used as the experimental unit for all growth performance measurements. Selected
105 individual birds were used as the experimental unit for the carcass measurement. Mean differences
106 were considered significant at $p < 0.05$. Tukey's multiple comparison test was used to determine
107 the significant differences between experimental groups when the mean shows a significant
108 difference. Nutritional response models were analyzed with a broken-line model and quadratic
109 model conducted to estimate the maximum dietary energy level [16].

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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 (Table 2). 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

Figures 1 to 6 show linear and quadratic plateau analysis to estimate the maximum requirement level of dietary AME. Figure 1 shows the linear plateau day 21 BW level to be at 3000.00 kcal/kg and the quadratic plateau requirement was determined at 3100.00 kcal/kg. Figure 2 shows the requirement of ADG from day 14 to 21. The linear plateau level was at 3053.45 kcal/kg and the quadratic plateau requirement was estimated at 3115.92 kcal/kg. Figure 3 shows the requirement of ADG from day 1 to 21, the linear plateau requirement level was at 3167.04 kcal/kg and the quadratic plateau requirement was estimated to be 3299.00 kcal/kg. Figure 4 displays the requirement of ADFI from day 14 to 21 and the linear plateau requirement level was at 3000.00 kcal/kg whereas the quadratic plateau requirement was at 3306.26 kcal/kg. Figure 5 exhibits the

134 FCR requirement from day 1 to 7 and the linear plateau level shows 3173.03 kcal/kg and the
135 quadratic plateau estimate is at 3154.17 kcal/kg. Figure 6 shows the requirement of FCR from day
136 1 to 21 and the linear plateau level is shown at 3173.00 kcal/kg while the quadratic plateau
137 requirement was gauged at 3104.14 kcal/kg.

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Discussion

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140 The dietary AME level is a critical issue in the animal production field. This is because
141 the optimization of the nutrient requirement is a really important step to cut down on the production
142 cost while maximizing productivity. Following previously published data, feeding a higher dietary
143 AME level diet could improve growth performance parameters such as BW, ADG, ADFI, and
144 FCR [1-5]. In this study, the growth performance and carcass traits data obtained agree with
145 previous studies that showed that starter Pekin ducklings fed a lower energy diet recorded higher
146 feed intake and thus increased feed conversion [11, 12, 17, 18]. This could be because a lower
147 dietary AME diet makes animals consume more to reach the required energy level. The current
148 data also supports the theory that the effect of dietary energy level on the performance of growing
149 birds is dependent on the birds' capacity to alter feed intake to meet changing demands for calories
150 [19, 20]. As a result, birds fed a higher dietary AME diet showed improved feed efficiency [1-4].

151 Dietary AME levels could also influence the carcass traits. Previous research suggested
152 that dietary energy causes the deposition of excess abdominal fat or carcass fat in broilers [1, 4, 8,
153 21], and ducks fed a high dietary AME level diet can accumulate larger amounts of abdominal fat
154 [11, 18, 22]. The high abdominal fat accumulation trait could negatively affect the consumers'
155 choices [23, 24].

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

158 Looking at the concept of broken line analysis as suggested by Whittemore and Fawcett
159 [25] states that when the dietary nutrient is over the threshold, then the performance nearly keeps
160 staying on the most improved side. That overlapped point between the highest performance graph
161 and regression graph is called the broken point and can be regarded as the maximum dietary

162 requirement. Figures 1 to 6 present the requirement of linear and quadratic plateau analysis results.
163 The requirement of linear plateau shows from 3000.00 kcal/kg to 3173.03 kcal/kg whereas the
164 requirement of quadratic plateau ranges from 3100.00 kcal/kg to 3306.26 kcal/kg. Those gaps
165 between linear and quadratic plateau requirements came from the characteristic of the regression
166 graph. Some research [26] suggests that estimation by quadratic regressions can be overestimated
167 when the requirement was not centered in the experimental nutrient. Therefore, the linear plateau
168 requirement could be a more accurate maximum dietary AME level. Previous study suggested that
169 the dietary AME requirement level is nearly 2,755.75 kcal/kg [11], which is lower than the
170 estimated maximum AME level. The currently estimated requirement based on growth
171 performance is much higher than that of the previous experiment because of the improved genetic
172 performance of the modern White Pekin duck. Maximum dietary AME level should be selected
173 based on the purpose of the diet formulation and the balance of the growth performance and
174 abdominal fat accumulation.

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252 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 P -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
Vit-Min 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 ³ (kcal/kg)	3203.0	3103.2	3003.4	2903.6	2803.8	2704.0
CP ⁴ (%)	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

253 ¹Treatment number indicate dietary AME (kcal/kg)

254 ²Vitamin and mineral pre-mixture provided the following nutrients per kg of diet: vitamin A, 24,000
255 IU; vitamin D3, 6,000 IU; vitamin E, 30 IU; vitamin K, 4 mg; thiamine, 4 mg; riboflavin, 12 mg; pyridoxine,
256 4 mg; folacine, 2 mg; biotin, 0.03 mg; vitamin B8 0.06 mg; niacin, 90 mg; pantothenic acid, 30 mg; Fe, 80
257 mg (as FeSO₄ · H₂O); Zn, 80 mg (as ZnSO₄ · H₂O); Mn, 80 mg (as MnSO₄ · H₂O); Co, 0.5 mg (as CoSO₄
258 · H₂O); Cu, 10 mg (as CuSO₄ · H₂O); Se, 0.2 mg (as Na₂SeO₃); I, 0.9 mg (as Ca (IO₃) · 2H₂O).

259 ³ME, Metabolizable energy260 ⁴CP, Crude protein.

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

Period	Diets ¹						SEM ²	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	1387.29 ^c	1360.06 ^{bc}	1341.76 ^{abc}	1246.99 ^{abc}	1239.50 ^{ab}	1209.65 ^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

262 ^{a-c} Values in a row with different superscripts differ significantly

263 ¹Treatment number indicates dietary AME (kcal/kg)

264 ²Standard error of the mean.

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

Factor	Diets ¹						SEM ²	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 ³ (%)	8.36	8.02	8.20	8.12	9.40	8.02	0.520	0.120
L/EBW ⁴ (%)	17.32 ^b	16.90 ^{ab}	17.52 ^b	15.28 ^{ab}	15.16 ^{ab}	14.49 ^a	0.830	0.006

267 ^{a-c} Values in a row with different superscripts differ significantly (P < 0.05).

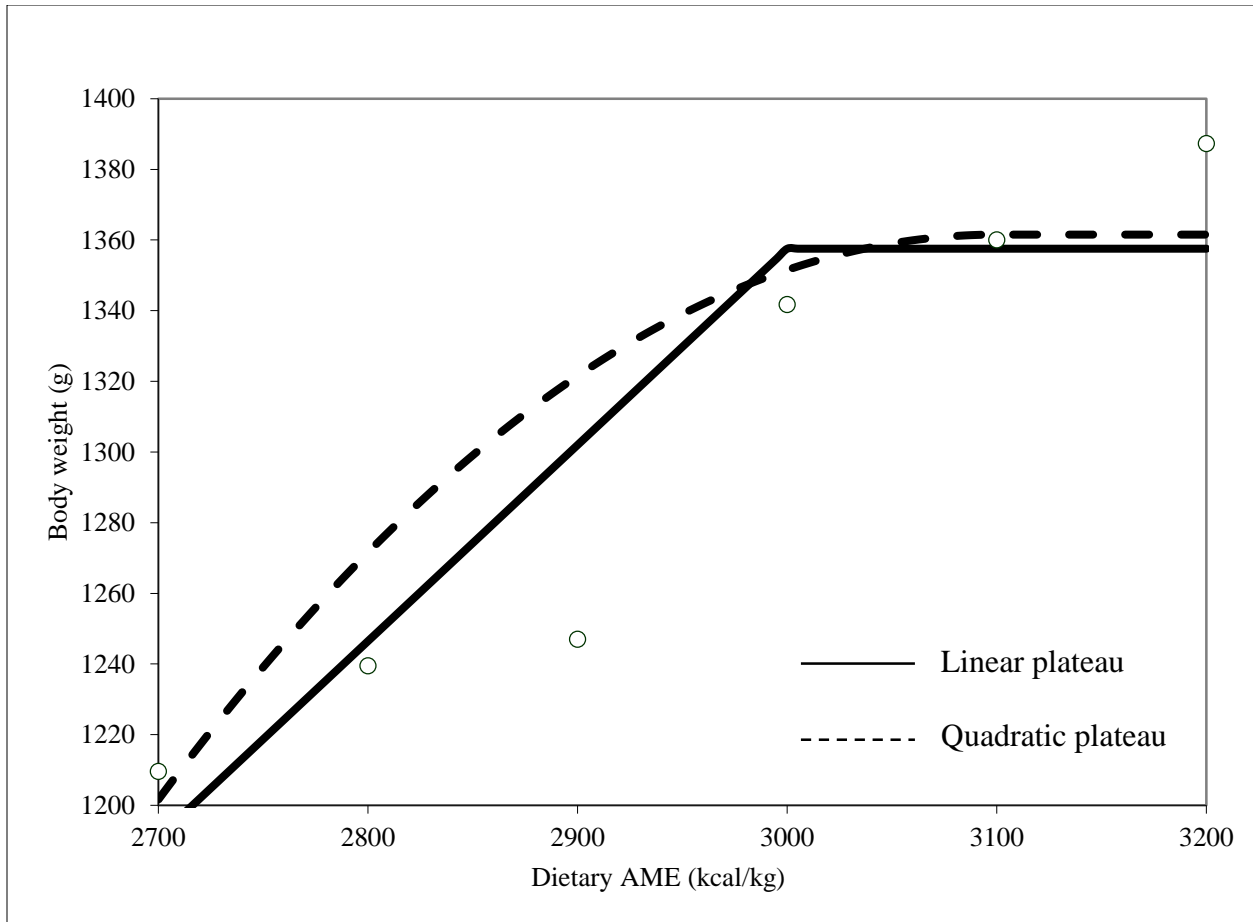
268 ¹Treatment number indicate dietary AME (kcal/kg)

269 ²Standard error of the mean.

270 ³Breast meat weight divided by empty body weight

271 ⁴Leg meat weight divided by empty body weight

ACCEPTED



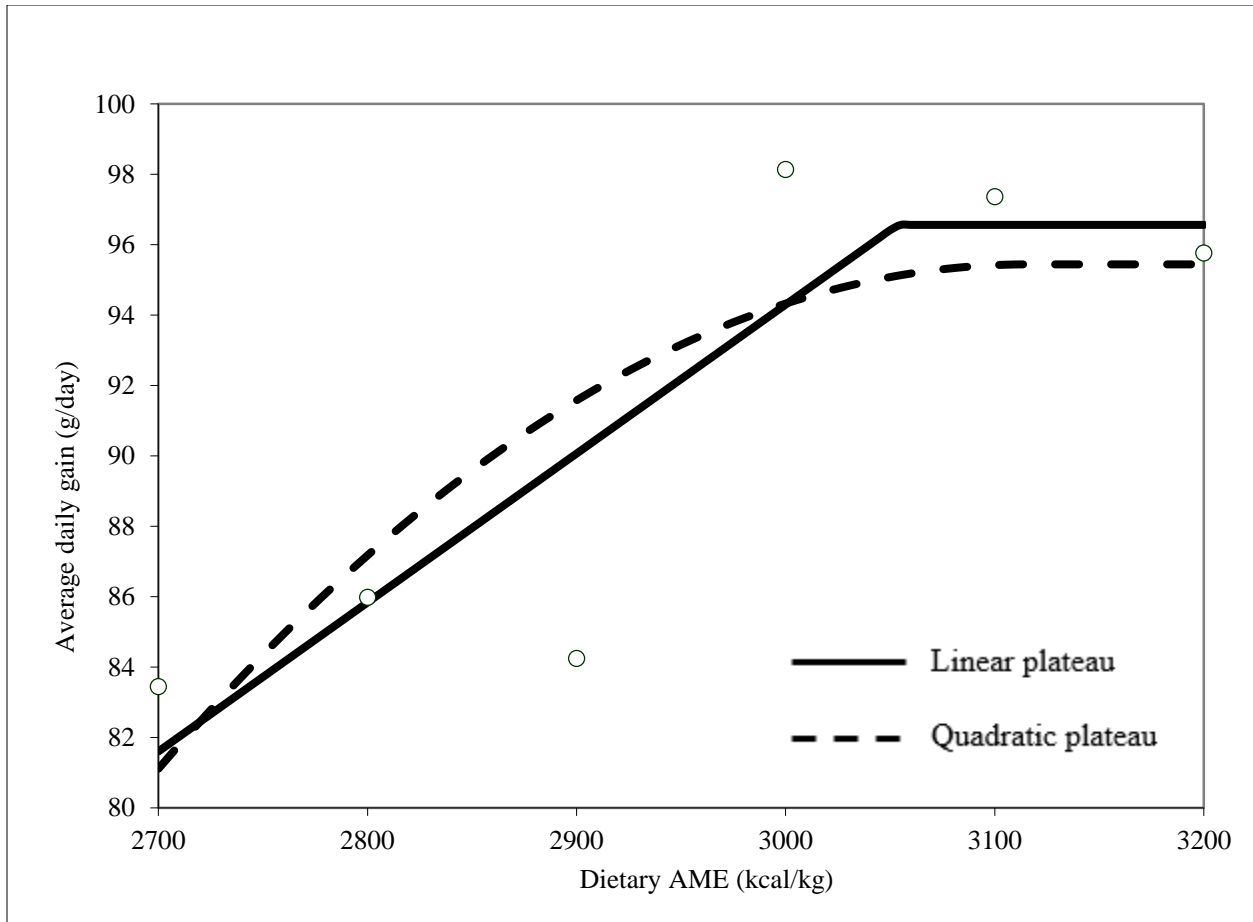
272

	Requirement (kcal/kg)	R ² (%)
Linear plateau	3000.00	83.435
Quadratic plateau	3100.00	73.079

273

Figure 1. Linear and quadratic plateau analysis of results of body weight on day 21¹

274

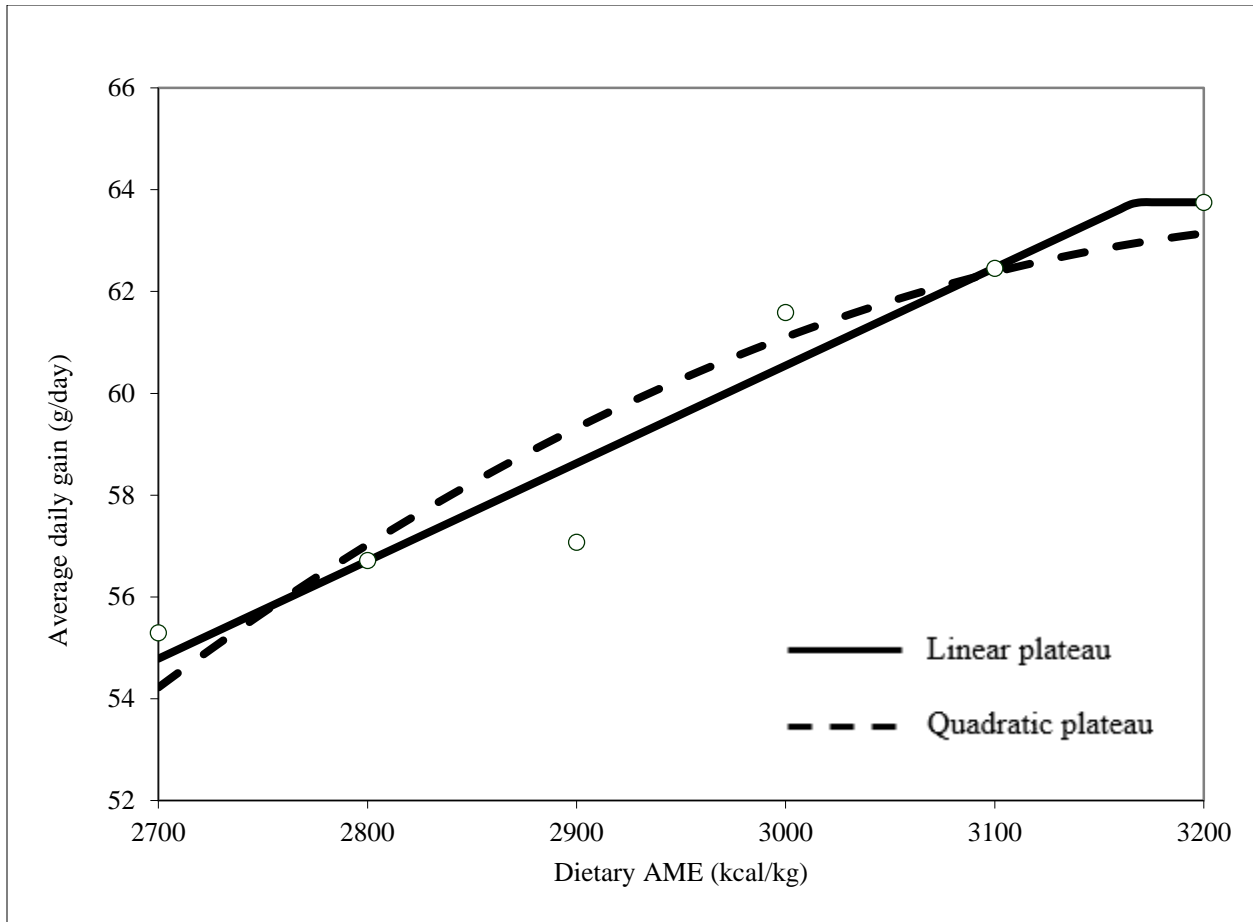


275

	Requirement (kcal/kg)	R ² (%)
Linear plateau	3053.45	77.972
Quadratic plateau	3115.92	67.333

276 Figure 2. Linear and quadratic plateau analysis of results of average daily gain from day 14 to day 21

277



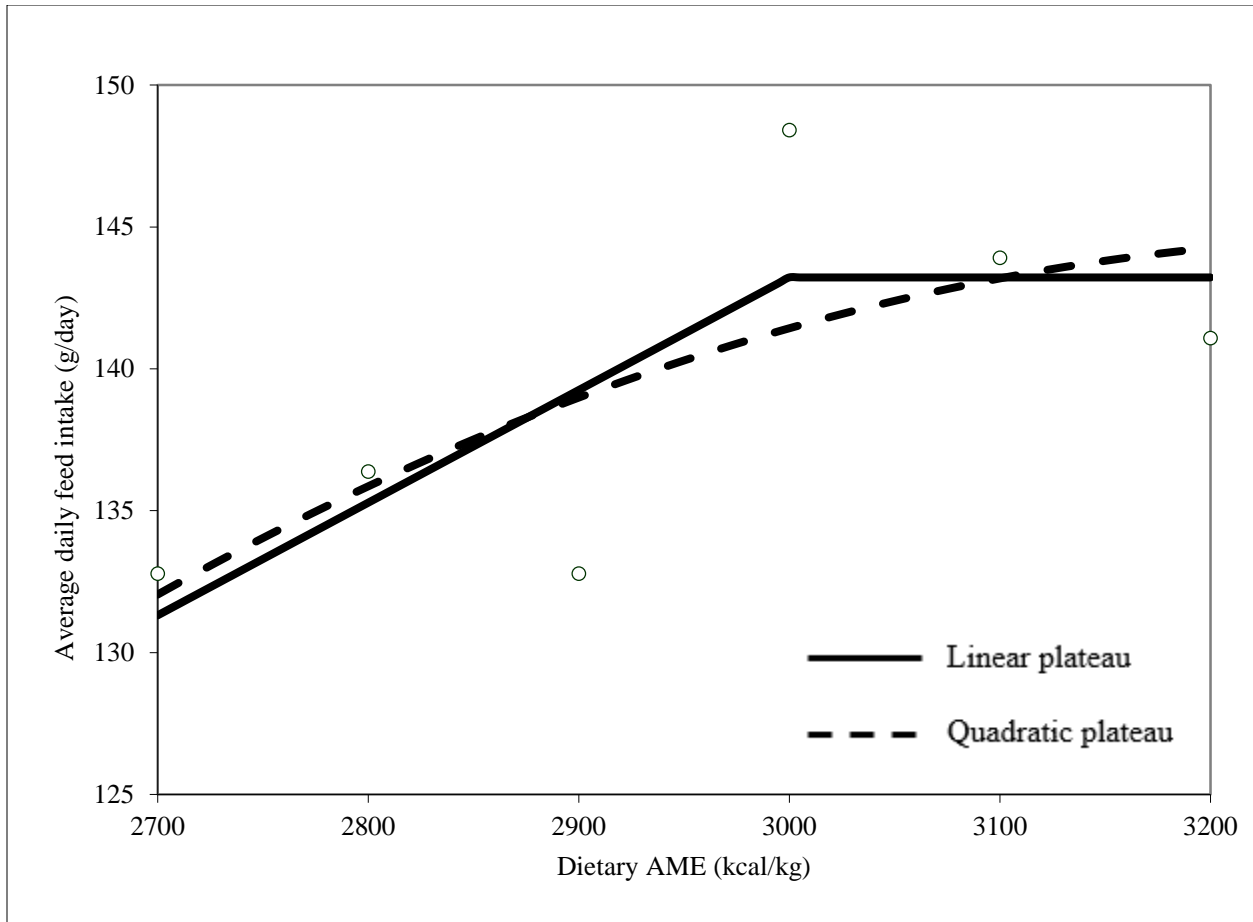
278

	Requirement (kcal/kg)	R ² (%)
Linear plateau	3167.04	93.991
Quadratic plateau	3299.72	88.944

279

Figure 3. Linear and quadratic plateau analysis of results of average daily gain from day 1 to day 21

280



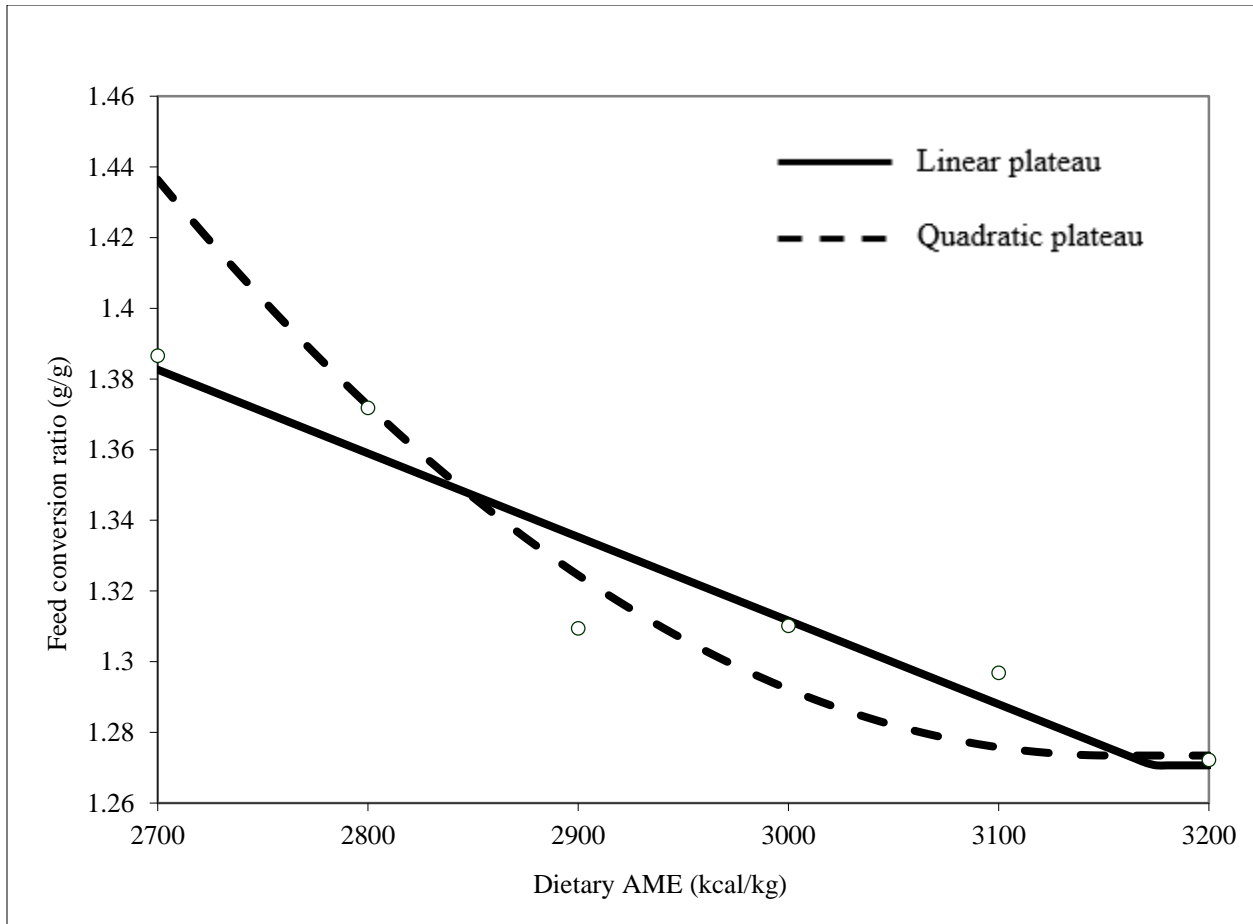
281

	Requirement (kcal/kg)	R ² (%)
Linear plateau	3000.00	61.591
Quadratic plateau	3306.26	50.911

282 Figure 4. Linear and quadratic plateau analysis of results of average daily feed intake from day 14 to day

283 21

284



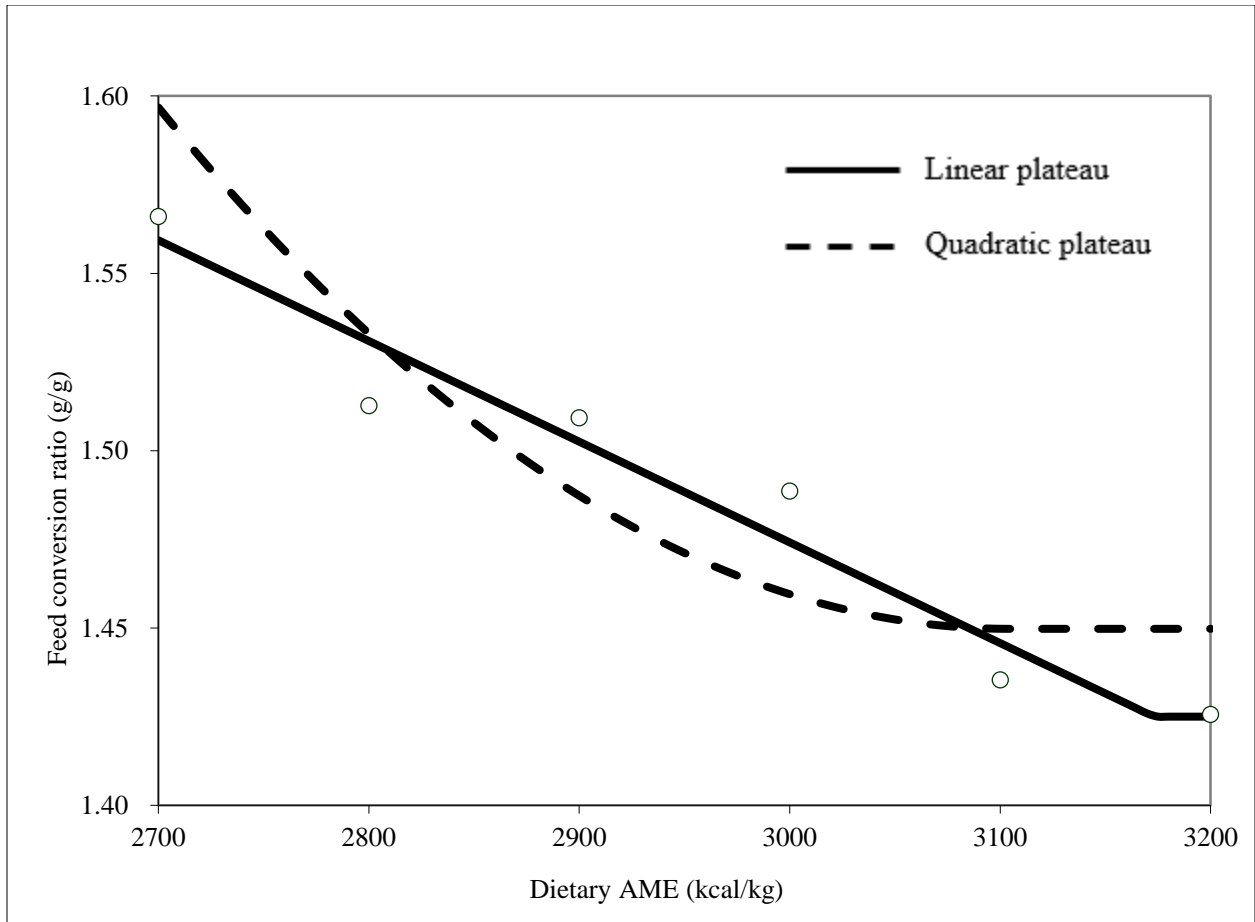
285

	Requirement (kcal/kg)	R ² (%)
Linear plateau	3173.03	90.705
Quadratic plateau	3154.17	65.383

286

Figure 5. Linear and quadratic plateau analysis of results of feed conversion ratio from day 1 to day 7

287



288

	Requirement (kcal/kg)	R ² (%)
Linear plateau	3173.00	94.630
Quadratic plateau	3104.14	74.797

289

Figure 6. Linear and quadratic plateau analysis of results of feed conversion ratio from day 1 to day 21

290