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นายประพจน์ มลิวัลย์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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ENERGY AND PROTEIN REQUIREMENTS OF KORAT CHICKENS FROM 0 TO 12 WEEKS OF AGE

Prapot Maliwan

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Animal Production Technology

Suranaree University of Technology

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ENERGY AND PROTEIN REQUIREMENTS OF KORAT CHICKENS FROM 0 TO 12 WEEKS OF AGE

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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งานวิจัยนี้มีวัตถุประสงค์ เพื่อศึกษาความต้องการพลังงานและโปรตีนของไก่โคราช ในช่วงอายุ 0-12 สัปดาห์ โดยแบ่งออกเป็น 3 การทดลอง

การทดลองที่ 1 เป็นการศึกษาความต้องการพลังงานของไก่โคราช ในช่วงอายุ 0-12 สัปดาห์ แบ่งออกเป็น 4 ระยะการทดลอง คือ ช่วงอายุ 0-3 3-6 6-9 และ 9-12 สัปดาห์ ในแต่ละระยะการทดลองกำหนดให้มีระดับพลังงานที่ใช้ประโยชน์ได้ในอาหารแตกต่างกัน 4 ระดับ คือ 2,750 2,900 3,150 และ 3,200 กิโลแคลอรีต่อกิโลกรัมอาหาร ผลการทดลองพบว่า ปริมาณอาหารที่กินของไก่ลดลง แต่ประสิทธิภาพการใช้อาหารดีขึ้น ($P < 0.05$) เมื่อระดับพลังงานในสูตรอาหารเพิ่มขึ้น ในทุกระยะการทดลอง ความต้องการพลังงานที่ใช้ประโยชน์ได้ของไก่โคราชที่เหมาะสมต่อประสิทธิภาพการใช้อาหาร ในช่วงอายุ 0-3 3-6 6-9 และ 9-12 สัปดาห์ โดยทำการประเมินด้วยวิธีการวิเคราะห์แบบ Broken-line regression คือ 2,978 3,151 3,200 และ 3,200 กิโลแคลอรีต่อกิโลกรัม ตามลำดับ

การทดลองที่ 2 เป็นการศึกษาความต้องการโปรตีนของไก่โคราช ในช่วงอายุ 0-12 สัปดาห์ แบ่งออกเป็น 4 ระยะการทดลอง คือ ช่วงอายุ 0-3 3-6 6-9 และ 9-12 สัปดาห์ ในแต่ละระยะการทดลองกำหนดให้มีระดับโปรตีนในอาหารแตกต่างกัน 5 ระดับ คือ 19 20 21 22 และ 23% (ระยะ 0-3 สัปดาห์); 18 19 20 21 และ 22% (ระยะ 3-6 สัปดาห์); 16 17 18 19 และ 20% (ระยะ 6-9 สัปดาห์); 15 16 17 18 และ 19% (ระยะ 9-12 สัปดาห์) อาหารทดลองทั้งหมดคำนวณให้มีระดับพลังงานที่ใช้ประโยชน์ได้ที่ระดับเดียวกัน คือ 2,978 3,151 3,200 และ 3,200 กิโลแคลอรีต่อกิโลกรัมอาหาร ในช่วงอายุ 0-3 3-6 6-9 และ 9-12 สัปดาห์ ตามลำดับ ผลการทดลองพบว่า ในทุกช่วงอายุ ไก่มีน้ำหนักตัว น้ำหนักตัวเพิ่ม อัตราการเจริญเติบโตเฉลี่ยต่อวัน และปริมาณโปรตีนที่กินได้เพิ่มขึ้น เมื่อระดับโปรตีนในสูตรอาหารเพิ่มขึ้น ($P < 0.05$) อย่างไรก็ตาม การเพิ่มขึ้นของระดับโปรตีนในอาหารช่วยเพิ่มประสิทธิภาพการใช้อาหาร และประสิทธิภาพการใช้พลังงานของไก่ในช่วงอายุ 6-9 และ 9-12 สัปดาห์ ($P < 0.05$) ในขณะที่ประสิทธิภาพการใช้โปรตีนลดลง ($P < 0.05$) เมื่อระดับโปรตีนในอาหารเพิ่มขึ้นในช่วงอายุ 0-3 และ 9-12 สัปดาห์ เมื่อทำการประเมินความต้องการโปรตีนของไก่โคราช ด้วยวิธีการวิเคราะห์แบบ Broken-line regression พบว่า ความต้องการโปรตีนของไก่โคราชที่เหมาะสมต่อน้ำหนักตัวเพิ่มในช่วงอายุ 0-3 3-6 6-9 และ 9-12 สัปดาห์ คือ 21.26 20.45 18.00 และ 17.94% ตามลำดับ ขณะที่ความต้องการโปรตีนของไก่โคราช

ที่เหมาะสมต่อประสิทธิภาพการใช้อาหารในช่วงอายุ 6-9 และ 9-12 สัปดาห์ คือ 18.04 และ 18.03% ตามลำดับ

การทดลองที่ 3 เป็นการประเมินการย่อยได้และใช้ประโยชน์ได้ของโภชนะ และค่าพลังงานที่ใช้ประโยชน์ได้ของอาหารสำหรับไก่โคราช โดยวิธีการเก็บมูลทั้งหมด ผลการทดลองพบว่า การย่อยได้ของวัตถุแห้งโดยประมาณ คือ 66.87 70.32 71.38 และ 71.40% และเปอร์เซ็นต์การเก็บกักไนโตรเจน คือ 59.00 57.16 53.20 และ 52.55% ในไก่โคราชช่วงอายุ 0-3 3-6 6-9 และ 9-12 สัปดาห์ ตามลำดับ ขณะที่ค่าพลังงานที่ใช้ประโยชน์ได้จากการประเมินมีค่าใกล้เคียงกับค่าพลังงานที่ใช้ประโยชน์ได้จากการคำนวณในสูตรอาหารในทุกช่วงอายุ

สาขาวิชาเทคโนโลยีการผลิตสัตว์ ลายมือชื่อนักศึกษา____________________

ปีการศึกษา 2559 ลายมือชื่ออาจารย์ที่ปรึกษา____________________

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม____________________

PRAPOT MALIWAN : ENERGY AND PROTEIN REQUIREMENTS OF KORAT CHICKENS FROM 0 TO 12 WEEKS OF AGE. THESIS ADVISOR : ASST. PROF. SUTISA KHEMPAKA, Ph.D., 132 PP.

ENERGY/PROTEIN/REQUIREMENT/KORAT CHICKEN

This research aimed to evaluate the energy and protein requirements of Korat chickens from 0 to 12 wk of age, which were divided into 3 experiments.

Experiment I was conducted to evaluate the metabolizable energy (ME) requirement of Korat chickens from 0 to 12 wk of age, which were divided into four experimental periods : 0-3, 3-6, 6-9 and 9-12 wk of age. In each experimental period, four dietary ME levels were composed of 2,750, 2,900, 3,050 and 3,200 kcal of ME/kg diet. The results showed that the feed intake of chickens was decreased, but the feed conversion ratio (FCR) was improved ($P < 0.05$) with increasing dietary energy levels in all experimental periods. The ME requirement of Korat chickens for optimal FCR in the periods 0-3, 3-6, 6-9 and 9-12 wk of age estimated by broken-line regression analysis were 2,978, 3,151, 3,200 and 3,200 kcal/kg, respectively.

Experiment II was conducted to evaluate the protein requirement of Korat chickens from 0 to 12 wk of age, which were divided into four experimental periods : 0-3, 3-6, 6-9 and 9-12 wk of age. In each experimental period, five dietary protein levels were composed of 19, 20, 21, 22 and 23% (0-3 wk of age); 18, 19, 20, 21 and 22% (3-6 wk of age); 16, 17, 18, 19 and 20% (6-9 wk of age) and 15, 16, 17, 18 and 19% (9-12 wk of age). All experimental diets were formulated to contain the same ME content as 2,978, 3,151, 3,200 and 3,200 kcal/kg diet in the experimental periods 0-3, 3-6, 6-9 and 9-12 wk of age, respectively. The results showed that all experimental periods, body weight, body weight gain (BWG), average daily gain and protein intake were increased when increasing dietary protein levels ($P < 0.05$). However, increasing dietary protein improved FCR and energy efficiency ratio of chickens in the periods 6-9 and 9-12 wk of age ($P < 0.05$). Whereas, the protein efficiency ratio was decreased ($P < 0.05$) with increasing dietary protein levels in the periods 0-3 and 9-12 wk of age. According to the broken-line regression analysis, the protein requirements of Korat chickens for optimal BWG in the periods 0-3, 3-6, 6-9 and 9-12 wk of age was 21.26, 20.45, 18.00 and 17.94%, respectively, whereas, the protein requirements of Korat chickens for optimal FCR in the periods 6-9 and 9-12 wk of age were 18.04 and 18.03%, respectively.

Experiment III was conducted to determine the nutrient digestibility and utilization and apparent metabolizable energy (AME) of diets for Korat chickens by using the total excreta collection method. The results showed that the apparent digestibility of dry matter were 66.87, 70.32, 71.38 and 71.40% and the percentages of N retention were 59.00, 57.16, 53.20 and 52.55% in the Korat chickens aged 0-3, 3-6, 6-9 and 9-12 wk, respectively, while the determined AME values were similar to the calculated AME in all periods of age.

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Academic Year 2016 Advisor's Signature Sutisa Khempaka

Co-advisor's Signature W. Molee

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LIST OF ABBREVIATIONS AND SYMBOLS

ADE	=	Apparent digestible energy
ADFI	=	Average daily feed intake
ADG	=	Average daily gain
AME, ME	=	Apparent metabolizable energy, metabolizable energy
AMEn	=	Nitrogen corrected apparent metabolizable energy
ANOVA	=	Analysis of variance
AOAC	=	Association of official analytical chemists
ASY	=	A saturation kinetics models or asymptotic models
B_f	=	Carcass nitrogen of animal fed the test protein diet
BLL, LP	=	Broken-line linear or linear-plateau
BLQ, CLP	=	Broken-line quadratic or curvilinear-plateau
B_k	=	Carcass nitrogen of animal fed a nitrogen-free diet
BUN	=	Blood urea nitrogen
BV	=	Biological value
BW	=	Body weight
BWG	=	Body weight gain
cal	=	Calorie
CF	=	Crude fiber
CP	=	Crude protein
CRD	=	Completely randomized design

LIST OF ABBREVIATIONS AND SYMBOLS (Continued)

CV	=	Coefficient of variation
°C	=	Degree celsius
d	=	Day
DE	=	Digestible energy
DM	=	Dry matter
DMRT	=	Duncan's new multiple range test
EAA	=	Essential amino acids
EDTA	=	Ethylene diamine tetraacetic acid
EE	=	Ether extract
EER	=	Energy efficiency ratio
EUN	=	Endogenous urinary nitrogen
FCR	=	Feed conversion ratio
FE	=	Fecal energy
F_fE	=	Fecal energy of feed
FI	=	Feed intake
F_mE	=	Metabolic fecal energy
g	=	Gram
GE	=	Gross energy
GE_e	=	Gross energy of excreta
GE_f	=	Gross energy of feed
GPD, GE	=	Gaseous products of digestion, gaseous energy
h	=	Hour

LIST OF ABBREVIATIONS AND SYMBOLS (Continued)

H_cE	=	Heat of thermal regulation
H_dE	=	Heat of digestion and absorption
H_eE	=	Basal metabolism
H_fE	=	Heat of fermentation
HI	=	Heat increment
H_jE	=	Heat of activity
H_pE	=	Heat of product formation
H_wE	=	Heat of waste formation and excretion
IE	=	Ingested energy
I_f	=	Nitrogen intake on the test protein diet
I_k	=	Nitrogen intake of animal fed a nitrogen-free diet
IU	=	International units
J	=	Joule
K	=	A constant
kcal	=	Kilocalorie
kg	=	Kilogram
MFN	=	Metabolic (endogenous) faecal nitrogen
min	=	Minute
N	=	Nitrogen
NB	=	Nitrogen balance
N_e	=	Nitrogen of excreta
NE	=	Net energy

LIST OF ABBREVIATIONS AND SYMBOLS (Continued)

NEAA	=	Nonessential amino acids
NE_m	=	Net energy for maintenance
NE_p	=	Net energy for production
NFE	=	Nitrogen free extract
NPG	=	Group fed the nitrogen-free diet
NPR	=	Net protein retention
NPV	=	Net protein value
NR	=	Nitrogen retention
NRC	=	National Research Council
P	=	Probability
PER	=	Protein efficiency ratio
PRE	=	Protein retention efficiency
QP	=	Quadratic polynomial
RMSE	=	Root mean square error
R^2	=	Coefficient of determination statistics, multiple
s	=	Second
SAS	=	Statistical analysis system
SEM	=	Standard error of the mean
SSE	=	Sum of squared residuals or sum of squared error
SST	=	Sum of squared total
TIC	=	Thai indigenous chickens
TME	=	True metabolizable energy

LIST OF ABBREVIATIONS AND SYMBOLS (Continued)

TME_n	=	Nitrogen corrected true metabolizable energy
TPG	=	Group fed the test protein diet
UE	=	Urinary energy
U_eE	=	Endogenous urinary energy
U_fE	=	Urinary energy of feed
vs.	=	Versus
wk	=	Week
%	=	Percentage

CHAPTER I

INTRODUCTION

In Southeast Asian countries, including China, Taiwan and Korea, the demand for indigenous chickens is increasing rapidly because consumers' preference for meat is changing to higher quality products. At present, the market share of indigenous chickens is constantly increasing, especially in China, which represents almost 50% of meat type chickens. Indigenous chicken meat is more tasty and healthy than broiler meat. Consequently, consumption of indigenous chicken meat has increased in spite of their relatively high prices. However, they have not been produced in sufficient numbers to meet consumer demand (Wattanachant et al., 2005; Chen et al., 2008; Choprakarn and Wongpichet, 2008; Wattanachant, 2008; Cheng et al., 2008; Choe et al., 2010). In general, the rearing period of indigenous chicken is usually longer (16-20 wk) compared to that of the broiler. This is the consequence of low production volume, size and irregular quality, resulting in high production costs. Therefore, the development of indigenous chickens is unlikely to establish a reliable product or, consequently, provide an adequate source of income for farmers. Thai indigenous crossbred 50% meat chicken strains have been established in order to solve the problem of an insufficient supply of indigenous chickens and they are now widely distributed throughout Thailand.

The Korat chicken is one of the Thai indigenous crossbred (50%) chicken strains derived from breeder lines through a cross breeding program, which is crossed between Thai indigenous chickens (Leung Hang Khoa male) and Suranaree University of Technology (SUT) synthetic breeder (female). This chicken strain has a better growth performance than indigenous chickens while meat qualities and consumer perceptions are similar to those of indigenous chickens. Korat chicken meat has a unique taste, texture, less fat and higher collagen. It is more delicious, so it attracts domestic consumers to a greater extent than broiler meat (Pongjanla et al., 2014; Sangsawad et al., 2016; Maliwan et al., 2017). This makes the costs of Korat chicken meat higher than broiler meat by about 1.5-2 times. However, as the genetics change, the nutrient requirements also need to be revised. Moreover, there is a general consensus that the determination of nutrient requirements of different types of poultry is necessary to efficiently use their genetic potential for specific production goals (Pym, 1990; NRC, 1994).

Feed represents approximately 60-70% of the total cost of production, especially dietary energy and protein, which is an expensive part of poultry diets. Energy and protein are the main macronutrients and play important roles in poultry diets as far as production cost is concerned. Normally, birds require energy for maintenance and production, therefore, to produce poultry meat, growing birds must consume enough feed to provide additional energy for body tissue synthesis and for the efficient functioning of the body (Latshaw and Moritz, 2009). Protein is an essential constituent of all tissues of the animal body and has a major effect on the growth performance of the bird (Kamran et al., 2004). Previous research studies reported that the metabolizable energy (ME) and protein requirements of various indigenous crossbred chickens in Thailand were about 2,600-3,200 kcal of ME/kg and 15-21% of crude protein (CP) during 0-16 wk of age (Vorachantra and Tancho, 1996;

Chomchai et al., 1998a, b; Tangtaweewipat et al., 2000; Pingmuang et al., 2001; Tananchai et al., 2001; Polsiri, 2001; Chomchai et al., 2003; Nguyen and Bunchasak, 2005; Nguyen et al., 2010). So far, Thai farmers have been using commercial broiler or layer diets to feed crossbred chickens since these feeds are available and easy to purchase. However, the nutritional content of these feeds may not be appropriate for other birds and may also cause pollution to the environment. Because of an excess or imbalance of nutrients, these imprecise nutrients can increase feed costs. In order to solve such problems, feeding Korat chickens with a suitable profile of nutrients to satisfy their requirements would help to improve nutrient utilization and consequently also reduce feed costs. However, information on the nutrient requirements for Korat chickens is lacking, particularly with respect to ME and protein. Therefore, the main purpose of this study was to evaluate the ME and protein requirements of Korat chickens during 0-12 wk of age.

1.1 Research hypothesis

The growth rate of Korat chicken is between that of the broiler and laying hen. Therefore, the metabolizable energy and protein requirements of Korat chicken may be lower than the nutrient requirements of broiler as recommended by NRC (1994).

1.2 Research objectives

1.2.1 To investigate the ME requirement of Korat chickens from 0 to 12 wk of age (0-3, 3-6, 6-9 and 9-12 wk of age).

1.2.2 To investigate the protein requirement of Korat chickens from 0 to 12 wk of age (0-3, 3-6, 6-9 and 9-12 wk of age).

1.3 Scope of the study

This study aimed to investigate the ME and protein requirements of Korat chickens on production efficiency from 0 to 12 wk of age, which was divided into 4 experimental periods or phases : 0-3, 3-6, 6-9 and 9-12 wk of age. The response of Korat chickens to various levels of energy and protein were measured for feed intake (FI), body weight (BW), BW gain, average daily gain (ADG), feed conversion ratio (FCR : feed/gain), feed cost per kg of BW gain, protein intake, protein efficiency ratio (PER), ME intake, energy efficiency ratio (EER) and blood urea nitrogen (BUN).

1.4 Expected results

1.4.1 To provide a regional knowledge base for ME and protein requirements of Korat chickens from 0 to 12 wk of age (0-3, 3-6, 6-9 and 9-12 wk of age).

1.4.2 To assist nutritionists apply this knowledge into a feed formulation tool for other Thai indigenous crossbred chicken strains.

1.4.3 This knowledge will be a valuable tool for commercial farming and will enable it to use a suitable feed formulation.

1.4.4 Further research can use this knowledge base to create additional studies, such as studies on amino acids or other nutrient requirements and feeding trials in Korat chickens.

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CHAPTER II

LITERATURE REVIEW

Thai indigenous chickens (TIC; *Gallus domesticus*) in Thailand have been part of the farmers' way of life for centuries. Throughout this time, TIC production systems have been sustainable and have given rise to few problems. These chickens are from parent stocks consisting of one cockerel and 3-5 hens per household. Flock size varies through the year, as it depends on the hatching rate, the availability of natural feed, the effects of endemic diseases, and the time available for farmers to take care of their birds. Periods of seasonal change are critical times of high mortality; about 30-70% of birds in a flock die annually. Thai indigenous chickens are raised in rural households under minimum feed and management, consequently their growth rate and feed efficiency are very poor. Therefore, production of TIC is very low compared with the commercial broiler. However, the production of TIC can be improved if they are raised by the conventionally confined system (Choprakarn and Wongpichet, 2008; Pttaraksa et al., 2012).

At present, the demand for TIC meat is always higher than supply, because of its tasty and healthy meat. As nutritious meat contains low fat, low cholesterol, low calorie, high protein and high collagen, this preference for TIC meat has resulted in the rapidly growing popularity of TIC. There are major differences in the market share of various types of chicken meat in Asian countries in spite of their relatively high prices. In Thailand, consumption of TIC meat took almost 20-25% of total chicken production in a recent year. Thus the market price of these chickens is routinely 2-3 times that of broilers. Moreover, other good characteristics of TIC, including resistance to some diseases, tolerance to heat stress, and good maternal ability, are heritable and need to be conserved (Choprakarn and Wongpichet, 2008; Wattanachant et al., 2004; Wattanachant, 2008; Jutarassitha et al., 2008; Pttaraksa et al., 2012; Cheng et al., 2008). However, factors affecting its quality should be reviewed to gain knowledge for developing or promoting this chicken meat in the future. Different breeds or genotypes of the indigenous chicken can cause a difference in the color of the meat. Rearing systems, such as intensive and extensive farming, result in differences in meat texture. The indigenous chicken reared under the intensive system has more tender meat and is yellowish in skin color. In general, the most suitable age of TIC for consumption or further processing products is recommended to be 16-18 wk of age, which is a longer rearing period than that for broilers, to ensure economical live weight and high meat quality (Wattanachant, 2008).

Currently, a new product derived from a crossbreed sired by TIC with an exotic breed is being produced commercially in standard farms to supply high-end niche markets. This meat-type of chicken grows faster than TIC and reaches the marketable weight of 1.3-1.5 kg within a shorter time of 13-15 wk. It has the same meat quality as TIC, in terms of flavor, texture and nutritional value (Tananchai, 2002; Choprakarn and Wongpichet, 2008). The Korat chicken therefore is one of the Thai indigenous crossbred (50%) chickens which, owing to its fast growth rate can be sent out to market within 10-12 wk, while its meat quality is similar to that of indigenous chickens (Likitdecharote et al., 2012; Molee et al., 2015; Maliwan et al., 2017). Korat chickens are generally well known for their excellent flavor, unique taste, chewier texture (particularly after cooking) and they contain less fat and higher quantities of collagen, so they are regarded as a delicacy and they are popular among consumers (Pongjanla et al., 2014; Sangsawad et al., 2016; Maliwan et al., 2017). As a result, the selling price of the meat is 1.5-2 times higher than the meat from commercial broilers in Thailand, because their meat is tastier and healthier than that of broiler meat (Pongjanla et al., 2014). This shows the importance of consumer preference as the major underlying cause for differences in market shares in Thailand and other countries in Asia compared to that in the West where nearly all of the consumption is of broilers (Cheng et al., 2008).

2.1 Thai indigenous crossbred (50%) chickens or Korat chickens

The Korat chicken is a new crossbred meat chicken derived from the development of breeder lines to enhance its efficient production and is conducted under the collaboration of Suranaree University of Technology (SUT), Thailand Research Fund (TRF), Department of Livestock Development (DLD) and Lat Bua Khao Farmers' Group. The main purpose of this project is to promote Korat chickens as a business opportunity for small and micro community enterprises, so farmers will eventually be able to secure a sustainable livelihood. At present, Korat chickens offer a high growth rate and the carcass and meat qualities are similar to those of indigenous chickens, but the future development in the genetic line of this bird needs to be conducted concurrently with other factors, for example, the technology related to farming, proper management and development of knowledge resources for production on a commercial scale (Likitdecharote et al., 2012; Molee et al., 2015).

Raising chickens to make a profit requires a combination of several factors, such as management, feed quality, prevention and control of disease, in order to obtain a healthy bird and to ensure its generation has a beneficial impact on both its growth performance and carcass quality. Generally, feed is an important factor in production costs. Therefore, feed formulation based on accurate requirements of each chicken strain should enhance nutrient digestibility and retention.

The Korat chicken reaches a market weight at 10 wk, with a body weight (BW) of approximately 1.36 kg and it has a growth rate which exceeds that of other crossbreds which reach the same market weight at 12 wk or more. The production costs of Korat chickens, when tested at either the university farm or a farmer's farm, reached around 54.07 baht per 1 kg for BW gain. The cost incurred for a portion of feed is about 61.39% (Likitdecharote et al., 2012). Therefore, if farmers can use an alternative feedstuff which is available within local areas, it will help them to reduce feed costs. To reach this target, a knowledge base relevant to basic nutrient needs, particularly the energy and protein requirements, is essential for studies, so that this information can be applied and modified according to the type of feedstuffs available locally. Growth performance and cost production of Korat chickens are presented in Tables 2.1, 2.2, 2.3 and 2.4, respectively.

Table 2.1 Growth performance of Korat chickens, indigenous × commercial layers and indigenous chickens (Leung Hang Khoa)[1].

Items	Korat chickens	Indigenous × Commercial layers	Indigenous chickens (Leung Hang Khoa)
Initial body weight, g	44.88 ± 3.67[2]	39.93 ± 0.45	29.87 ± 0.14
Period 0-4 wk of age			
Body weight, g	400.11 ± 58.97	331.02 ± 2.28	245.02 ± 3.24
Average daily gain, g/d	12.69 ± 2.11	10.40 ± 0.08	7.68
Feed conversion ratio	1.66	1.82 ± 0.01	2.17 ± 0.05
Period 0-6 wk of age			
Body weight, g	696.96 ± 104.15	581.45 ± 6.79	458.53 ± 5.98
Average daily gain, g/d	15.53 ± 2.48	12.90 ± 0.16	10.20
Feed conversion ratio	1.88	2.15 ± 0.03	2.05 ± 0.05
Period 0-8 wk of age			
Body weight, g	1,045.57 ± 175.41	883.01 ± 12.99	652.08 ± 9.18
Average daily gain, g/d	17.87 ± 3.58	15.06 ± 0.23	11.11
Feed conversion ratio	2.04	2.31 ± 0.05	2.38 ± 0.07
Period 0-9 wk of age			
Body weight, g	1,240.61 ± 206.77	959.59 ± 11.54	-
Average daily gain, g/d	18.98 ± 3.28	-	-
Feed conversion ratio	2.13	2.66 ± 0.07	-
Period 0-10 wk of age			
Body weight, g	1,404.93 ± 242.15	1,092.93 ± 17.00	863.89 ± 12.62
Average daily gain, g/d	19.43 ± 3.46	15.40 ± 0.24	11.94
Feed conversion ratio	2.31	2.79 ± 0.05	3.95 ± 0.12

[1]The experiment was studied at SUT's poultry farm.

[2]Mean ± standard deviation.

Source : Adapted from Likitdecharote et al. (2012).

Table 2.2 Growth performance of Korat chickens at 1.3 kg[1].

Items	Korat chickens
Period of age, d	70
Body weight 1-d-old, g/bird	44.88
Body weight 70-d-old, g/bird	1,317.75
Average daily gain, g/bird/d	19.43
Feed intake, g/bird	3,037.00
Feed intake, g/bird/d	43.39
Feed conversion ratio	2.31

[1]The experiment was studied at SUT's poultry farm.

Source : Adapted from Likitdecharote et al. (2012).

Table 2.3 Cost production of Korat chickens at 1.3 kg of body weight[1].

Items	Expense (Baht)
1. Chick at 1-d-old	16.00
2. Feed cost	45.14
3. Vaccine	1.10
4. Housing depreciation	9.48
5. Labor	1.40
6. Utility and other	0.41
Total costs	**73.53**
Market weight, kg	1.36
Cost production of Korat chickens/1 kg of body weight gain	**54.07**

[1]The experiment was studied at SUT's poultry farm.

Source : Adapted from Likitdecharote et al. (2012).

Table 2.4 Growth performance and feed cost of Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age[1].

Items	Periods (wk of age)			
	0-3	3-6	6-9	9-12
Initial body weight, g/bird	43.15	238.37	667.67	1,144.87
Final body weight, g/bird	238.37	667.67	1,144.87	1,612.94
Body weight gain, g/bird	195.22	429.30	477.20	468.07
Average daily gain, g/bird/d	9.30	20.44	22.72	22.29
Feed intake, g/bird	387.68	870.42	1,347.74	1,605.58
Feed intake, g/bird/d	18.46	41.45	64.18	76.46
Feed conversion ratio	1.99	2.03	2.82	3.43
Feed cost/body weight gain, Baht/kg	35.72	35.69	46.91	50.12

[1]All birds were studied at SUT's poultry farm during March 2013 to June 2013. All chickens were fed a commercial broiler and laying hen diets (CPF Public Company Ltd., Nakhon Ratchasima, Thailand), with 21% CP for 0-3 wk of age, with 19% CP for 3-6 wk of age, with 17% CP diet during 6-9 wk of age and then a 15% CP diet during 9-12 wk of age.

2.2 Nutrient requirements of Thai indigenous crossbred (50%) chickens

In Thailand, various varieties of Thai indigenous crossbred chickens are established. However, information on the nutrient requirements of these chickens is limited, especially essential amino acids. Many attempts have been made to study nutrient requirements, unfortunately, the evaluations were limited only to energy and protein, but did not study amino acids in depth. The energy and protein requirements of various chicken strains is presented in Table 2.5. It is well known that nutrient requirements influence breed, stage of age and growth rate. It is also known that the energy and protein requirements of various indigenous crossbred chickens in Thailand are lower than those of commercial broilers.

Table 2.5 Energy and protein requirements of broilers, Thai indigenous and Thai indigenous crossbred chickens.

Reference	Chicken type	Age (wk)	Energy and protein requirements
NRC (1994)	Broilers	0-3	3,200 kcal ME/kg, 23% CP
		3-6	3,200 kcal ME/kg, 20% CP
		6-8	3,200 kcal ME/kg, 18% CP
Leeson and Summers (2005)	Broilers	0-18 d	3,050 kcal ME/kg, 22% CP (starter)
		19-30 d	3,100 kcal ME/kg, 20% CP (grower)
		31-41d	3,150 kcal ME/kg, 18% CP (finisher)
		42 d + Withdrawal	3,200 kcal ME/kg, 16% CP
Daghir (2008)	Broilers	0-3	3,000 kcal ME/kg, 22% CP (starter)
		3-6	3,050 kcal ME/kg, 20% CP (grower)
		6-market	3,100 kcal ME/kg, 18% CP (finisher)
Arbor Acres (2009)	Arbor Acres	0-10 d	3,025 kcal ME/kg, 22-25% CP
		11-24 d	3,150 kcal ME/kg, 21-23% CP
		25-42 d	3,200 kcal ME/kg, 19-20% CP
		43 d-market weight	3,225 kcal ME/kg, 17-21% CP
Vorachantra and Tancho (1996)	Thai indigenous crossbred (NSRB)	0-6	3,000 kcal ME/kg, 20% CP
		6-12	3,000 kcal ME/kg, 18% CP
	(NSR) Suvan VI Breed	12-16	3,000 kcal ME/kg, 16% CP
Chomchai et al. (1998a)	Thai indigenous crossbred (NSRB)	0-14	2,600-3,000 kcal ME/kg 17.4-19.8% CP
Chomchai et al. (1998b)	Thai indigenous crossbred (NSRB)	2-16	3,000 kcal ME/kg, 18% CP
Tangtaweewipat et al. (2000)	Thai indigenous crossbred (NSRB)	0-5	2,900 kcal ME/kg, 21% CP
		6-10	2,900 kcal ME/kg, 17% CP
		11-13	2,600 kcal ME/kg, 15% CP
Pingmuang et al. (2001)	Thai indigenous crossbred (NSRB)	6-10	2,900 kcal ME/kg, 17% CP-Male
			2,600 kcal ME/kg, 17% CP-Female

Table 2.5 Energy and protein requirements of broilers, Thai indigenous and Thai indigenous crossbred chickens (Continued).

Reference	Chicken type	Age (wk)	Energy and protein requirements
Tananchai et al. (2001)	Thai indigenous crossbred (NSRB)	11-13	2,600 kcal ME/kg, 15% CP
Polsiri (2001)	Thai indigenous crossbred (NSRB)	0-8	2,800 kcal ME/kg, 18% CP
		8-16	2,800 kcal ME/kg, 18% CP
		16-22	3,100 kcal ME/kg, 12% CP
Chomchai et al. (2003)	Thai indigenous crossbred (NASRB)	0-12	3,000 kcal ME/kg 16-20% CP
Nguyen and Bunchasak (2005)	Betong	0-6	3,000-3,200 kcal ME/kg, 19% CP
Nguyen et al. (2010)	Betong	6-12	3,000 kcal ME/kg, 19% CP

N : Native chicken; S : Shanghai chicken; R : Rhode Island Red chicken; B : Barred Plymouth Rock chicken; A : Arbor Acres chicken.

2.3 Energy

Energy is not a nutrient and chemical entity, but a property of energy-yielding nutrients when they are oxidized during metabolism. It is a summation of the biologically available energy of the chemical constituents of feed (e.g. carbohydrates, protein and fats). Energy is one of the most important factors in the evaluation of feed intake because it is a key role in the control of feed intake. The energy value of a feed ingredient or of a diet can be expressed in several ways. Thus, a description is presented below of terminology associated with dietary energy values, including units of measure (e.g. gross energy; GE; digestible energy : DE, metabolizable energy : ME, net energy : NE, etc.). For poultry, ME is measured more easily than DE, because the feces and urine are voided together. Therefore, ME values are most commonly used to define the dietary energy available to poultry, and there are several procedures for determining ME values, by using bioassays or estimates based on proximate analysis, which are described in many studies (NRC, 1994; MacLeod, 2002; McDonald et al., 2011). Partition of ingested energy in chicken is described schematically in Figure 2.1. The terminology and abbreviations are taken from Sibbald (1982).

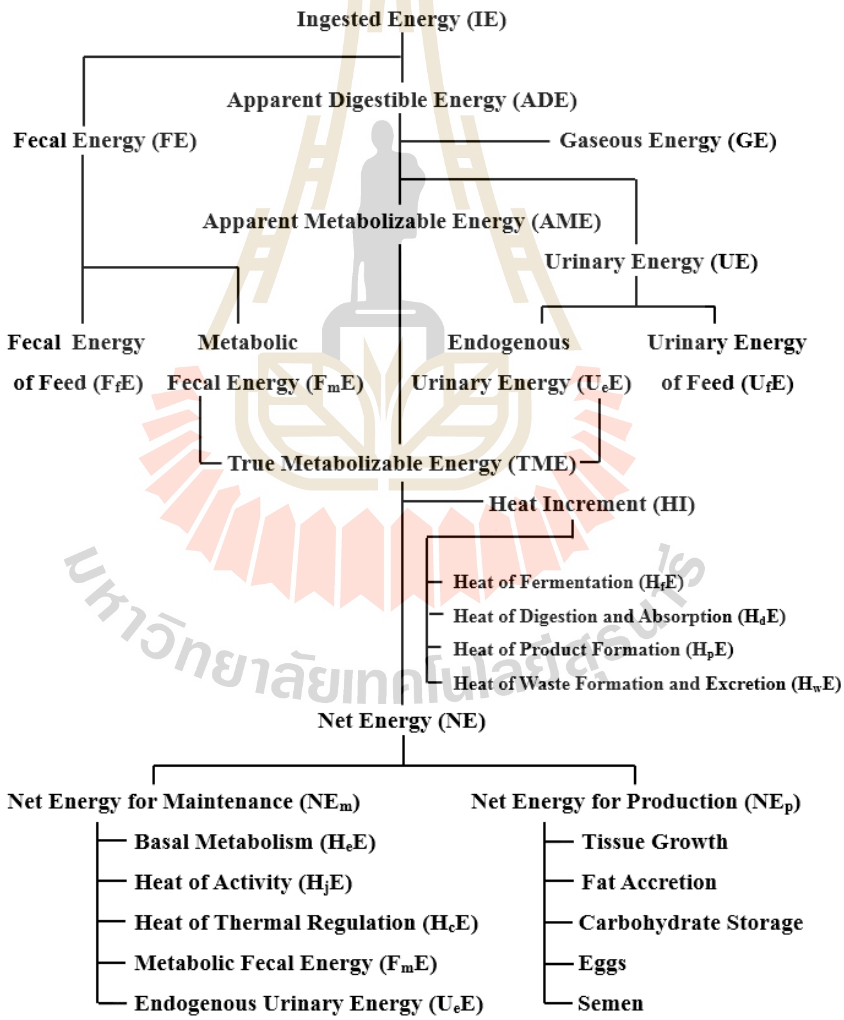


Figure 2.1 Partition of ingested energy in chicken.

Source : Sibbald (1982).

2.3.1 Energy unit

Energy can be converted to heat, so heat units have been used to represent the energy involved in metabolism. Traditionally, the basic unit used has been the thermochemical calorie (cal), based on the calorific value of benzoic acid as the reference standard. However, a calorie is a small unit of energy that is the heat required to raise the temperature of 1 g of water from 16.5°C to 17.5°C. Because the specific heat of water changes with temperature, however, 1 cal is defined more precisely as 4.184 joules (1 joule; J = 0.239 cal). A kilocalorie (1 kcal) equals 1,000 cal and is a common unit of energy used in the poultry feed industry (NRC, 1994; Scott et al., 1982; McDonald et al., 2011). However, the International Union of Nutritional Sciences and the National Committee of the International Union of Physiological Sciences have now recommended the joule (J) as the unit of energy for use in nutritional, metabolic and physiological studies.

2.3.2 Energy partition

Any discussion of energy evaluation must be informed by a knowledge of how energy is partitioned among different functions. A classical representation is shown in Figure 2.1 (Sibbald, 1982; Sibbald, 1986; NRC, 1994; Reynolds, 2000; MacLeod, 2002; McDonald et al., 2011).

1. Ingested energy (IE) or gross energy (GE) is the energy released as heat when an organic substance is completely oxidized to carbon dioxide and water. It is also referred to as the heat of combustion. Although, IE is related to chemical composition, it does not provide any information regarding the availability of that energy to the animal. Thus, IE is of limited use for assessing the value of a particular diet or dietary ingredient as an energy source for animals. It is generally measured using 25 to 30 atmospheres of oxygen in a bomb calorimeter.

2. Fecal energy (FE) is the gross energy of the feces, which contain, in addition to the energy of feed residues (F_fE), a metabolic fraction (F_mE) comprising bile, mucosal cell and unabsorbed intestinal secretions.

$$FE = F_fE + F_mE$$

3. Apparent digestible energy (ADE or DE) is the gross energy of the feed consumed minus the gross energy of the feces (FE).

$$ADE = IE - FE \text{ or}$$

$$ADE = IE - (F_fE + F_mE)$$

Birds excrete feces and urine together via a cloaca, but it is difficult to separate the feces and then to measure digestibility. As a consequence, DE values are not generally employed in poultry feed formulation.

4. Gaseous products of digestion (GPD) or gaseous energy (GE) is the energy lost as a gas during the passage of ingesta through the alimentary canal, which is usually neglected in poultry balance experiments. Gaseous energy is about 0.5-1% of DE.

5. Urinary energy (UE) is the gross energy of the urine in the form of nitrogenous waste and other compounds not oxidized by an animal's body, it contains the urinary energy of feed (U_fE) and endogenous urinary energy (U_eE).

$$UE = U_fE + U_eE$$

6. Apparent metabolizable energy (AME or ME) is the gross energy of the feed consumed minus the gross energy contained in the feces, urine, and gaseous products of digestion (GPD) or gaseous energy (GE). For poultry the gaseous products are usually negligible, so AME represents the gross energy of the feed minus the gross energy of the excreta. A correction for nitrogen retained in the body is usually applied to yield a nitrogen-corrected AME (ME_n) value. AME_n, as determined by using the method described by Sibbald (1989), or slight modifications thereof, is the most common measure of available energy used in the formulation of poultry feeds.

$$AME = IE - (FE + UE) - GPD \text{ or}$$

$$AME = IE - (FE + UE)$$

Hill and Anderson (1958); MacLeod (2002) reported that the mean gross energy of the nitrogenous excretory products in birds is 8.22 kcal/g or 34.4 kJ/g. This is the energy obtained when uric acid is completely oxidized.

7. True metabolizable energy (TME) is the gross energy of the feed consumed minus the gross energy of the excreta of feed origin. A correction for nitrogen retention may be applied to give a TME_n value. Most ME_n values in the literature have been determined by assays in which the test material is substituted for part of the test diet or for some ingredient of known ME value. When birds in these assays are allowed to consume feed on an ad libitum basis, the ME_n values obtained approximate TME_n values for most feedstuffs.

$$TME = IE - (FE + UE) + (F_mE + U_eE)$$

8. Heat increment (HI) or specific dynamic action (SDA) is to be found in the processes associated with digestion of feed and metabolism of the nutrients derived from feed. For example, heat of fermentation (H_fE), heat of digestion and absorption (H_dE), heat of product formation (H_pE) and heat of waste formation and excretion (H_wE). As this heat energy is lost, no value to the animal need to be considered, like the energy of the excreta. It is used when the animal is in a particularly cold environment or at a critical temperature for the maintenance of the body temperature, that is, for keeping the body warm.

9. Net energy (NE) is metabolizable energy minus the energy lost as the heat increment. Net energy is available to the animal for useful purposes such as for body maintenance (NE_m) and in various forms of production (NE_p). Net energy may include the energy used for maintenance only or for maintenance and production ($NE_m + NE_p$). There is no absolute NE value for each feedstuff because NE is used at different levels of efficiency for maintenance or the various productive functions. For this reason, productive energy, once a popular measure of the energy available to poultry from feedstuffs and an estimate of NE, is seldom used.

$$NE = ME - HI$$

2.3.3 Energy requirement of chickens

The energy requirements of chickens are normally stated for both maintenance and production. Since chickens consume feed to satisfy their energy need, it is not possible to express the energy requirement in terms of a specific number of kilocalories per kilogram of diet. However, the energy requirement should be expressed in terms of the number of kilocalories of ME required per bird per day for normal growth and production. This would be very difficult to assess in young chicks since the energy requirement increase daily as the chick grows older. So it more convenient to indicate the range of dietary energy levels in kilocalories of ME per kilogram of diet which will allow the chick to consume feed within its capacity, and to obtain its desired energy requirement for each day. Normally, birds are able to consume feed at the rate of 10% of BW on dry matter basis (DM basis), although it has been suggested that appetite per se governs intake. This concept is very important because the nutrients in the diet are generally formulated in relation to the energy content of the ration. However, a chicken can adjust its feed intake to obtain sufficient energy for maximum growth over a range of dietary energy levels from approximately 2,800-3,400 kcal ME/kg of diet. Furthermore, energy requirements are affected by the environmental temperature or environmental conditions to which chickens are subjected with temperature being a major factor (Scott et al., 1982; NRC, 1994; Lopez and Leeson, 2008).

The diet must be digested and absorbed to be a useful source of energy. Therefore, the diet must contain sufficient energy to support the metabolic reactions involved in growth, to maintain the normal physical activity of the animal and to maintain the body temperature.

Net energy for maintenance (NE_m) is a large portion of the total energy requirement simply to maintain life including basal metabolism, thermoregulation and normal activity. The basal metabolism is the minimum energy expended in fasting for a resting animal under optimal environmental conditions (normal comfort zone, 25°C). All the data from several studies were analyzed using the assumption that maintenance energy requirements are proportional to BW raised to the power of 0.75 which is referred to as metabolic weight or metabolic size for estimating heat production. Since the body temperature of chickens is higher than that of mammals, its energy expenditure for maintenance is greater. The net energy requirement for basal metabolism of adult hens or broiler breeders may be calculated according to the formula (Scott et al., 1982; Latshaw and Bishop, 2004; Lopez and Lesson, 2005) :

$$NE_m = 83 \times BW\ (kg)^{0.75} \qquad (kcal/bird/day)$$

Generally, the metabolizable energy requirement is approximately 18% higher than the net energy requirements, when the chickens consume a nutritionally balanced diet. This is in accordance with the theory that consumption of protein causes an approximately 30% increase in heat increment (specific dynamic action of the protein) while consumption of carbohydrate produces about 15% heat increment and fat produces approximately 10% increase in heat increment. In a well-balanced diet containing 20% protein, 5% fat and 65% carbohydrate, the average heat increment is about 18%. Thus the net energy for maintenance requirement (NE_m) is approximately 82% of the metabolizable energy for maintenance requirement (ME_m) and or, conversely, by the following equation (Scott et al., 1982).

$$NE_m = 0.82 \times ME_m \qquad (kcal/bird/day)$$

and $$ME_m = \frac{NE_m}{0.82} \qquad (kcal/bird/day)$$

The energy requirement for activity naturally ($ME_{activity}$) depends on the degree of activity of the animal. Under normal conditions, this energy is about 50% of the energy needed for basal metabolism or ME_m (Scott et al., 1982; Lopez and Leeson, 2008). In addition, these energy requirements can be affected by the rearing conditions, when $ME_{activity}$ is 30% of ME_m for birds which were reared in cages and about 50% of ME_m for birds reared on the floor (MacLeod et al., 1982; Boshouwers and Nicaise, 1985).

$$ME_{activity} = 0.50 \times ME_m \qquad (kcal/bird/day)$$

The energy requirement for production in chickens is the energy needed for growth, egg production and reproduction. Energy for growth (ME_{growth}) depends on the amount of fat in relation to protein in the BWG or average daily gain (ADG) and can be calculated by the following equation (Scott et al., 1982; Shyam Sunder et al., 2007).

$$ME_{egg} = 86 \times \frac{\text{Egg production}}{100} \qquad \text{(kcal/bird/d)}$$

Body weight gain (BWG, g/d) is composed of 18% protein (1 g of protein equals 4.0 kcal) and 15% fat (1 g of fat equals 9.0 kcal) :

$$ME_{growth} = (0.18 \times BWG \times 4) + (0.15 \times BWG \times 9) \qquad \text{(kcal/bird/day)}$$

Therefore, the total ME requirements of laying hens (egg production) is calculated by :

$$= ME_{m} + ME_{activity} + ME_{egg} + ME_{growth} \qquad \text{(kcal/bird/d)}$$

Then, the total ME requirements of broilers or meat chickens (ME required for targeted BW) is calculated by :

$$= ME_{m} + ME_{activity} + ME_{growth} \qquad \text{(kcal/bird/d)}$$

From the above equations, the amount of total ME in a diet can be calculated by the amount of feed consumed by a chicken or average daily feed intake (g/bird/d). This is calculated by :

$$= \frac{\text{Total ME requirements} \times 1{,}000}{\text{Average daily feed intake}}$$

2.4 Protein and amino acids

2.4.1 Protein

Proteins are essential and complex organic compounds of large molecules which range in weight from 35,000 to several hundred thousand grams. In common with carbohydrates and fats they contain carbon, hydrogen and oxygen, but in addition, they all contain nitrogen (N) and generally sulfur. Proteins are found in all living cells and organisms, where they are intimately connected with all phases of activity that constitute the life of a cell. All cells synthesize proteins for part or all of their life cycles, and without protein synthesis life could not exist (Pond et al., 2005; McDonald et al., 2011).

Protein is very widely used in chemical composition, physical properties, size, shape, solubility and biological formation. All proteins are long chains of amino acids that have been linked together. Proteins have a variety of unique functions within an animal's body. For example, protecting the body (hair, feather, skin), digesting feed (enzymes), metabolizing nutrients in the animal's cells (enzymes), stimulating growth (hormones) and defending the animal against invading organisms (immunoglobulins) (Pond et al., 2005; Kellems and Church, 2010).

2.4.2 Amino acids

Amino acids are produced when proteins are hydrolyzed by enzymes, acids or alkalis. Although more than 200 amino acids have been isolated from biological materials, only 20 of these are commonly found as components of proteins and up to 10 are required in the diet of animals because they cannot be synthesized adequately to meet metabolic needs. The essential components of amino acids are a carboxyl group (–COOH) and an amino group ($–NH_2$) on the carbon (C) atom adjacent to the carboxyl group. This NH_2 group is designated the α-amino group (Pond et al., 2005; Wu, 2009; McDonald et al., 2011). The general structure for all amino acids is presented as follows in Figure 2.2.

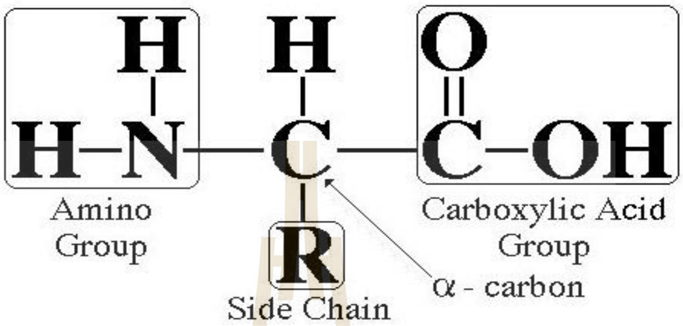


Figure 2.2 The general structure of amino acids.

Whereas R is the remainder of the molecule attached to the C atom associated with the α-amino group of the amino acid.

The amino acids are subdivided into two categories: essential or indispensable amino acids and non-essential or dispensable amino acids. Essential amino acids cannot be synthesized in poultry in sufficient amounts to meet its requirements, therefore, it must be supplied in the diet, whereas non-essential amino acids can be synthesized by the body in poultry in adequate amounts to meet optimal requirements. The essential and non-essential amino acids required by chickens are listed in Table 2.6 (Wu, 2009).

Table 2.6 Nutritional classification of amino acids for chickens.

Essential amino acids : EAA (indispensable amino acids)	Non-essential amino acids : NEAA (dispensable amino acids)
Arginine (Arg)	Alanine (Ala)
Histidine (His)	Aspartate or Aspartic acid (Asp)
Isoleucine (Ile)	Asparagine (Asn)
Leucine (Leu)	Glutamate or Glutamic acid (Glu)
Lysine (Lys)	Glutamine (Gln)
Methionine (Met)	Hydroxyproline
Phenylalanine (Phe)	Hydroxylysine[1]
Threonine (Thr)	Cystine[1] (Cys)
Tryptophan (Trp)	Cysteine (Cys)
Valine (Val)	Taurine (Tau)
	Tyrosine[1] (Tyr)
	Glycine[2] (Gly)
	Serine[2] (Ser)
	Proline[3] (Pro)

[1]Hydroxylysine, cystine and tyrosine are synthesized from lysine, methionine and phenyl-alanine, respectively.

[2]Amino acids required in addition to the essential amino acids by a chick for optimal or more rapid growth because of this synthesis may not be sufficient.

[3]When diets composed of crystalline amino acids are used, proline may be necessary to achieve maximum growth.

Source : Adapted from Wu (2009).

2.4.3 Protein and amino acid nutrition of chickens

In the past, the protein nutrition of poultry was based on the crude protein content of the diet. Nowadays, the dietary levels and biological availability of each essential amino acid are considered, together with an adequate level of non-essential amino acids, and nitrogen is supplied to the chickens in the diet at the cellular level with all of the elements needed to synthesize all its body and egg proteins efficiently and economically. However, chickens which are slightly deficient in amino acids will over consume energy. The principle that a low protein diet causes a decrease in carcass protein and an increase in carcass fat content is used in some period rations because of the inability of chickens to make productive use of energy. In those conditions, the ration does not contain a sufficient protein or amino acid balance for optimum protein tissue growth. Thus, the optimum ratios for growth performance of chicken should also consider the ratio of essential and non-essential amino acids which is a ratio of 55 : 45 and a balance of the both amino acids (Bedford and Summers, 1985). This is in accordance with the suggestion of Heger (2003), who recommended that the property ratio of essential amino acids and total amino acids should be 0.55-0.60.

Generally, poultry diets use corn as the energy source and soybean meal as the protein source, which is about 65-75% of the ration. For corn, the limiting amino acid order for chicks is 1^{st}-lysine, 2^{nd}-threonine, 3^{rd}-tryptophan, 4^{th}-arginine, valine and isoleucine (equally limiting), 5^{th}-sulfur amino acid (SAA), 6^{th}-phenylalanine + tyrosine, and 7^{th}-histidine. The order of limiting amino acids in soybean meal is 1^{st}-SAA, 2^{nd}-threonine, 3^{rd}-lysine and valine (equally limiting), 4^{th}-non-specific amino nitrogen, and 5^{th}-histidine. Therefore, methionine is the first limiting amino acid and lysine is the second amino acid in corn-soybean basal diet for chickens which depends on the level of protein content in corn, soybean meal or corn-soybean basal diet. There are commercial sources for these amino acids, synthetic amino acids, which can be supplied to meet the amino acid requirement (Wu, 2009; Baker, 2009).

2.4.4 Protein requirement of chickens

The dietary protein requirement for chicken are usually expressed in the amount of crude protein and essential amino acids with additional information on some of the limiting amino acids. There are substantial volumes of information on the amino acid contents of all major feedstuffs that are used in rations. However, chemical composition analyses do not provide information about the digestibility and the availability of feedstuffs. Thus, the feed formulation of chickens should consider the daily protein and essential amino acid requirements. In addition, it should also include the percentage of proteins required in the diet to support nitrogen use in the biosynthesis of non-essential amino acids which can be readily satisfied by almost any practical diet which meets the essential amino acid needs economically.

Protein requirements are always at the highest level for young (starter period), rapidly growing (grower period) animals and decline gradually to maturity, when only adequate protein to maintain body tissue is needed. Many factors may influence feed consumption and protein requirement in chickens under standard management conditions, for example, breed, environmental temperature, age, growth rate, and energy content of the diet (Kellems and Church, 2010).

2.4.5 Calculation of daily protein requirement of chickens

The calculation of protein requirement of chickens is calculated based on the daily feed consumption and the amounts of protein deposited daily in the tissue plus the amounts used daily for maintenance and production.

The protein retained by growing broiler strains of chickens with their protein requirements indicates that these strains are about 67% efficient in the retention of dietary protein (Scott et al., 1982). Thus, the daily protein consumed, which is approximately 67%, can be retained in the daily growth of tissue, of feathers and as replacement of the daily endogenous nitrogen loss.

In general, Scott et al. (1982) suggests that the daily protein requirement of growing chickens can be divided into three parts : 1) protein requirement for tissue growth; 2) protein requirement for maintenance; and 3) protein requirement for feather growth.

Protein requirement for tissue growth : The carcass of chickens contains about 18% of protein. Daily protein requirements for tissue growth can be calculated by :

$$= \frac{\text{Daily gain (g)} \times 0.18}{0.67}$$

When 0.67 is 67% efficiency of utilization of feed protein by growing broiler strains of chickens.

Protein requirement for maintenance : The endogenous nitrogen loss in chickens has been determined to be approximately 250 mg of nitrogen per kg of BW. Therefore, the protein loss can be calculated by multiplying the % nitrogen × 6.25 indicates that 1,600 mg of protein lost per kg of BW per day. The daily protein requirements for maintenance can be calculated by :

$$= \frac{0.0016 \times \text{Body weight (g)}}{0.67}$$

Protein requirement for feather growth : At 3 weeks of age, the feathers are about 4% of the BW and will increase to 7% at 4 wk of age and then remain relatively constant thereafter. The protein content of the feathers is about 82%. Thus, the daily protein requirements for feather growth can be calculated by :

$$= \frac{0.07 \times \text{Daily gain (g)} \times 0.82}{0.67}$$

Therefore, the daily protein requirement is calculated as :

Daily protein requirement (g)

$$= \frac{[\text{Daily gain (g)} \times 0.18] + [0.0016 \times \text{Body weight (g)}] + [0.07 \times \text{Daily gain (g)} \times 0.82]}{0.67}$$

2.4.6 Measurement of the nutritive value of protein

There are many values which can be used to define the nutritive value of protein in terms of biological value (BV). The degree of utilization of a feed protein depends on several factors, such as its digestibility, absorbability and utilization after absorption. Moreover, it depends on how the resultant amino acid balance compares with the animal's requirement of amino acids. The determination of biological value in chickens is difficult because of the difficultly of separating of the faeces and the urine in excreta. The measurements of the nutritive value of protein in chickens can be evaluated by net protein value (NPV), protein retention efficiency (PRE) or net protein retention (NPR), biological value (BV), protein efficiency ratio (PER), protein digestibility and nitrogen balance (NB) or N-retention (NR). However, the term PER is one of the measures of protein quality which is simple and easy. The PER is calculated as the weight gain of a chicken divided by the protein intake (Scott et al., 1982; Lopez and Leeson, 2005; Pond, et al., 2005; McDonald et al., 2011). These are defined as follows :

$$NPV = \frac{B_f - B_k + I_k}{I_f} \times 100$$

where B_f = carcass nitrogen of animal fed the test protein diet

B_k = carcass nitrogen of animal fed a nitrogen-free diet

I_k = nitrogen intake of animal fed a nitrogen-free diet

I_f = nitrogen intake of the test protein diet

$$PRE = \frac{\text{weight gain of TPG} - \text{weight loss of NPG}}{\text{weight of protein consumed of the test protein diet}} \times 18.0$$

where TPG = group fed the test protein diet

NPG = group fed the nitrogen – free diet

18.0 = the percentage of the carcass protein content of the chicken

$$BV = \frac{\text{N intake} - (\text{Faecal N} - \text{MFN}) - (\text{Urinary N} - \text{EUN})}{\text{N intake} - (\text{Faecal N} - \text{MFN})} \times 100$$

where MFN = metabolic (endogenous) faecal nitrogen

EUN = endogenous urinary nitrogen.

$$PER = \frac{\text{g of body weight gain}}{\text{g of protein intake}} \times 100$$

NB = N intake – (Faecal N + (Urinary N) or

NR = N intake – N in the excreta (Faeces + Urine)

2.5 Estimation of the nutritional requirements

2.5.1 Methods to estimate nutritional requirements

The rearing livestock should take into account the efficiency and economy of animal production, therefore, it is very important to know the nutrient content in feedstuffs and the nutrient requirements of the animals. It is also necessary to use unconventional feedstuffs and to avoid using some feedstuffs, which compete with the production of ethanol, and human foods and to reduce excretory nitrogen in order to decrease environmental pollution. Accordingly, many nutritionists have conducted studies to estimate the nutrient requirements by using experimental data, which may be called traditional methods. These methods use growth data, nitrogen balance and carcass analysis as parameters for the determination of nutrient requirements. Although, traditional methods take a long time and a large number of animals have to be studied, they can be used for the estimation of energy and protein requirements. In order to determine the amino acid requirements, traditional methods are not suitable for such variable conditions within a short experimental period. Therefore, the usefulness of the plasma amino acid concentration as a parameter to determine amino acid requirements is one of the methods used in this study, which is more easily and accurately determined for a short period (Robbins et al., 1979; Ishibashi and Yonemochi, 2002; Pesti et al., 2009).

Further, many nutritionists have suggested that the conventional dose-response method that has normally been used to determine the dose corresponds to the response. In animal nutrition, the requirement for a specific nutrient, and particularly amino acids, can be defined as the minimal amount of this nutrient (dose or level of nutrient) needed to reach maximum performance (response) assuming that all the other nutrients are provided in adequate amounts. The objective of determining the amino acid requirements is to use these values to feed populations of animals. The aim of a dose-response experiment is estimated a single value applicable to the whole population; the individual variations that exist within the population, therefore, should be taken into account in the estimation (Gous and Morris, 1985; Ajinomoto, 2012).

Pomar et al. (2003) reported that there are different methods to estimate a nutrient requirement. First is the factorial approach, for which daily requirements are obtained for an individual animal at a specific point in time by combining the estimated requirements for maintenance and production (hypothetical growth). Secondly, is the empirical approach, for which nutritional requirements are defined as the minimal amount of nutrients needed to maximize or minimize population responses for one or several performance criteria during a given period.

The definition of the term "requirement" for growing animals is thus defined by the scope of the empirical method and dose-response studies allow one to estimate the energy, protein and amino acid requirements by showing the response of a growing population to increase in levels of energy, protein and amino acids. This method consists of testing different concentrations of a nutrient and then determining through statistical methods which level gives the best performance, although reported results can be quite variable (Ajinomoto, 2012). In such studies, a diet is formulated that is complete with the exception of the nutrient in question, which is added in increasing increments. The diets are fed to birds with growth being the primary determinant of the requirement (Lamberson and Firman, 2002).

Moreover, positioning the dose-response levels is also very important for the estimation of an optimum nutrient requirement level, which corresponds to the maximum response. Thus, the dose levels should be allocated to ¼ in the ascending portion of the curve, to ½ near the a priori requirement and to ¼ at high enough levels so that the plateau-value can be defined. For example, Figure 2.3 presents 7 treatments, with 2 levels in the ascending portion, 3 levels around the requirement and 2 levels on the plateau-value (Shearer, 2000; Ajinomoto, 2012). Furthermore, Ajinomoto (2012) suggests that the dose-response observations and therefore the estimated requirements, are very dependent on the study design and should provide three main characteristics (Figure 2.4).

1. There should be less variability between individuals (or pens, depending on the experimental unit) in the response for each tested dose.

2. The different treatments should have structure, which means that the dose-response is linked so they can be classified in increasing order (contrary to unstructured treatments; for example “castrated” vs. “entire males” or “with” vs. “without a specific product” or “male” vs. “female” are treatments without any structure).

3. The searched dose is a continuous variable that can have any value between 0 and $+\infty$ (and not only one among the tested doses).

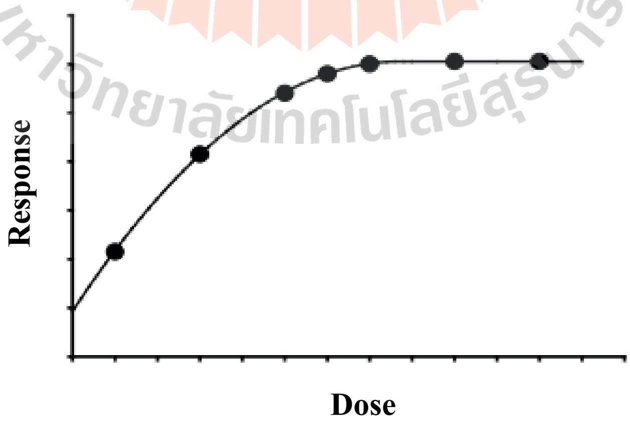


Figure 2.3 The position of the tested levels depends on the a priori shape of the response and on the requirement.

Source : Adapted from Ajinomoto (2012).

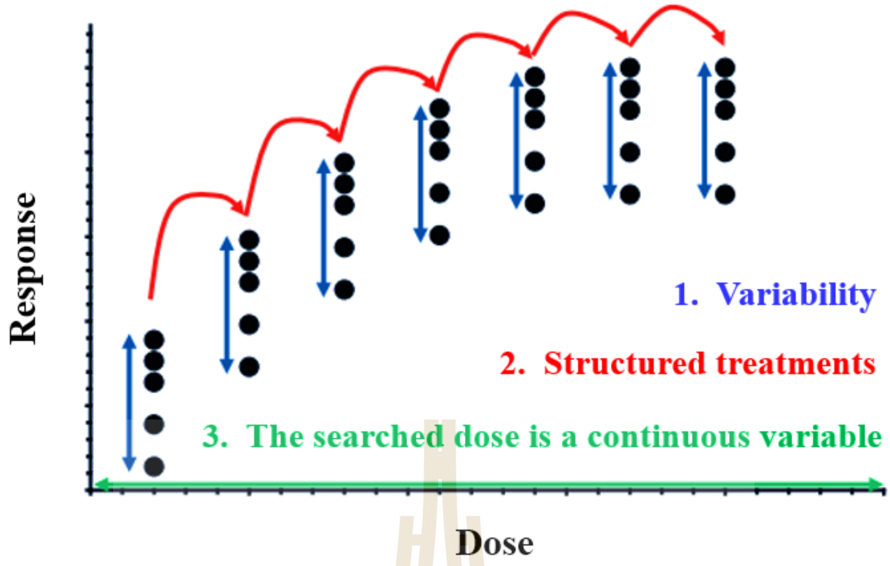


Figure 2.4 Experimental data from dose-response experiment.

Source : Adapted from Ajinomoto (2012).

2.5.2 Statistical models for the response curve to estimate nutritional requirements

In animal feeding trials, there are many different curves of results that relate animal response to feed composition can be fitted to data from animal feeding trials as shown in Figure 2.5. The most realistic curve for each set of experimental data is difficult to choose in consequence of the variability in the responses of different individuals, or pens of individuals, fed on the same diet. The data points appear to be scattered about or around a continuum with an ascending portion where the nutrient in question is limiting some response, such as growth performance, carcass composition, or lean meat yield. When enough of the nutrient is fed, a plateau results or be stable, where a maximum or minimum performance levels have been achieved that depend on the parameter for each response. If very high levels of any dietary nutrient are fed, the diet becomes imbalanced or the nutrient may become toxic resulting in decreased growth performance (Gous, 1986; Pesti et al., 2009; Lamberson and Firman, 2002).

In the first place, the simplest analysis of nutritional response data has been just to compare points or comparisons of group means by using paired *t*-tests, multiple comparisons (Duncan's new multiple range tests : DMRT) or orthogonal contrasts. The requirement is defined as the lowest concentration of the nutrient that results in a response that is not significantly different from the maximum or minimum response at some arbitrarily chosen level of significance. Such interpretations always result in conclusions that the requirement is between two levels of the nutrient that were fed in the experiment. There is no way to tell exactly what the requirement is, or to tell the level of confidence in the requirement estimate. Since there is no function defined, interpolation between two known points is not even possible (Pesti et al., 2009).

Furthermore, another simple way to analyze nutrient response data is to fit a polynomial model or expression, usually a quadratic, to the data. With quadratic models, the requirement is defined as the nutrient concentrations resulting in the maximum predicted response value. With quadratic polynomials, the ascending portion is curved, increasing at a decreasing rate until the maximum is reached. There is a single maximum point, not a plateau, and further increases in nutrient concentration result in (predicted) reduced performance levels (Pesti et al., 2009).

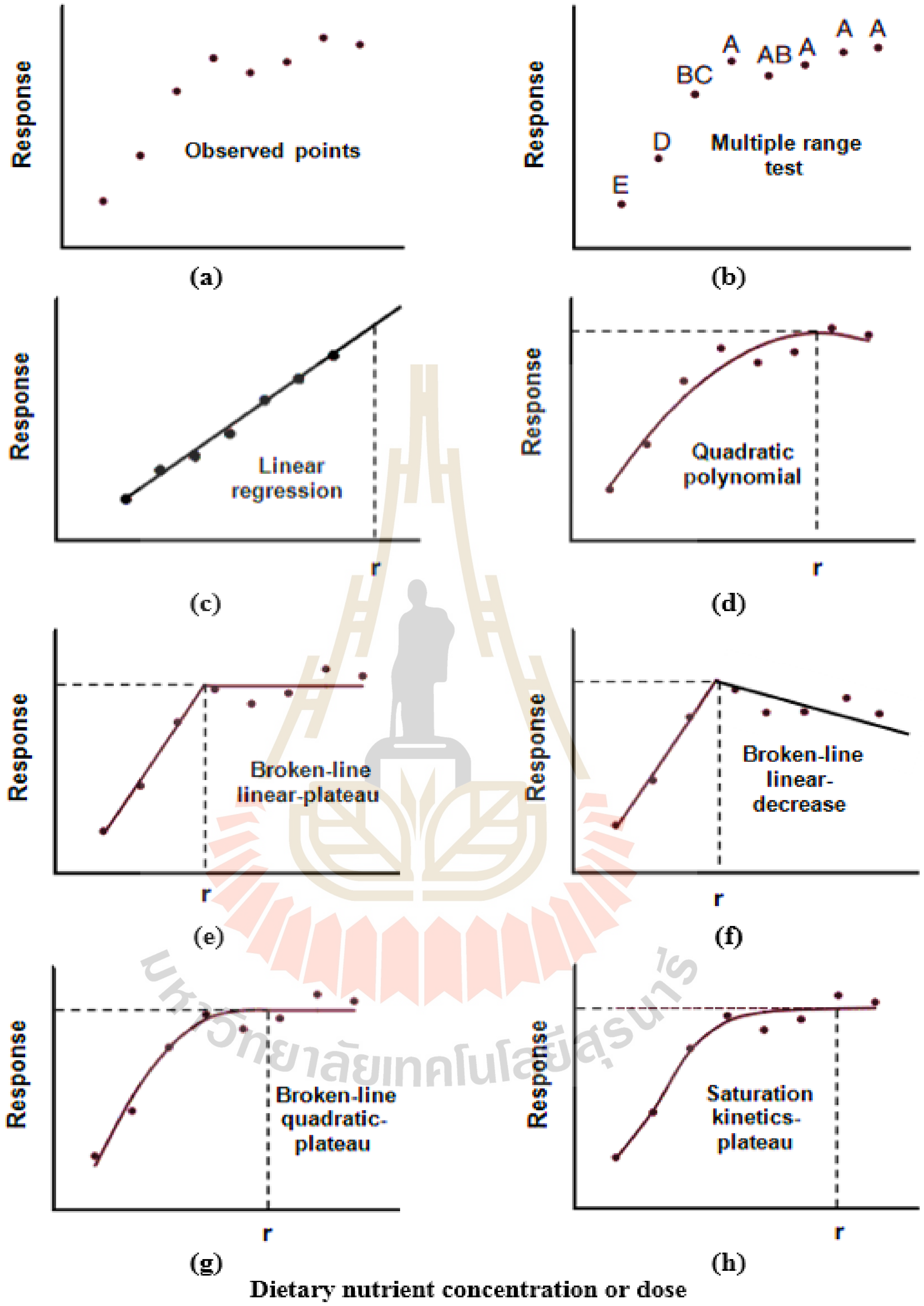


Figure 2.5 Several graphic representations of response to dietary nutrient levels.

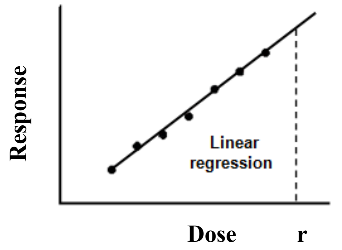
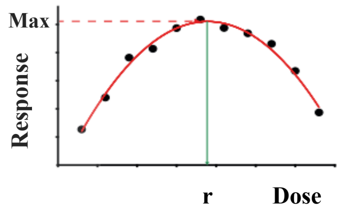
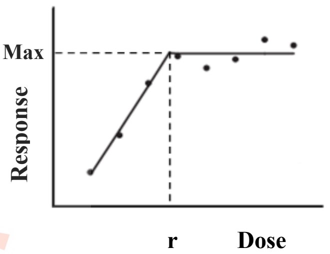
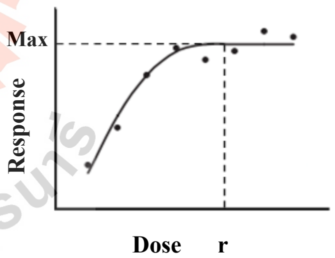
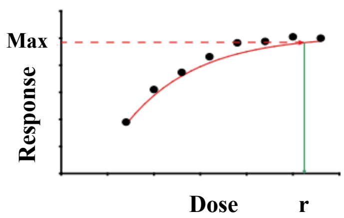
Source : Adapted from Pesti et al. (2009) and Ajinomoto (2012).

Naturally, after data collection, a statistical test is performed to estimate the requirement. The choice of the statistical model depends on the shape of the response curve of the data or a pattern of the data (Table 2.7). Hence, the nutritionist should choose a realistic curve that relates animal response to dietary nutrient level in order to estimate the nutritional requirements. Usually, there are two types of statistical models : linear models and non-linear models (Pesti et al., 2009; Ajinomoto, 2012).

Linear models include linear regression which is used to describe a linear relationship between two variables but do not allow the estimation of a requirement. When dietary nutrient concentration increases, linear performance increases within a certain region (Table 2.7). Requirements are sometimes estimated using quadratic functions (which are also linear models) but these models may not be appropriate if the response criterion does not further respond to a high level of nutrients (Robbins et al., 2006; Pesti et al., 2009; Ajinomoto, 2012).

Non-linear regression models have many types of models (Table 2.7) such as a quadratic polynomial (QP), a broken-line linear (BLL or a linear-plateau; LP), a broken-line quadratic (BLQ or a curvilinear-plateau; CLP), a saturation kinetics model (or asymptotic model; ASY), a compartmental model and a logistic model, which are frequently used to estimate nutrient requirements (Robbins et al., 2006; Vedenov and Pesti, 2008; Pesti et al., 2009; Ajinomoto, 2012).

Table 2.7 Statistical models for the response curve to estimate nutritional requirements.

Shape of the response	Type of model	Type of model
1. Increases linearly	Linear model : linear function y = a + bx	
2. Increases, then decreases after reaching a maximum response	Linear model : quadratic function $y = a + bx + cx^2$ r = –b/2a	
3. Increases and is stable after	Non-linear model : 1. Linear-plateau (LP) $y = l + u \times (r - x)$ for $x < r$ $y = l$ for $x \geq r$ (Broken-line linear)	
	2. Curvilinear-plateau (CLP) $y = l + u \times (r - x) \times (r - x)$ for $x < r$ $y = l$ for $x \geq r$ (Broken-line quadratic)	
	3. Asymptotic $y = l - a \times \exp^{(-bx)}$	

y represents the response, l = the maximum response, x = the dose;
r represents the requirement, a, b, c and u = parameters of the models to be estimated.

Source : Adapted from Robbins et al. (2006) and Ajinomoto (2012).

Moreover, several nutritionists have fitted such data to a plethora of statistical interpretations and mathematical models. Some models were used simply when they fitted the data. However, some nutritionists tried to develop a software that is a Microsoft Office Excel workbook. This is more commonly available and easier to use. For example, the NRM.xls (Nutritional Response Models) was produced with Microsoft Office Excel 2003 with the Solver module (Solver.xla) installed. (http://extension.uga.edu/publications/detail.cfm?number=RB440). The NRM.xlsm was used to fit nutritional response data to several models and it has a tutorial on its use and is also available free of charge. These models may be used to estimate the nutritional requirements or the most economical feeding levels of critical nutrients (Vedenov and Pesti, 2008; Xie et al., 2010; Wickramasuriya et al., 2015).

2.5.3 Statistical comparison of models to estimate nutritional requirements

However, the choice of the statistical model contributes considerably to the variability in estimated requirements; dose-response interpretations have therefore to be conducted with respect to some statistical and biological rules. The model which is chosen for estimating nutritional requirements is the one with the best fit and which has the lowest or minimal of a sum of squared residuals (sum of squared error : SSE) or lowest root mean square error (RMSE) and a higher coefficient of determination statistics (R^2). This is defined as follows (Robbins et al., 2006; Vedenov and Pesti, 2008; Pesti et al., 2009; Ajinomoto, 2012; Patra, 2013) :

$$R^2 = \frac{SST - SSE}{SST} \quad \text{or} \quad = 1 - \left[\frac{SSE}{SST}\right]$$

where SST = sum of squared total

However, many regression models have been used to determine the nutritional requirements of poultry, including broken-line, quadratic and quadratic broken-line regression models, which take into account energy, protein, amino acids and vitamin requirements of poultry. As a consequence, many papers investigating the nutritional requirements of poultry are based on broken-line models, which are a subset of spline models where the slope of one line is equal to 0 (Robbins et al., 1979; Labadan et al., 2001; Lamberson and Firman, 2002; Sterling et al., 2002; Fan et al., 2008; Dozier et al., 2008; 2009 and 2010; Pesti et al., 2009; Xie et al., 2010; Strathe et al., 2011; Saki et al., 2012; Wang et al., 2013; Wen et al., 2014; Wickramasuriya et al., 2015). In fact, researchers may also wish to consider optimal regression models according to maximum growth performance or profitability.

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CHAPTER III

THE STUDY OF ENERGY REQUIREMENT OF KORAT CHICKENS FROM 0 TO 12 WEEKS OF AGE

3.1 Abstract

The purpose of this study was to evaluate the metabolizable energy (ME) requirement of Korat chickens from 0 to 12 wk of age, which were divided into 4 experimental periods : 0-3, 3-6, 6-9 and 9-12 wk of age. The numbers of mixed-sex Korat chickens used in each experimental periods were 720, 720, 624 and 576 birds, respectively. The chickens were randomly divided into 4 dietary treatments, with 6 replicates of each treatment in a completely randomized design (CRD) and were assigned to receive one of the experimental diets with different dietary ME levels as 2,750, 2,900, 3,050 and 3,200 kcal of ME/kg. The results showed that the feed intake of Korat chickens was decreased ($P < 0.05$), while feed conversion ratio (FCR) was improved ($P < 0.05$) with increasing dietary ME levels. However, body weight, body weight gain (BWG), average daily gain, feed cost per kg of BWG and energy efficiency ratio did not significantly differ ($P > 0.05$) among treatments. According to the broken-line regression analysis, the ME requirements for optimal FCR of Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age were 2,978, 3,151, 3,200 and 3,200 kcal/kg, respectively.

Key words : Korat chicken, growth performance, metabolizable energy, requirement

3.2 Introduction

Korat chickens, especially their meat, are of interest to consumer in Thailand and Asian countries. At present, they are raised mainly on commercial broiler feeds, since they are convenient to purchase. However, the nutritional content of these feeds may not be appropriate for other birds because the nutrients may be excreted in the form of excreta, resulting in environmental pollution and increasing production cost (Leeson and Summers, 2005). Therefore, the nutrient requirements also need to be revised. Moreover, there is a general consensus that the determination of nutrient requirements of different types of poultry is necessary to efficiently use their genetic potentials for specific production goals and is generally ahead of the established nutrient requirements needed for optimal performance (Pym, 1990; NRC, 1994).

Energy is the main macronutrient in poultry diets as far as a major cost in poultry production is concerned. Energy-contributing ingredients which constitute approximately 65% of the dietary cost for chickens are the greatest portion (Donohue and Cunningham, 2009). To produce poultry meat, growing birds must consume enough feed to provide additional energy for growth and healthy functioning of body's tissues and organs (Latshaw and Moritz, 2009). At present, many studies conducted to determine the effects of the dietary energy on growth performance of chickens and ducks found that increasing dietary energy levels could improve FCR by decreasing FI and increasing BWG. It has been reported that birds can adjust their FI to satisfy their energy requirements, thus resulting in improving feed efficiency (Jackson et al., 1982a, b; Nahashon et al., 2005; Dozier et al., 2006 and 2007; Ghaffari et al., 2007; Fan et al., 2008; Mosaad and Iben, 2009). Regarding this matter, feeding Korat chickens with a suitable profile of nutrients to satisfy their requirement would help to improve nutrient utilization and consequently can reduce feed cost. However, information on ME requirement of Korat chickens is lacking. Therefore, this study was purposed to evaluate the ME requirement of Korat chickens from 0 to 12 wk of age.

3.3 Objective

The objective of this experiment was to investigate the ME requirement of Korat chickens from 0 to 12 wk of age.

3.4 Materials and methods

All experiments were conducted according to the principles and guidelines approved by the Animal Care and Use Committee of Suranaree University of Technology.

3.4.1 Bird husbandry

The experimental period was divided into 4 periods : 0-3, 3-6, 6-9 and 9-12 wk of age in order to estimate the ME requirement of Korat chickens. Two thousand and seven hundred 1-d-old Korat chicks were obtained from a hatchery and raised in an open-sided, naturally ventilated chicken house, with a daily photoperiod of 24 h of light. Birds were housed in a floor on rice husks.

All chicks were vaccinated at the hatchery for Marek's disease, inoculated with Newcastle disease and infectious bronchitis vaccines on d 7 and 21, with inactivated infectious bursal disease vaccine on d 14 and with flow pox vaccine on d 35. The chicks were fed with a commercial broiler diet (CPF Public Company Ltd., Nakhon Ratchasima, Thailand), with 21% CP for 0-3 wk of age, with 19% CP for 3-6 wk of age and then a 17% CP diet during 6-9 wk of age. During these periods, feed and water were available for *ad libitum* consumption. The birds were kept under standard management conditions, and when the chickens were 21-d-old, 42-d-old and 63-d-old, they were used for the start of each experimental period.

Prior to each experiment, the birds were grouped by weight and randomly distributed in each of 24 floor pens (1.75×2.40 m^2) in such a way as to reduce variation in mean chick weights per pen. Each pen was equipped with a tray feeder until 14 d of age and was replaced with a hanging feeder, a nipper-type drinker line (7 nipples) and used the litter. The diets were fed in mash form and were provided *ad libitum*. Water was also provided freely throughout the experimental period. A completely randomized design (CRD) was employed in all the experimental periods.

The mixed-sex Korat chickens were used at 1-d-old (720 birds, average initial BW = 38.99 ± 0.42 g), 21-d-old (720 birds, average initial BW = 277.88 ± 4.83 g), 42-d-old (624 birds, average initial BW = 795.51 ± 12.03 g) and 63-d-old (576 birds, average initial BW = 1,264.77 ± 20.44 g) in the experimental period 0-3, 3-6, 6-9 and 9-12 wk of age, respectively. The Korat chickens were randomly divided into 4 dietary treatments, with 6 replicates of each treatment which contained 30, 30, 26 and 24 birds per pen (6-7 birds/m^2), respectively. These birds were raised with similar management practices until 3, 6, 9 and 12 wk of age, respectively.

3.4.2 Dietary treatment

Four experiments were conducted along with the 4 experimental periods: from 0 to 3, 3 to 6, 6 to 9 and 9 to 12 wk of age. In each experiment, four dietary treatments were formulated to contain 2,750, 2,900, 3,050 and 3,200 kcal of ME/kg, respectively. The experimental diets were formulated to meet or exceed the nutrient requirements for the broiler as recommended by the NRC (1994) with the exception of ME (Tables 3.1, 3.2, 3.3 and 3.4). The experimental diets were prepared in mash form.

3.4.3 Data collection

Feed intake and BW were recorded by pen at the initial and the end of each experimental period. These data were used to calculate BWG, average daily gain (ADG), feed conversion ratio (FCR : feed/gain), feed cost per kg of BWG, protein intake, ME intake and energy efficiency ratio (EER). The EER was calculated as g of BWG × 100/total ME intake. Mortality was recorded daily.

3.4.4 Laboratory analysis

Feed samples were pooled to make representative samples for proximate analysis. Samples were ground through a 1 mm screen and analyzed for chemical composition. Dry matter (DM) was determined by hot air oven at 135°C for 3 h (method No. 930.15; AOAC, 1990). Crude protein was analyzed by the Kjeldahl method (method No. 988.05; AOAC, 1990) and calculated as nitrogen (N; %) × 6.25. Ether extract (EE) was determined by using petroleum ether for fat extraction by the Soxhlet method (method No. 920.39; AOAC, 1990). Crude fiber (CF) was determined by using Fiber Analyzer (method No. 962.09; AOAC, 1990). Ash content was determined by burning in a muffle furnace at 550°C for 3 h (method No. 942.05; AOAC, 1990). The chemical analysis was expressed on the air dry basis.

Table 3.1 Compositions of the experimental diets for Korat chickens in the period 0-3 wk of age (as-fed basis).

Items	Level of ME (kcal/kg)			
	2,750	**2,900**	**3,050**	**3,200**
Ingredient				
Corn	36.74	37.10	37.59	38.60
Soybean meal, 44% CP	31.20	32.25	33.30	34.43
Extracted rice bran	13.99	10.58	7.08	3.09
Rice bran oil	2.11	4.10	6.07	7.92
Full-fat soybean	4.00	4.00	4.00	4.00
Cassava pulp	3.00	3.00	3.00	3.00
Meat meal, 60% CP	6.00	6.00	6.00	6.00
Calcium carbonate, $CaCO_3$	0.80	0.80	0.80	0.80
Monocalcium phosphate, $Ca(H_2PO_4)_2$	0.85	0.85	0.85	0.85
DL-methionine	0.30	0.31	0.31	0.31
L-threonine	0.06	0.06	0.05	0.05
Salt	0.45	0.45	0.45	0.45
Premix[1]	0.50	0.50	0.50	0.50
Calculated composition, %				
ME, kcal/kg	2,750	2,900	3,050	3,200
CP	23.00	23.00	23.00	23.00
Calcium	1.00	1.00	1.00	1.00
Available phosphorus	0.52	0.52	0.52	0.53
Digestible lysine	1.15	1.16	1.17	1.18
Digestible methionine	0.62	0.63	0.63	0.63
Digestible methionine + cystine	0.90	0.90	0.90	0.90
Digestible threonine	0.80	0.80	0.80	0.80
Digestible tryptophan	0.27	0.28	0.28	0.28
Analyzed composition, %				
DM	91.43	91.55	91.15	91.09
CP	23.99	23.97	23.82	23.96
CF	5.29	4.92	4.55	4.13
EE	5.38	7.25	8.81	10.64
Ash	8.62	8.23	7.65	7.12
Price, Baht/kg	15.68	16.30	16.89	17.47

[1]Premix (0.5%) provided the following (per kg of diet) : vitamin A, 15,000 IU; vitamin D_3, 3,000 IU; vitamin E, 25 IU; vitamin K_3, 5 mg; vitamin B_1, 2 mg; vitamin B_2, 7 mg; vitamin B_6, 4 mg; vitamin B_{12}, 25 mg; pantothenic acid, 11.04 mg; nicotinic acid, 35 mg; folic acid, 1 mg; biotin, 15 µg; choline chloride, 250 mg; Cu, 1.6 mg; Mn, 60 mg; Zn, 45 mg; Fe, 80 mg; I, 0.4 mg; Se, 0.15 mg.

Table 3.2 Compositions of the experimental diets for Korat chickens in the period 3-6 wk of age (as-fed basis).

Items	Level of ME (kcal/kg)			
	2,750	**2,900**	**3,050**	**3,200**
Ingredient				
Corn	43.22	43.60	44.05	44.50
Soybean meal, 44% CP	23.49	24.52	25.57	26.62
Extracted rice bran	17.46	14.09	10.63	7.18
Rice bran oil	1.34	3.33	5.30	7.27
Full-fat soybean	2.00	2.00	2.00	2.00
Cassava pulp	4.00	4.00	4.00	4.00
Meat meal, 60% CP	6.00	6.00	6.00	6.00
Calcium carbonate, $CaCO_3$	0.71	0.71	0.71	0.71
Monocalcium phosphate, $Ca(H_2PO_4)_2$	0.60	0.60	0.60	0.60
DL-methionine	0.19	0.19	0.19	0.19
L-lysine	0.06	0.04	0.03	0.01
L-threonine	0.11	0.10	0.10	0.10
Salt	0.32	0.32	0.32	0.32
Premix[1]	0.50	0.50	0.50	0.50
Calculated composition, %				
ME, kcal/kg	2,750	2,900	3,050	3,200
CP	20.00	20.00	20.00	20.00
Calcium	0.90	0.90	0.90	0.90
Available phosphorus	0.44	0.45	0.45	0.45
Digestible lysine	1.01	1.01	1.00	1.00
Digestible methionine	0.48	0.48	0.48	0.48
Digestible methionine + cystine	0.72	0.72	0.72	0.72
Digestible threonine	0.74	0.74	0.74	0.74
Digestible tryptophan	0.22	0.22	0.23	0.23
Analyzed composition, %				
DM	91.53	91.34	90.94	90.83
CP	20.91	20.83	20.90	20.72
CF	5.38	5.01	4.65	4.28
EE	4.39	6.29	8.40	10.29
Ash	7.53	7.14	6.82	6.64
Price, Baht/kg	14.16	14.74	15.32	15.90

[1]Premix (0.5%) provided the following (per kg of diet) : vitamin A, 15,000 IU; vitamin D_3, 3,000 IU; vitamin E, 25 IU; vitamin K_3, 5 mg; vitamin B_1, 2 mg; vitamin B_2, 7 mg; vitamin B_6, 4 mg; vitamin B_{12}, 25 mg; pantothenic acid, 11.04 mg; nicotinic acid, 35 mg; folic acid, 1 mg; biotin, 15 μg; choline chloride, 250 mg; Cu, 1.6 mg; Mn, 60 mg; Zn, 45 mg; Fe, 80 mg; I, 0.4 mg; Se, 0.15 mg

Table 3.3 Compositions of the experimental diets for Korat chickens in the period 6-9 wk of age (as-fed basis).

Items	Level of ME (kcal/kg)			
	2,750	**2,900**	**3,050**	**3,200**
Ingredient				
Corn	50.22	50.60	51.08	51.50
Soybean meal, 44% CP	18.41	19.44	20.50	21.56
Extracted rice bran	17.19	13.82	10.31	6.84
Rice bran oil	0.13	2.11	4.08	6.06
Full-fat soybean	1.00	1.00	1.00	1.00
Cassava pulp	5.00	5.00	5.00	5.00
Meat meal, 60% CP	6.00	6.00	6.00	6.00
Calcium carbonate, $CaCO_3$	0.55	0.55	0.55	0.55
Monocalcium phosphate, $Ca(H_2PO_4)_2$	0.48	0.48	0.48	0.48
DL-methionine	0.11	0.11	0.11	0.12
L-lysine	0.01	0.00	0.00	0.00
L-threonine	0.12	0.11	0.11	0.11
Salt	0.28	0.28	0.28	0.28
Premix[1]	0.50	0.50	0.50	0.50
Calculated composition, %				
ME, kcal/kg	2,750	2,900	3,050	3,200
CP	18.00	18.00	18.00	18.00
Calcium	0.80	0.80	0.80	0.80
Available phosphorus	0.41	0.41	0.41	0.42
Digestible lysine	0.85	0.85	0.86	0.87
Digestible methionine	0.38	0.38	0.38	0.39
Digestible methionine + cystine	0.60	0.60	0.60	0.60
Digestible threonine	0.68	0.68	0.68	0.68
Digestible tryptophan	0.19	0.19	0.19	0.20
Analyzed composition, %				
DM	90.70	90.66	91.04	90.80
CP	18.83	18.82	18.89	18.92
CF	5.22	4.86	4.48	4.11
EE	3.17	5.07	6.90	8.90
Ash	7.11	6.17	6.08	5.82
Price, Baht/kg	13.00	13.59	14.21	14.84

[1]Premix (0.5%) provided the following (per kg of diet) : vitamin A, 15,000 IU; vitamin D_3, 3,000 IU; vitamin E, 25 IU; vitamin K_3, 5 mg; vitamin B_1, 2 mg; vitamin B_2, 7 mg; vitamin B_6, 4 mg; vitamin B_{12}, 25 mg; pantothenic acid, 11.04 mg; nicotinic acid, 35 mg; folic acid, 1 mg; biotin, 15 µg; choline chloride, 250 mg; Cu, 1.6 mg; Mn, 60 mg; Zn, 45 mg; Fe, 80 mg; I, 0.4 mg; Se, 0.15 mg

Table 3.4 Compositions of the experimental diets for Korat chickens in the period 9-12 wk of age (as-fed basis).

Items	Level of ME (kcal/kg)			
	2,750	**2,900**	**3,050**	**3,200**
Ingredient				
Corn	52.63	55.61	56.06	56.50
Soybean meal, 44% CP	13.27	14.58	15.63	16.66
Extracted rice bran	19.65	13.97	10.50	7.08
Rice bran oil	0.09	1.50	3.48	5.45
Cassava pulp	6.00	6.00	6.00	6.00
Meat meal, 60% CP	6.00	6.00	6.00	6.00
Calcium carbonate, $CaCO_3$	0.58	0.58	0.58	0.58
Monocalcium phosphate, $Ca(H_2PO_4)_2$	0.50	0.50	0.50	0.50
DL-methionine	0.16	0.16	0.16	0.16
L-lysine	0.16	0.15	0.14	0.13
L-threonine	0.19	0.18	0.18	0.17
Salt	0.27	0.27	0.27	0.27
Premix[1]	0.50	0.50	0.50	0.50
Calculated composition, %				
ME, kcal/kg	2,750	2,900	3,050	3,200
CP	16.00	16.00	16.00	16.00
Calcium	0.80	0.80	0.80	0.80
Available phosphorus	0.40	0.40	0.41	0.41
Digestible lysine	0.85	0.85	0.85	0.85
Digestible methionine	0.41	0.41	0.41	0.41
Digestible methionine + cystine	0.60	0.60	0.60	0.60
Digestible threonine	0.68	0.68	0.68	0.68
Digestible tryptophan	0.16	0.16	0.16	0.17
Analyzed composition, %				
DM	90.98	90.75	90.47	90.48
CP	16.85	16.80	16.83	16.87
CF	5.32	4.73	4.36	3.99
EE	2.62	3.97	6.31	8.04
Ash	7.17	6.33	6.22	5.94
Price, Baht/kg	12.47	13.01	13.61	14.20

[1]Premix (0.5%) provided the following (per kg of diet) : vitamin A, 15,000 IU; vitamin D_3, 3,000 IU; vitamin E, 25 IU; vitamin K_3, 5 mg; vitamin B_1, 2 mg; vitamin B_2, 7 mg; vitamin B_6, 4 mg; vitamin B_{12}, 25 mg; pantothenic acid, 11.04 mg; nicotinic acid, 35 mg; folic acid, 1 mg; biotin, 15 µg; choline chloride, 250 mg; Cu, 1.6 mg; Mn, 60 mg; Zn, 45 mg; Fe, 80 mg; I, 0.4 mg; Se, 0.15 mg

3.4.5 Statistical analysis

All data were analyzed using CRD by the one-way analysis of variance (ANOVA) procedure of SAS software (SAS Institute, 1996). When the treatment effect was significant, the differences among treatment means were considered statistically significant at $P < 0.05$ by Duncan's New Multiple Range Test (DMRT) using SAS software (SAS Institute, 1996). The NLIN procedure of SAS software (SAS Institute, 1996) was used to determine the broken-line regression model for estimating the ME requirement of Korat chickens (Robbins et al., 2006). The broken-line regression model was as follows $y = l + u (r - x)$ where y = FCR; x = dietary energy level (kcal/kg); r = requirement of dietary energy; l = the response at x = r; and u = the steepness of the curve. In this model, y = l when x > r. R^2 value were determined as follows : $R^2 = (SST - SSE) / SST$ or $1 - (SSE / SST)$ when SSE = sum of squared residuals or sum of squared error, SST = sum of squared total.

3.4.6 Experimental location

The experiment was conducted at Suranaree University of Technology's poultry farm, the Center for Scientific and Technological Equipment Building 10, Suranaree University of Technology.

3.4.7 Experimental period

The experiment was done from January 2014 to May 2014.

3.5 Results and discussion

3.5.1 Period 0-3 wk of age

The effects of dietary energy on growth performance and feed cost of Korat chickens in the period 0-3 wk of age are presented in Table 3.5. There were significant differences ($P < 0.05$) in FI, FCR and protein intake whereas no significant differences were found in BW, BWG, ADG, ME intake, EER and feed cost per kg of BWG among treatments ($P > 0.05$). As dietary energy levels increased from 2,750 to 3,200 kcal of ME/kg, the average FI was decreased. The birds fed a diet containing 2,750 kcal of ME/kg consumed more feed about 9.94 and 13.98% than those fed diet containing 3,050 and 3,200 kcal of ME/kg, respectively ($P < 0.05$), but no change occurring in BWG. In general, birds can adjust their FI to primarily meet the energy requirements and changing demands for calories (Morris, 1968; Golian and Maurice, 1992; Leeson et al., 1993). Although the difference of ME intake between the lowest and highest energy diets (2,750 vs. 3,200 kcal of ME/kg) was approximately 24 kcal of ME/birds (2.10%), there were no significant effects of ME intake, BWG and EER among treatments. This observation is corroborated by Leeson and Summers (2005), who also reported that energy intake was independent of the ME content of the diet within a range of 2,700 to 3,300 kcal of ME/kg. This finding is also in agreement with Leeson et al. (1996) who revealed that poultry can adjust their FI for the difference in the dietary ME level to maintain a constant ME intake. Normally, dietary energy content is a key role in the control of FI (MacLeod, 2002). Other factors, such as size and age, environmental temperature, daylight, activity, stage of reproduction, feed palatability, dietary factors, dietary toxicities and availability of water (Ferket and Gernat, 2006; Duke, 1986) are related to FI and needed to be concerned. Furthermore, the differences of the breed also influence on FI, and this may be a different gene encoding key regulatory factors, like, hormones, enzymes and metabolic pathway (Richards and Proszkowiec-Weglarz, 2007).

Table 3.5 Effects of dietary energy on growth performance and feed cost of Korat chickens in the period 0-3 wk of age.

Items	**Level of ME, kcal/kg**				**SEM**	***P*-value**
	2,750	**2,900**	**3,050**	**3,200**		
FI, g/bird	415.72[a]	395.27[ab]	378.12[bc]	364.72[c]	7.02	0.0003
BW 1-d-old, g/bird	38.78	39.06	39.11	39.00	0.18	0.5696
BW 3-wk-old, g/bird	271.11	279.40	278.58	274.17	2.60	0.1155
BWG, g/bird	232.33	240.34	239.47	235.17	2.59	0.1313
ADG, g/bird/day	11.06	11.44	11.40	11.20	0.12	0.1344
FCR, g of feed/g of BWG	1.79[a]	1.64[b]	1.58[b]	1.55[b]	0.03	0.0001
Feed cost/BWG, Baht/kg	28.08	26.80	26.69	27.10	0.50	0.2174
Protein intake, g/bird	99.73[a]	94.74[b]	90.08[bc]	87.40[c]	1.68	0.0002
ME intake, kcal/bird	1,143	1,146	1,153	1,167	21.04	0.8569
EER, %	20.35	20.98	20.79	20.19	0.36	0.3981

[a, b, c]Means within each row with different superscripts are significantly different ($P < 0.05$).

The FCR improved by 13.41% with increasing dietary energy levels from 2,750 to 3,200 kcal of ME/kg but there was no significant change on the EER ($P = 0.3981$) because both ME intake and BWG were similar among treatments. Thus increasing dietary ME levels could directly affect FCR. Since the experimental diets were formulated to be isonitrogenous, this made the protein intake dropped by 12.36% when increasing dietary energy from 2,750 to 3,200 kcal of ME/kg although the protein intake alteration did not affect the birds' BWG. This interpretation is in line with the observation that EER remained similar with decreasing protein intakes. The poorer FCR was found in 2,750 and 2,750 to 2,900 kcal of ME/kg, respectively. In fact, although birds were able to alter their feed consumption to fulfill the energy requirement, others nutrients, such as protein in each dietary treatment, which were formulated at a constant level, may be over the birds' requirements, resulting in reduced feed efficiency in the low energy diets of the current study. A similar result was also found in broilers, Pekin ducks, Japanese quails, Korean native ducklings and indigenous crossbred chickens (Nahashon et al., 2005; Ghaffari et al., 2007; Fan et al., 2008; Mosaad and Iben, 2009; Xie et al., 2010; Dozier et al., 2011; Gheisari et al., 2011; Engku Azahan et al., 2011; Wickramasuriya et al., 2015).

In this study, although the fiber content in the lowest and highest ME diets differ approximately 1.12% in all periods (0-12 wk of age) from using extracted rice bran to adjust the energy, the CF content (3.99-5.38%) still did not exceed the recommended level. Latshaw (2008) found that FI and BWG of broilers were not changed significantly when increasing dietary fiber level from 5.88 to 9.78%. Moreover, the growth performance of the Korat chickens in the present study was similar to the observation measured in SUT's poultry farm in the periods 0-12 wk of age (Likitdecharote et al., 2012; Molee et al., 2015; Maliwan et al., unpublished data). Therefore, the varying levels of CF in all experimental diets may not be a key factor to interfere the response of Korat chickens to their dietary energy.

3.5.2 Period 3-6 wk of age

The effects of dietary energy on growth performance and feed cost of Korat chickens in the period 3-6 wk of age are shown in Table 3.6. There were significant differences in FI, FCR, protein intake and ME intake ($P < 0.05$), while no significant differences were found in BW, BWG, ADG, EER and feed cost per kg of BWG ($P > 0.05$). In this period, FI decreased significantly as dietary ME levels increased from 2,750 to 3,200 kcal of ME/kg ($P < 0.05$) in which chickens fed with 2,750 kcal of ME/kg consumed more feed as compared with the other groups ($P < 0.05$). However, there were no significant effects on BWG, so FCR was adversely affected by increased dietary ME content, similarly as found in the period 0-3 wk of age. Even though the birds in this period attempted to adjust FI in order to satisfy their energy requirement, the daily ME intake of chickens fed with low energy diets were still insufficient and their BWG was likely to be reduced (P = 0.1883).

Table 3.6 Effects of dietary energy on growth performance and feed cost of Korat chickens in the period 3-6 wk of age.

Items	**Level of ME, kcal/kg**				**SEM**	***P*-value**
	2,750	**2,900**	**3,050**	**3,200**		
FI, g/bird	1,104^{a}	1,056^{b}	1,021^{c}	989^{d}	10.52	0.0001
BW 3-wk-old, g/bird	276.95	279.44	277.50	277.61	2.07	0.8432
BW 6-wk-old, g/bird	783.87	791.83	791.56	794.33	4.42	0.3925
BWG, g/bird	506.92	512.39	514.06	516.72	3.12	0.1883
ADG, g/bird/day	24.14	24.40	24.48	24.61	0.15	0.1843
FCR, g of feed/g of BWG	2.18^{a}	2.06^{b}	1.99^{c}	1.91^{d}	0.02	0.0001
Feed cost/BWG, Baht/kg	30.84	30.37	30.41	30.44	0.28	0.5493
Protein intake, g/bird	230.90^{a}	219.92^{b}	213.36^{c}	205.03^{d}	2.19	0.0001
ME intake, kcal/bird	3,036^{b}	3,062^{b}	3,113^{ab}	3,166^{a}	30.91	0.0356
EER, %	16.71	16.74	16.52	16.33	0.14	0.1659

$^{a, b, c, d}$Means within each row with different superscripts are significantly different (P < 0.05).

Interestingly, FCR was improved (approximately 12.39%) when increasing dietary energy levels from 2,750 to 3,200 kcal of ME/kg. This phenomenon could be due to a decreased FI; however, BWG was similar among treatments. The increased FI in chickens fed with low energy diets, and a consequence of higher protein intake lead to an excess protein or imbalanced amino acid which is higher than their requirement. As a result, these birds had poorer FCR since they utilized excess protein or amino acids inefficiently and these surplus amino acids were deaminated and excreted as uric acid (Kamran et al., 2004). Moreover, it is likely that energy expenditure was used for catabolism and the excess of amino acids (MacLeod, 1997). In general, the metabolism of protein generates heat production, approximately 30%, which is higher than carbohydrate and fat (Scott et al., 1982; Klasing, 1998). Thus, this phenomenon is another factor that may cause the poor FCR in birds fed with low energy diets.

3.5.3 Period 6-9 wk of age

The effects of dietary energy on growth performance and feed cost of Korat chickens in the period 6-9 wk of age are presented in Table 3.7. There were significant differences in FI and FCR ($P < 0.05$), while no significant differences were found in BW, BWG, ADG, protein intake, ME intake, EER and feed cost per kg of BWG ($P < 0.05$). As dietary energy levels increased from 2,750 to 3,200 kcal of ME/kg, the average FI was decreased. The birds fed a diet containing 2,750 kcal of ME/kg consumed more feed about 8.15% than those birds fed a diet containing 3,200 kcal of ME/kg ($P < 0.05$), but there was no change occurring in their growth performance or final weights. Although the birds in this period attempted to adjust FI to compensate for the low energy diets; however, due to a physical gut capacity, the ingested ME could not satisfy their energy requirement (Griffiths et al., 1977; Hidalgo et al., 2004; Ferket and Gernat, 2006; Kamran et al., 2008a, b). Moreover, the birds become larger when they grow older, and the physical constraint on the amount of FI is decreased (Griffiths et al., 1977; Hidalgo et al., 2004; Kamran et al., 2008b).

The protein intake tended to decrease ($P = 0.0526$), while ME intake was likely to increase ($P = 0.0781$) with increasing dietary ME levels. On the other hand, the daily ME intake of chickens fed with low energy diets are still inadequate and tended to reduce BWG (*P* = 0.2052). Similar to the finding in the periods 0-3 and 3-6 wk of age, all diets were formulated based on isonitrogenous basis, therefore, increased FI in the bird groups fed with low energy diets caused an increase in the protein intake. In addition, an excess of protein intake in chickens received low energy diets also requires more energy for metabolizing excessive amounts of protein (amino acids) and hence less energy is available for growth (Chen et al., 1999).

Table 3.7 Effects of dietary energy on growth performance and feed cost of Korat chickens in the period 6-9 wk of age.

Items	**Level of ME, kcal/kg**				**SEM**	***P*-value**
	2,750	**2,900**	**3,050**	**3,200**		
FI, g/bird	1,486^{a}	1,476^{a}	1,424^{ab}	1,374^{b}	27.63	0.0340
BW 6-wk-old, g/bird	799.30	794.62	797.44	790.71	5.06	0.6571
BW 9-wk-old, g/bird	1,283	1,302	1,308	1,312	15.02	0.5289
BWG, g/bird	483.27	507.56	510.99	521.22	12.44	0.2052
ADG, g/bird/day	23.01	24.17	24.33	24.82	0.59	0.2052
FCR, g of feed/g of BWG	3.08^{a}	2.91^{b}	2.79^{c}	2.64^{d}	0.03	0.0001
Feed cost/BWG, Baht/kg	40.02	39.56	39.63	39.15	0.34	0.3731
Protein intake, g/bird	279.83	277.83	269.06	259.97	5.21	0.0526
ME intake, kcal/bird	4,087	4,281	4,343	4,397	83.31	0.0781
EER, %	11.82	11.85	11.76	11.85	0.10	0.9111

$^{a, b, c, d}$Means within each row with different superscripts are significantly different (*P* < 0.05).

In this period, FCR was improved approximately 14.29% when increasing dietary energy levels from 2,750 to 3,200 kcal of ME/kg, but there was no significant change on the EER (*P* = 0.9111) because both ME intake and BWG were similar among treatments.

3.5.4 Period 9-12 wk of age

The effects of dietary energy on growth performance and feed cost of Korat chickens in the period 9-12 wk of age are presented in Table 3.8. There were significant ($P < 0.05$) effects of dietary energy levels on FI, FCR, protein intake and ME intake (Table 3.8). Body weight, BWG, ADG, feed cost per kg of BWG and EER of chickens were not different ($P > 0.05$) among treatments. However, BWG tended to increase with increasing dietary ME levels ($P = 0.0501$). The lower BWG of birds fed with 2,750 and 2,900 kcal of ME/kg diets could be due to inadequate energy requirement. Although, the birds attempted to increase FI in the low energy diets in an effort to maintain their energy need, this consumption did not fulfill their energy requirement. It may be due to physical limitations (Griffiths et al., 1977; Hidalgo et al., 2004). In addition, the lower BWG in bird groups fed low energy diets was probably because of an excess of protein intake, and these birds may require more energy for the metabolizing excessive amounts of protein or amino acids, and thus less energy is available for growth or less energy efficiency utilization for growth (Chen et al., 1999). This finding could suggest that it is reasonable to reduce BWG in these birds. The birds fed a diet containing 2,750 kcal of ME/kg consumed more feed about 5.08, 6.67 and 7.03% than those fed diets containing 2,900, 3,0750 and 3,200 kcal of ME/kg, respectively ($P < 0.05$), but there was no change occurring in their growth performance or final weights. Moreover, the decline in FI did not fully counteract with the increasing dietary ME levels and energy intake was found to be 8.72% greater ($P = 0.0016$) when the feed contained 3,200 instead of 2,750 kcal ME/kg. However, it may be suggested that the observed greater ME intake is, at least apparently, not relevant in terms of BWG because BWG was found to be similar among treatments. This notion is in line with the observation that EER was not affected (P = 0.7195) by the experimental diets.

Table 3.8 Effects of dietary energy on growth performance and feed cost of Korat chickens in the period 9-12 wk of age.

Items	Level of ME, kcal/kg				SEM	P-value
	2,750	2,900	3,050	3,200		
FI, g/bird	1,752[a]	1,663[b]	1,639[b]	1,637[b]	24.26	0.0098
BW 9-wk-old, g/bird	1,262	1,260	1,275	1,263	8.57	0.6176
BW 12-wk-old, g/bird	1,703	1,701	1,727	1,740	13.17	0.1462
BWG, g/bird	441.46	441.88	452.59	476.18	9.25	0.0501
ADG, g/bird/day	21.02	21.04	21.55	22.68	0.44	0.0502
FCR, g of feed/g of BWG	3.97[a]	3.77[b]	3.63[c]	3.44[d]	0.03	0.0001
Feed cost/BWG, Baht/kg	49.52	48.95	49.32	48.86	0.46	0.7191
Protein intake, g/bird	295.17[a]	279.33[b]	275.84[b]	276.08[b]	4.08	0.0091
ME intake, kcal/bird	4,817[b]	4,822[b]	4,999[b]	5,237[a]	72.53	0.0016
EER, %	9.16	9.16	9.05	9.09	0.09	0.7195

[a, b, c, d]Means within each row with different superscripts are significantly different (P < 0.05).

As increasing dietary energy levels from 2,750 to 3,200 kcal of ME/kg, FCR was improved by 13.35% but there was no significant effect of ME content on the EER (P = 0.7195) of birds in this period. The improved FCR of chickens was due to a reduction in FI caused by high dietary energy, with no change occurring in BWG and tended to increase BWG (P = 0.0501). In the light of the fore mentioned data and the fact that isonitrogenous diets were fed, better FCR which is similar to the periods 0-3, 3-6 and 6-9 wk of age was identified.

3.5.5 Broken-line regression analysis for estimating ME requirement

The result of the estimating ME requirement of Korat chickens based on broken-line regression analysis in aged 0-3, 3-6, 6-9 and 9-12 wk are presented in Table 3.9. In the period 0-3 wk of age, the estimated ME requirement for optimal FCR of Korat chickens was 2,978 kcal/kg while daily ME requirement was 59 kcal/bird/d. The regression equations predicted the ME requirement for optimal FCR was $y = 1.5658 + 0.00099 \times (2{,}978 - x)$ [$P < 0.01$, $R^2 = 0.65$]. In the period 3-6 wk of age, the ME requirement for optimal FCR of Korat chickens was 3,151 kcal/kg and daily ME requirement was 152 kcal/bird/d. The regression equations predicted the ME requirement for optimal FCR was $y = 1.915 + 0.00064 \times (3{,}151 - x)$ [$P<0.01$, $R^2 = 0.85$]. Finally, the estimated ME requirement for optimal FCR of Korat chickens in the periods 6-9 and 9-12 wk of age were 3,200 kcal/kg whereas daily ME requirement were 209 and 249 kcal/bird/d, respectively. For the regression equations predicted the ME requirement for optimal FCR in the periods 6-9 and 9-12 wk of age were $y = 2.6367 + 0.00097 \times (3{,}200 - x)$ [$P<0.01$, $R^2 = 0.89$] and $y = 3.44 + 0.00116 \times (3{,}200 - x)$ [$P<0.01$, $R^2 = 0.86$], respectively.

However, the ME requirement of Korat chicken in each experimental period was higher than those of other breeds of Thai indigenous crossbred as proposed by Tangtaweewipat et al. (2000); Pingmuang et al. (2001); Polsiri (2001) and Nguyen et al. (2010). In particular, their energy requirement were expressed in a range of 2,800-2,900 kcal/kg of the diet in aged 0-3 and 3-6 wk and in a range of 2,800-3,000 kcal/kg of the diet in aged 6-12 wk. While the ME requirement of Korat chickens in aged 0-3 and 3-6 wk were lower than those of broiler chickens (3,200 kcal/kg of the diet), but were similar to those of broiler chickens (3,200 kcal/kg of the diet) in the period 6-8 wk of age (NRC, 1994; Leeson and Summers, 2005). Regarding daily ME requirement, the broiler chickens require higher ME than Korat chickens about 2.28 to 2.83 times in all periods (134 vs. 59, 395 vs. 152 and 592 vs. 209 kcal/bird/d during 0-3, 3-6 and 6-9 wk of age, respectively). In general, the FI of broiler chickens was higher than that of Korat chickens, approximately 2-3 times to achieve the maximum growth rate and maximum meat yield. The energy requirement of Korat chickens per g of BWG in the periods 0-3, 3-6, 6-9 and 9-12 wk of age were 5.15, 6.20, 8.44 and 11.00 kcal, respectively while the requirement in broilers aged 0-3, 3-6 and 6-9 wk were 4.61, 6.57 and 9.70 kcal/g of BWG, respectively (NRC, 1994). Lopez and Leeson (2005) also reported that the energy requirement of broilers in aged 2, 4 and 6 were 5.00, 7.00 and 7.00 kcal/g of BWG, respectively.

Table 3.9 Metabolizable energy requirement of Korat chickens based on broken-line model analyses in the periods 0-3, 3-6, 6-9 and 9-12 wk of age.

Items	Regression equations[1]	Estimated Requirement[1]	SE	*P*-value	R^2
0-3 wk					
FCR	y = 1.5658 + 0.00099 × (2,978 – x)	2,978	52.70	0.0001	0.65
3-6 wk					
FCR	y = 1.9150 + 0.00064 × (3,151 – x)	3,151	45.78	0.0001	0.85
6-9 wk					
FCR	y = 2.6367 + 0.00097 × (3,200 – x)	3,200	47.38	0.0001	0.89
9-12 wk					
FCR	y = 3.4400 + 0.00116 × (3,200 – x)	3,200	54.18	0.0001	0.86

[1]The linear broken-line model is y = l + u × (r − x), where y = FCR; x = dietary ME level (kcal/kg); r = Requirement of dietary ME; l = the response at x = r; and u = the steepness of the curve. In this model, y = l when x > r.

Moreover, it may be attributed to the types of chicken breed, which cause differences in daily ME requirement for optimal growth performance between Korat chickens and other breeds. In addition, genetic improvements in the growth rate have been continuous and generally ahead of the established nutrient requirements needed for optimal performance or specific production. Furthermore, each of chicken breed grows with its own characteristics and proportions of body tissues, and there is a consequence of the daily ME requirements for maintenance and growth. The current commercial broiler chickens require high ME in order to meet the rapid growth (Pym, 1990; NRC, 1994; Klasing, 1998; Zhao et al., 2009), and this is consistent with the report by Emmans and Fisher (1986) which indicated that chickens grow based on their genetic potentials. It is also interesting to note that the ME requirement was increased with age. This is because old birds require higher-ME for maintenance which includes ME for basal metabolic rate, heat increment, thermoreguation and activities of chickens and depositing tissues (NRC, 1994). This supports the data of Sales and Du Preez (1997), who reported a steady increase in energy requirement proportionate to the age of birds.

3.6 Conclusion

Based on the current results, the ME requirement for optimal FCR of Korat chickens in the period 0-3, 3-6, 6-9 and 9-12 wk of age were 2,978, 3,151, 3,200 and 3,200 kcal/kg, respectively while daily ME requirement of Korat chickens in the period 0-3, 3-6, 6-9 and 9-12 wk of age were 59, 152, 209 and 249 kcal/bird/d, respectively.

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CHAPTER IV

THE STUDY OF PROTEIN REQUIREMENT OF KORAT CHICKENS FROM 0 TO 12 WEEKS OF AGE

4.1 Abstract

The aim of this study was to estimate the protein requirement of Korat chickens from 0 to 12 wk of age, which were divided into 4 experimental periods : 0-3, 3-6, 6-9 and 9-12 wk of age. The numbers of mixed-sex Korat chickens used in each experimental periods were 900, 780, 720 and 720 birds, respectively. The chickens were randomly divided into 5 dietary treatments, with 6 replicates of each treatment in a completely randomized design (CRD) and each replicate was assigned to receive one of the experimental diets, which composed of 5 dietary protein levels for each experimental period as follows : 19, 20, 21, 22 and 23% (period 0-3 wk of age); 18, 19, 20, 21 and 22% (period 3-6 wk of age); 16, 17, 18, 19 and 20% (period 6-9 wk of age); and 15, 16, 17, 18, and 19% (period 9-12 wk of age). All experimental diets of each experimental period were formulated to contain the same ME content of 2,978, 3,151, 3,200 and 3,200 kcal/kg, respectively. The results showed that the growth performance of chickens in terms of body weight, body weight gain (BWG), average daily gain as well as the protein intake were increased with increasing dietary protein levels ($P < 0.05$). Although feed conversion ratio (FCR) and energy efficiency ratio of chickens in the periods 0-3 and 3-6 wk of age were not affected by the dietary protein levels, the significant improvement ($P < 0.05$) was found in the periods 6-9

and 9-12 wk of age. Additionally, increasing dietary protein levels depressed the protein efficiency ratio of chickens in the periods 0-3 and 9-12 wk of age ($P < 0.05$), while this negative effect was slightly shown in the periods 3-6 and 6-9 wk of age. According to the broken-line regression analysis, the protein requirements of Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age for optimal BWG were 21.26, 20.45, 18.00 and 17.94%, respectively, whereas the protein requirements of Korat chickens in the periods 6-9 and 9-12 wk of age for optimal FCR were 18.04 and 18.03%, respectively.

Key words : growth performance, Korat chicken, protein, requirement

4.2 Introduction

Chicken meat is an important source of protein in human diets and it will play an increasingly significant role in the global food supply for human nutrition in the future. To date, consumers have become more concerned about health and chicken meat quality. White meat, like chicken meat, is considered superior in health aspects to red meat because of comparably less fat and low cholesterol. In addition, consumers tend to prefer slow-growing indigenous chickens over fast-growing commercial broilers as the broiler meat seems to have a negative impact on the functional qualities and sensory properties (Jaturasitha et al., 2008; Dyubele et al., 2010). Therefore, in Southeast Asian countries, including Thailand, consumers always prefer indigenous and crossbred (50%) chickens meat with appearance high in sensory quality, texture and flavor and healthy meat. As a result, their other good characteristics, namely disease resistance, tolerance of heat stress, and good maternal ability are heritable and need to be conserved (Choprakarn and Wongpichet, 2008; Wattanachant, 2008). This chicken breed has been widely raised because it could adapt to the climate and environmental conditions in Thailand. The Korat chicken is one of the Thai indigenous crossbred (50%) chicken strains derived from breeder lines through a cross breeding program. Korat chicken meat has a unique taste, texture, less fat and high collagen. It is also more delicious so that it attracts domestic consumers to a greater extent than the broiler meat. The demand for this meat is generally increased although its price is about 1.5-2 times higher than that of broiler meat.

Protein plays an important role in growth, maintenance, and repair of tissues in the body. The dietary requirement for protein is actually a requirement for amino acid contained in the protein. Amino acids obtained from dietary protein are used by poultry to fulfill a variety of functions such as constituents of structural component of skin, feathers, bone matrix, ligaments and soft tissues, as well as to serve as an important metabolic roles in blood plasma protein, enzymes, hormones, and immune antibodies (NRC, 1994; Pond et al., 2005). Chickens require the essential amino acid and some amounts of nonessential amino acid to synthesize the protein at the acceptable rates (Pesti, 2009). The sum of the essential and non-essential amino acid requirements of the bird are functions of the total CP level, and it may also be referred to as the CP requirement. According to the NRC (1994) recommendation, the protein requirement for 0-3, 3-6 and 6-8 wk old broilers are approximately 23, 20 and 18%, respectively. In case of indigenous crossbred chickens in Thailand, although previous studies suggested that the protein requirements of various crossbred chickens during 0-16 wk of age were about 15-21% of CP with the dietary energy of 2,600-3,200 kcal ME/kg (Vorachantra and Tancho, 1996; Chomchai et al., 1998a, b; Tangtaweewipat et al., 2000; Pingmuang et al., 2001; Tananchai et al., 2001; Polsiri, 2001; Chomchai, et al., 2003; Nguyen and Bunchasak, 2005; Nguyen et al., 2010), such recommendations with a too wide age range of chicken may not be appropriate data to apply in Korat chickens for a whole period of age. If the dietary protein is insufficient, there is a reduction in the growth rate and a withdrawal of the protein from less vital body tissues to maintain the functions of more vital tissues (NRC, 1994) or degradation tissues protein in the body (Sharma, 2010). On the other hand, if the dietary protein is exceeded, the protein may excrete in the form of excreta, resulting in environmental pollution and increasing production cost (Leeson and Summers, 2005). Thus, there is crucially important for the arrangement of appropriate feeds in Korat chicken; however, information on the protein requirement for the Korat chickens is lacking. Therefore, the objective of this study was to estimate the protein requirement of Korat chickens from 0 to 12 wk of age.

4.3 Objective

The objective of this experiment was to investigate the protein requirements of Korat chickens from 0 to 12 wk of age.

4.4 Materials and methods

All experiments were conducted according to principles and guidelines approved by the Animal Care and Use Committee of Suranaree University of Technology.

4.4.1 Bird husbandry

In this study, the whole experimental period was divided into 4 phases : 0-3, 3-6, 6-9 and 9-12 wk of age in order to estimate the protein requirements of Korat chickens. A total of 3,700 one-d-old Korat chicks were obtained from a hatchery and raised in an open-sided, naturally ventilated chicken house. The lighting was provided continuously for 24 h. These birds were reared on the floor pens littered with rice husks.

All chicks were vaccinated at the hatchery for Marek's disease, inoculated with Newcastle disease and infectious bronchitis vaccines on d 7 and 21, with inactivated infectious bursal disease (Gumboro) vaccine on d 14 and with flow pox vaccine on d 35. The chicks were fed with a commercial broiler diet (CPF Public Company Ltd., Nakhon Ratchasima, Thailand), with 21, 19 and 17% CP diets in the periods 0-3, 3-6 and 6-9 wk of age, respectively. Feed and water were available for *ad libitum* consumption. The birds were kept under standard management conditions, and when the chickens were 21-d-old, 42-d-old and 63-d-old, they were used for the start of each experimental period.

Prior to each experiment, the birds were weighed individually and randomly allocated into each of 30 experimental units (1.75×2.40 m^2) in such a way as to reduce variations in mean chick weights per pen. Each pen was equipped with a tray feeder until 14 d of age and was replaced with a hanging feeder, a nipper-type drinker line (7 nipples) and used the litter. Birds were offered with the experimental diets (mash form) on an *ad libitum* basis for the period of study, fresh water was also provided freely throughout the experimental period, and lighting was continuous for 24 h. As each pen was equipped with a 100-Watt scroll bulb to maintain continuous light during the night. A completely randomized design (CRD) was utilized in all the experiments.

Upon arrival, the mixed-sex Korat chickens were used at 1-d-old (900 birds, average initial BW = 43.34 ± 0.30 g), 21-d-old (780 birds, average initial BW = 275.59 ± 3.10 g), 42-d-old (720 birds, average initial BW = 748.90 ± 9.83 g) and 63-d-old (720 birds, average initial BW = 1,076.65 ± 13.57 g) in the experimental periods 0-3, 3-6, 6-9 and 9-12 wk of age, respectively. In each experimental period, birds were randomly divided into 4 dietary treatments, with 6 replicate pens per treatment which contained 30, 30, 26 and 24 birds per pen (stocking density 6-7 birds/m^2), respectively. All of the birds were reared under the similar conditions until the ages of 3 or 6 or 9 or 12 wk, before the birds in each period were allocated to receive the experimental diets.

4.4.2 Dietary treatment

There were five dietary treatments in each experimental period. The dietary treatments were formulated to contain 19, 20, 21, 22 and 23% CP in the period 0-3 wk of age; 18, 19, 20, 21 and 22% CP in the period 3-6 wk of age; 16, 17, 18, 19 and 20% CP in the period 6-9 wk of age, and 15, 16, 17, 18, and 19% CP in the period 9-12 wk of age, respectively. All experimental diets were formulated to meet or exceed the nutrient requirements for the broiler recommended specification by NRC (1994) except the ME content. The dietary ME levels of each period were formulated based on the results of the previous study (chapter III), in which the dietary ME content in the experimental periods 0-3, 3-6, 6-9 and 9-12 wk of age were 2,978, 3,151, 3,200 and 3,200 kcal of ME/kg, respectively. The digestible amino acid (lysine, methionine, threonine and tryptophan) content of the diets was calculated based on the digestibility value of feedstuffs (NRC, 1994; Ajinomoto, 1998). In addition, the ratios of the essential amino acids to protein levels were similar between the dietary treatments

(Baéza et al., 2012). Crystalline amino acids (lysine, methionine, and threonine) were added to achieve the essential amino acid requirements. All diets were provided in mash form. Feed ingredients and compositions of the experimental diets in the periods 0-3, 3-6, 6-9 and 9-12 wk of age are shown in Tables 4.1, 4.2, 4.3 and 4.4, respectively.

4.4.3 Data collection

Feed intake and BW were recorded by pen at the initial and the end of each experimental period. These data were used to calculate for BWG, average daily gain (ADG), feed conversion ratio (FCR : feed/gain), feed cost per kg of BWG, protein intake and ME intake. Protein efficiency ratio (PER) and energy efficiency ratio (EER) were also calculated for each period. The PER was calculated as g of BWG per g of protein intake, whereas the EER was calculated as g of BWG × 100/total ME intake. Mortality was recorded as it occurred.

At the end of each experimental period (3, 6, 9 and 12 wk of age), the blood samples were collected from the bird's jugular or wing vein (two birds per pen) at 2 h post-feeding (Donsbough et al., 2010). Blood was placed in 5-ml plastic polypropylene tubes without ethylene diamine tetraacetic acid (EDTA), and the samples were held on the ice until centrifuged at 1,609 × g at 4°C for 10 min, and subsequently serum (0.5 ml) of each tube was collected for the blood urea nitrogen (BUN) analysis (Mathies, 1960; Anino and Giese, 1976).

4.4.4 Laboratory analysis

All experimental diets were sampled in duplicate and prepared for proximate, which was analyzed in triplicate for their DM, CP, EE, CF and ash content according to AOAC (1990) as described in chapter III (see section 3.4.4). The chemical analysis was expressed on the air dry basis.

Table 4.1 Compositions of the experimental diets for Korat chickens in the period 0-3 wk of age (as-fed basis).

Items	Level of CP				
	19%	**20%**	**21%**	**22%**	**23%**
Ingredient					
Corn	53.79	50.25	46.63	43.02	39.45
Soybean meal, 44% CP	20.93	23.93	26.95	29.95	32.97
Rice bran oil	2.26	2.84	3.45	4.05	4.64
Extracted rice bran	7.08	7.08	7.08	7.08	7.08
Full-fat soybean	4.00	4.00	4.00	4.00	4.00
Cassava pulp	3.00	3.00	3.00	3.00	3.00
Meat meal, 60% CP	6.00	6.00	6.00	6.00	6.00
Calcium carbonate, $CaCO_3$	0.92	0.92	0.90	0.90	0.88
Monocalcium phosphate, $Ca(H_2PO_4)_2$	0.75	0.70	0.70	0.68	0.66
DL-methionine	0.23	0.25	0.27	0.29	0.31
L-lysine	0.06	0.04	0.03	0.02	0.00
L-threonine	0.05	0.06	0.06	0.06	0.06
Salt	0.43	0.43	0.43	0.45	0.45
Premix[1]	0.50	0.50	0.50	0.50	0.50
Calculated composition, %					
ME, kcal/kg	2,978	2,978	2,978	2,978	2,978
CP	19.00	20.00	21.00	22.00	23.00
Calcium	1.00	1.00	1.00	1.00	1.00
Available phosphorus	0.48	0.48	0.48	0.48	0.48
Digestible lysine	0.96	1.02	1.07	1.12	1.17
Digestible methionine	0.52	0.54	0.57	0.60	0.63
Digestible methionine + cystine	0.75	0.79	0.83	0.87	0.90
Digestible threonine	0.66	0.70	0.74	0.77	0.81
Digestible tryptophan	0.21	0.23	0.24	0.26	0.28
Analyzed composition, %					
DM	90.70	90.63	90.49	90.15	90.22
CP	19.46	20.48	21.42	22.41	23.48
CF	4.04	4.17	4.30	4.43	4.56
EE	5.82	6.21	6.85	7.13	7.85
Ash	6.84	6.58	7.04	7.75	7.73
Price, Baht/kg	15.43	15.86	16.31	16.75	17.19

[1]Premix (0.5%) provided the following (per kg of diet) : vitamin A, 15,000 IU; vitamin D_3, 3,000 IU; vitamin E, 25 IU; vitamin K_3, 5 mg; vitamin B_1, 2 mg; vitamin B_2, 7 mg; vitamin B_6, 4 mg; vitamin B_{12}, 25 mg; pantothenic acid, 11.04 mg; nicotinic acid, 35 mg; folic acid, 1 mg; biotin, 15 µg; choline chloride, 250 mg; Cu, 1.6 mg; Mn, 60 mg; Zn, 45 mg; Fe, 80 mg; I, 0.4 mg; Se, 0.15 mg.

Table 4.2 Compositions of the experimental diets for Korat chickens in the period 3-6 wk of age (as-fed basis).

Items	Level of CP				
	18%	19%	20%	21%	22%
Ingredient					
Corn	54.46	50.87	47.28	43.72	40.12
Soybean meal, 44% CP	19.35	22.35	25.37	28.37	31.38
Extracted rice bran	6.98	6.98	6.98	6.98	6.98
Rice bran oil	4.74	5.34	5.93	6.52	7.12
Full-fat soybean	3.00	3.00	3.00	3.00	3.00
Cassava pulp	3.00	3.00	3.00	3.00	3.00
Meat meal, 60% CP	6.00	6.00	6.00	6.00	6.00
Calcium carbonate, $CaCO_3$	0.74	0.73	0.71	0.71	0.70
Monocalcium phosphate, $Ca(H_2PO_4)_2$	0.62	0.60	0.60	0.57	0.55
DL-methionine	0.16	0.17	0.19	0.20	0.22
L-lysine	0.05	0.04	0.02	0.01	0.00
L-threonine	0.09	0.10	0.10	0.10	0.11
Salt	0.31	0.32	0.32	0.32	0.32
Premix[1]	0.50	0.50	0.50	0.50	0.50
Calculated composition, %					
ME, kcal/kg	3,151	3,151	3,151	3,151	3,151
CP	18.00	19.00	20.00	21.00	22.00
Calcium	0.90	0.90	0.90	0.90	0.90
Available phosphorus	0.45	0.45	0.45	0.45	0.45
Digestible lysine	0.90	0.95	1.00	1.05	1.11
Digestible methionine	0.43	0.45	0.48	0.50	0.53
Digestible methionine + cystine	0.65	0.68	0.72	0.75	0.79
Digestible threonine	0.67	0.70	0.74	0.78	0.82
Digestible tryptophan	0.20	0.21	0.23	0.25	0.26
Analyzed composition, %					
DM	90.51	90.53	90.66	90.46	90.46
CP	18.49	19.75	20.58	21.53	22.69
CF	3.92	4.05	4.18	4.31	4.45
EE	6.06	6.58	7.02	7.35	8.00
Ash	6.82	6.54	6.63	6.77	6.95
Price, Baht/kg	15.51	15.94	16.38	16.81	17.26

[1]Premix (0.5%) provided the following (per kg of diet) : vitamin A, 15,000 IU; vitamin D_3, 3,000 IU; vitamin E, 25 IU; vitamin K_3, 5 mg; vitamin B_1, 2 mg; vitamin B_2, 7 mg; vitamin B_6, 4 mg; vitamin B_{12}, 25 mg; pantothenic acid, 11.04 mg; nicotinic acid, 35 mg; folic acid, 1 mg; biotin, 15 µg; choline chloride, 250 mg; Cu, 1.6 mg; Mn, 60 mg; Zn, 45 mg; Fe, 80 mg; I, 0.4 mg; Se, 0.15 mg.

Table 4.3 Compositions of the experimental diets for Korat chickens in the period 6-9 wk of age (as-fed basis).

Items	Level of CP				
	16%	17%	18%	19%	20%
Ingredient					
Corn	60.11	56.48	52.92	49.33	45.80
Soybean meal, 44% CP	15.28	18.30	21.30	24.31	27.32
Rice bran oil	4.65	5.26	5.85	6.44	7.02
Extracted rice bran	6.96	6.96	6.96	6.96	6.96
Full-fat soybean	1.00	1.00	1.00	1.00	1.00
Cassava pulp	4.00	4.00	4.00	4.00	4.00
Meat meal, 60% CP	6.00	6.00	6.00	6.00	6.00
Calcium carbonate, $CaCO_3$	0.62	0.60	0.60	0.60	0.58
Monocalcium phosphate, $Ca(H_2PO_4)_2$	0.38	0.38	0.35	0.33	0.30
DL-methionine	0.09	0.10	0.11	0.13	0.14
L-lysine	0.06	0.05	0.03	0.02	0.00
L-threonine	0.10	0.10	0.11	0.11	0.11
Salt	0.25	0.27	0.27	0.27	0.27
Premix[1]	0.50	0.50	0.50	0.50	0.50
Calculated composition, %					
ME, kcal/kg	3,200	3,200	3,200	3,200	3,200
CP	16.00	17.00	18.00	19.00	20.00
Calcium	0.80	0.80	0.80	0.80	0.80
Available phosphorus	0.39	0.39	0.39	0.39	0.39
Digestible lysine	0.79	0.84	0.89	0.94	0.99
Digestible methionine	0.34	0.36	0.38	0.41	0.43
Digestible methionine + cystine	0.53	0.57	0.60	0.63	0.67
Digestible threonine	0.60	0.64	0.68	0.72	0.76
Digestible tryptophan	0.16	0.18	0.20	0.21	0.23
Analyzed composition, %					
DM	90.54	90.61	90.61	90.55	90.67
CP	16.64	17.70	18.77	19.73	20.79
CF	3.74	3.87	4.00	4.13	4.27
EE	7.48	8.16	8.64	9.10	9.61
Ash	5.78	5.87	6.27	5.77	5.74
Price, Baht/kg	14.81	15.23	15.65	16.07	16.49

[1]Premix (0.5%) provided the following (per kg of diet) : vitamin A, 15,000 IU; vitamin D_3, 3,000 IU; vitamin E, 25 IU; vitamin K_3, 5 mg; vitamin B_1, 2 mg; vitamin B_2, 7 mg; vitamin B_6, 4 mg; vitamin B_{12}, 25 mg; pantothenic acid, 11.04 mg; nicotinic acid, 35 mg; folic acid, 1 mg; biotin, 15 µg; choline chloride, 250 mg; Cu, 1.6 mg; Mn, 60 mg; Zn, 45 mg; Fe, 80 mg; I, 0.4 mg; Se, 0.15 mg.

Table 4.4 Compositions of the experimental diets for Korat chickens in the period 9-12 wk of age (as-fed basis).

Items	Level of CP				
	15%	16%	17%	18%	19%
Ingredient					
Corn	62.55	59.01	55.39	51.91	48.31
Soybean meal, 44% CP	12.54	15.54	18.56	21.54	24.56
Rice bran oil	4.20	4.78	5.39	5.95	6.55
Extracted rice bran	6.65	6.65	6.65	6.65	6.65
Full-fat soybean	1.00	1.00	1.00	1.00	1.00
Cassava pulp	5.00	5.00	5.00	5.00	5.00
Meat meal, 60% CP	6.00	6.00	6.00	6.00	6.00
Calcium carbonate, $CaCO_3$	0.64	0.62	0.62	0.60	0.60
Monocalcium phosphate, $Ca(H_2PO_4)_2$	0.42	0.40	0.38	0.34	0.32
DL-methionine	0.08	0.09	0.10	0.11	0.13
L-lysine	0.07	0.05	0.03	0.02	0.00
L-threonine	0.09	0.10	0.10	0.11	0.11
Salt	0.26	0.26	0.27	0.27	0.27
Premix[1]	0.50	0.50	0.50	0.50	0.50
Calculated composition, %					
ME, kcal/kg	3,200	3,200	3,200	3,200	3,200
CP	15.00	16.00	17.00	18.00	19.00
Calcium	0.80	0.80	0.80	0.80	0.80
Available phosphorus	0.39	0.39	0.39	0.39	0.39
Digestible lysine	0.73	0.78	0.83	0.88	0.93
Digestible methionine	0.31	0.34	0.36	0.38	0.41
Digestible methionine + cystine	0.50	0.53	0.57	0.60	0.63
Digestible threonine	0.57	0.60	0.64	0.68	0.72
Digestible tryptophan	0.15	0.16	0.18	0.20	0.21
Analyzed composition, %					
DM	90.50	90.39	90.57	90.92	91.25
CP	15.50	16.72	17.65	18.74	19.65
CF	3.70	3.83	3.96	4.09	4.23
EE	7.62	8.25	8.50	8.85	9.39
Ash	7.13	6.31	5.80	5.80	5.88
Price, Baht/kg	14.53	14.94	15.35	15.75	16.16

[1]Premix (0.5%) provided the following (per kg of diet) : vitamin A, 15,000 IU; vitamin D_3, 3,000 IU; vitamin E, 25 IU; vitamin K_3, 5 mg; vitamin B_1, 2 mg; vitamin B_2, 7 mg; vitamin B_6, 4 mg; vitamin B_{12}, 25 mg; pantothenic acid, 11.04 mg; nicotinic acid, 35 mg; folic acid, 1 mg; biotin, 15 µg; choline chloride, 250 mg; Cu, 1.6 mg; Mn, 60 mg; Zn, 45 mg; Fe, 80 mg; I, 0.4 mg; Se, 0.15 mg.

4.4.5 Statistical analysis

The experimental unit was the replicate pen mean for statistical analysis. All data were subjected to a one-way ANOVA analyzed as a CRD using the General Linear Model procedure of SAS software (SAS Institute, 1996). When the treatment effect was significant, the differences among treatment means were considered statistically significant at $P < 0.05$ by Duncan's New Multiple Range Test (DMRT) using SAS software (SAS Institute, 1996). The broken-line model was evaluated using the NLIN procedure of SAS software (SAS Institute, 1996) based on Robbins et al. (2006) for estimating the protein requirement of Korat chickens. The model was fitted as follows : $y = l + u\,(r - x)$ where y = BWG or FCR as dependent variable; x = dietary protein level (%) as independent variable; r = requirement of dietary protein; l = the response at x = r; and u = the steepness of the curve. In this model, $y = l$ when $x > r$. R^2 value were determined as follows : $R^2 = (SST - SSE) / SST$ or $1 - (SSE / SST)$.

4.4.6 Experimental location

The experiment was conducted at Suranaree University of Technology's poultry farm, the Center for Scientific and Technological Equipment Building 10, Suranaree University of Technology.

4.4.7 Experimental period

The experiment was done from June 2014 to October 2014.

4.5 Results and discussion

4.5.1 Period 0-3 wk of age

There were significant differences ($P < 0.05$) in BW, BWG, ADG, protein intake and PER among treatments, which are presented in Table 4.5. It was found that

BW, BWG, ADG and protein intake increased with increasing dietary protein levels from 19 to 23%. The Korat chicken groups fed diets containing 21, 22 and 23% CP had higher BW, BWG and ADG than the chicken groups fed the 19 and 20% CP ($P < 0.05$). However, there were no significant differences among the groups fed dietary protein from 21 to 23%. The average BWG increased by 5.13% with increasing dietary protein levels from 19 to 23%. Because a high-protein diet (21-23% CP) has sufficient quantities of amino acid, they must also be available for protein synthesis in the chicken's body. The low-protein diets (19-20% CP) in the current study may contain insufficient amounts of amino acids for muscle protein synthesis and thus resulted in lower protein retention (Sklan and Noy, 2003). As reported in previous studies, the BW of chickens increased as the dietary protein increased (Smith and Pesti, 1998; Sklan and Noy, 2003; Baéza et al., 2012; Gheorghe et al., 2013; Malomo et al., 2013). Although increasing dietary protein from 19 to 23% can increase the BW, BWG and ADG of Korat chickens, there were no significant differences among 21, 22 and 23% CP. This indicates that the CP content at the level of 21% showed the beneficial effect on growth performance. In the case of 22 and 23% CP, this protein level might be higher than the birds' requirement, and as a consequence, energy is required in order to deaminate the excess protein (amino acids) and is excreted as uric acid. As a result, these birds had less available energy for their growth (MacLeod, 1997; Chen et al., 1999; Kamran et al., 2004).

Table 4.5 Effects of dietary protein on growth performance and feed cost of Korat chickens in the period 0-3 wk of age.

Items	**Level of CP**					**SEM**	***P*-value**
	19%	**20%**	**21%**	**22%**	**23%**		
FI, g/bird	411.70	414.24	427.52	425.98	422.51	10.19	0.7488
BW 1-d-old, g/bird	43.33	43.39	43.28	43.45	43.28	0.13	0.8582
BW 3-wk-old, g/bird	260.94^{b}	263.15^{b}	271.99^{a}	272.71^{a}	272.06^{a}	2.17	0.0008
BWG, g/bird	217.61^{b}	219.76^{b}	228.71^{a}	229.26^{a}	228.78^{a}	2.20	0.0009
ADG, g/bird/day	10.36^{b}	10.47^{b}	10.89^{a}	10.92^{a}	10.89^{a}	0.10	0.0010
FCR, g of feed/g of BWG	1.89	1.88	1.87	1.87	1.85	0.04	0.9295
Feed cost/BWG, Baht/kg	29.20	29.87	30.50	31.12	31.74	0.64	0.0730
Protein intake, g/bird	80.13^{c}	84.82^{c}	91.56^{b}	95.48^{ab}	99.20^{a}	2.16	0.0001
PER, g/g	2.72^{a}	2.61^{ab}	2.50^{bc}	2.41^{cd}	2.31^{d}	0.05	0.0001
ME intake, kcal/bird	1,226	1,234	1,273	1,269	1,258	30.33	0.7489
EER, %	17.76	17.91	18.00	18.13	18.20	0.38	0.9296
BUN, mg/dL	1.26	1.25	1.35	1.44	1.54	0.15	0.5870

$^{a, b, c, d}$Means within each row with different superscripts are significantly different ($P < 0.05$).

The protein intake was increased by 23.80% with increasing dietary protein levels from 19 to 23%. However, a low-protein diet was more effective in improving PER than a high-protein diet. The mechanism of improving PER in birds fed with low-protein diets is still unclear, and this observation was recorded, probably due to the fact that all experimental diets are composed of similar amino acid to protein ratios. In addition, all diets also contained the optimum essential to total amino acid ratios of 0.58, 0.59, 0.59, 0.59 and 0.60 in dietary protein levels of 19, 20, 21, 22 and 23%, respectively. These mean values were within the optimum range between 0.55-0.60 for growth (Heger, 2003). Therefore, the proportion of low-protein diets (19-20% CP) may be suitable for leading to more efficient protein utilization. This result was also in accordance with the BUN values, which indicate that the birds fed with a low-protein diet had lower BUN than those fed with a high-protein diet. However, a decreased BWG in bird groups fed 19-20% CP may be due to the fact that these diets contain insufficient amounts of amino acids in order to maximize the growth rate. This observation was in agreement with the findings of Cheng et al. (1997) and Nguyen and Bunchasak (2005), who observed a linear decrease in PER when increasing dietary protein content from 16 to 24% and 17 to 23%, respectively. Regarding other parameters, like BW, BWG, ADG, FCR, feed cost per kg of BWG and EER, the study indicates that feeding dietary protein 21% to Korat chickens showed the best beneficial effects on growth performance.

Feed intake and ME intake of chickens did not show any significant differences among treatments ($P > 0.05$), because the dietary ME in the present study was formulated to contain a similar level (2,978 kcal of ME/kg) in all treatments. Although several previous studies reported that FI increased with increasing protein levels content in the diet (Kingori et al., 2003; Sklan and Noy, 2003; Nahashon et al., 2005; Mosaad and Iben, 2009), the FI of chickens in the current study was not influenced ($P > 0.05$) by the dietary protein levels. The result was in agreement with previous studies (Summers et al., 1992; Bregendahl et al., 2002; Nguyen and Bunchasak, 2005; Zaman et al., 2008; Niu et al., 2009; Laudadio et al., 2012; Gheorghe et al., 2013; Lui et al., 2015), which found no significant effect on FI of birds when they were fed with several levels of protein contained in the diet.

Moreover, FCR was also unaffected by dietary protein levels, which was in accordance with the recent finding of Laudadio et al. (2012), who found that there were no differences in FCR among treatments throughout the trial. Furthermore, in our study, there were no significant differences ($P > 0.05$) in feed cost per kg of BWG, EER and BUN values among treatments.

4.5.2 Period 3-6 wk of age

The effects of dietary protein on growth performance and feed cost of Korat chickens in this period are presented in Table 4.6. The BW, BWG, ADG, and protein intake among treatments increased as increasing the dietary protein levels from 18 to 22%. The birds fed 20, 21 and 22% CP diets had significantly higher average BW, BWG and ADG ($P < 0.05$) than those fed with lower-protein diets (18-19% CP). However, there were no significant differences in dietary protein from 20 to 22%. In this period, the average BW and BWG increased by 5.16 and 8.20%, respectively with increasing dietary protein levels from 18 to 22%. The trend of responses to dietary protein was similar to a period 0-3 wk of age. Although, the protein intake increased by 18.50% with increasing dietary protein levels from 19 to 23%, the PER did not show the significant differences among treatments. However, the PER assay for determining protein qualities tended to improve with decreasing dietary protein levels ($P = 0.0803$). The improvement of PER in low protein diets were similar to that of the period 0-3 wk of age; however, the mechanism to explain this phenomenon remained unclear. All experimental diets had the similar amino acid to protein ratios and the optimal essential to total amino acid ratios were 0.58, 0.59, 0.59, 0.59 and 0.60 in diets containing 18, 19, 20, 21 and 22% CP, respectively. This ratio values were within the optimum range for growth which ranged between 0.55-0.60 (Heger, 2003). As a result, the proportion of low-protein diets (18-19% CP) may be optimized for more efficient protein utilization. This result was also confirmed by BUN values, which were lower in birds fed with low-protein diets than those fed with high-protein diets. However, a decreased BWG against the results of PER and BUN in bird groups fed 18-19% CP diets may associate with the insufficiency of amino acid content to maximize the growth. When considering other parameters, such as BW, BWG, ADG, FCR, feed cost per kg of BWG and EER, the study indicates that the feeding of 20% CP to Korat chickens showed the best beneficial effects on growth performance.

Table 4.6 Effects of dietary protein on growth performance and feed cost of Korat chickens in the period 3-6 wk of age.

Items	**Level of CP**					**SEM**	***P*-value**
	18%	**19%**	**20%**	**21%**	**22%**		
FI, g/bird	1,044	1,031	1,039	1,059	1,008	28.32	0.7823
BW 3-wk-old, g/bird	275.64	274.49	275.00	277.18	275.64	1.30	0.6632
BW 6-wk-old, g/bird	742.31^{c}	756.02^{b}	773.65^{a}	783.33^{a}	780.58^{a}	4.50	0.0001
BWG, g/bird	466.67^{c}	481.54^{b}	498.65^{a}	506.15^{a}	504.94^{a}	3.98	0.0001
ADG, g/bird/day	22.22^{c}	22.93^{b}	23.75^{a}	24.10^{a}	24.05^{a}	0.19	0.0001
FCR, g of feed/g of BWG	2.24	2.14	2.09	2.09	2.00	0.06	0.0785
Feed cost/BWG, Baht/kg	34.69	34.13	34.14	35.17	34.48	1.50	0.9265
Protein intake, g/bird	193.04^{c}	203.73^{bc}	213.82^{ab}	227.97^{a}	228.76^{a}	5.75	0.0005
PER, g/g	2.43	2.37	2.34	2.23	2.22	0.06	0.0803
ME intake, kcal/bird	3,290	3,250	3,274	3,337	3,177	89.23	0.7823
EER, %	14.28	14.85	15.25	15.23	15.95	0.39	0.0724
BUN, mg/dL	1.43	1.43	1.47	1.49	1.55	0.27	0.9979

$^{a, b, c}$Means within each row with different superscripts are significantly different ($P < 0.05$).

Furthermore, FI and ME intake of chickens did not show any significant differences among treatments ($P > 0.05$), because ME contents in all experimental diets in this period were formulated to contain a similar level (3,151 kcal of ME/kg). In generally, birds could adjust FI to meet their metabolic energy needs and changing demands for calories (Scott et al., 1982).

In this period, FCR was not affected by dietary protein levels. However, it tended to improve with increasing dietary protein levels (*P* = 0.0785). Because birds consumed the same amount of FI, there was a significant increase in BW of the birds when the dietary protein levels were increased. Moreover, there were no significant differences (*P* > 0.05) in feed cost per kg of BWG, EER and BUN values among treatments.

4.5.3 Period 6-9 wk of age

The effects of dietary protein on growth performance and feed cost of Korat chickens in this period are shown in Table 4.7. There were significant differences (*P* < 0.05) in BW, BWG, ADG and protein intake among treatments. The results showed that the BW, BWG and ADG of Korat chickens fed diets containing 18, 19 and 20% CP had a significantly higher value than the groups fed 16 and 17% CP (*P* < 0.05), but there were no significant differences in the groups fed 18 to 20% CP. Moreover, birds received 18% CP diet had the highest BW, BWG and ADG. In addition, the protein intake increased by 23.93%, with increasing dietary protein levels from 16 to 20%. Although PER was unaffected by dietary protein levels, it tended to improve with decreasing the protein levels (*P* = 0.0713), and this response trend was similar to that of the periods 0-3 and 3-6 wk of age. The low-protein diet was more effective in improving PER than in that from a high-protein diet. However, the mechanism of improved PER in birds fed with low-protein diets is not clearly seen, and it might correlate with the ratio of essential amino acid to protein which all experimental diets were formulated in the same ratio. These ratios were 0.57, 0.58, 0.58, 0.59 and 0.59 in dietary protein levels of 16, 17, 18, 19 and 20%, respectively. The result of PER was in accordance with BUN values, which are lower in birds fed with low-protein diets than those fed with high-protein diets (Cheng et al., 1997; Aletor et al., 2000; Nguyen and Bunchasak, 2005; Widyaratne and Drew, 2011; Gheorghe et al., 2013). Nevertheless, the decreased BWG of bird groups fed 16-17% CP was probably due to insufficient amino acid content in diets for their maximum growth. When considering other parameters, like, BW, BWG, ADG, FCR, feed cost per kg of BWG and EER, the study reveals that birds fed with dietary protein 18% showed the best beneficial effects on growth performance.

Table 4.7 Effects of dietary protein on growth performance and feed cost of Korat chickens in the period 6-9 wk of age.

Items	**Level of CP**					**SEM**	***P*-value**
	16%	**17%**	**18%**	**19%**	**20%**		
FI, g/bird	1,459	1,478	1,467	1,441	1,447	30.68	0.9147
BW 6-wk-old, g/bird	742.43	750.00	751.53	754.72	745.83	3.87	0.2155
BW 9-wk-old, g/bird	1,235^{b}	1,268^{b}	1,319^{a}	1,304^{a}	1,310^{a}	11.42	0.0001
BWG, g/bird	492.29^{b}	517.78^{b}	567.36^{a}	549.05^{a}	563.85^{a}	10.64	0.0001
ADG, g/bird/day	23.44^{b}	24.66^{b}	27.02^{a}	26.15^{a}	26.85^{a}	0.51	0.0001
FCR, g of feed/g of BWG	2.97^{a}	2.86^{a}	2.59^{b}	2.63^{b}	2.58^{b}	0.07	0.0008
Feed cost/BWG, Baht/kg	43.88	43.55	40.46	42.25	42.50	1.07	0.2103
Protein intake, g/bird	242.83^{d}	261.62^{c}	275.33^{bc}	284.37^{ab}	300.95^{a}	5.80	0.0001
PER, g/g	2.03	1.99	2.06	1.93	1.88	0.05	0.0713
ME intake, kcal/bird	4,668	4,731	4,693	4,612	4,631	98.17	0.9147
EER, %	10.56^{b}	10.97^{b}	12.09^{a}	11.92^{a}	12.20^{a}	0.28	0.0008
BUN, mg/dL	1.68	1.75	1.78	1.81	1.81	0.15	0.9735

$^{a, b, c, d}$Means within each row with different superscripts are significantly different ($P < 0.05$).

The FCR was improved when increasing the protein levels ($P < 0.05$) (Table 4.7). This result could be due to an increased BW without changing the amount of FI in which the FCR of bird group received 18% CP diet improved significantly as compared to the groups fed with low-protein diets (16-17% CP), but it did not differ when being compared to the high-protein diets (19-20% CP). Moreover, these differences were probably due to the fact that the birds fed 18% CP diet had the highest BW and the maximal PER. This result was in accordance with several previous findings (Sterling et al., 2002; Kingori et al., 2003; Zaman et al., 2008; Niu et al., 2009; Baéza et al., 2012; Gheorghe et al., 2013; Malomo et al., 2013). In addition, increasing dietary protein content can also improve EER ($P < 0.05$), and this response trend was similar to the FCR.

Feed intake and ME intake of chickens did not significantly differ among treatments ($P > 0.05$), which are presented in Table 4.7. Because dietary ME in all experimental diets were formulated to contain a similar level (3,200 kcal of ME/kg). Moreover, feed cost per kg of BWG and BUN values of chickens were not found to be significantly different among treatments ($P > 0.05$). These results were similar and in agreement with those of the periods 0-3 and 3-6 wk of age.

Therefore, the optimal dietary protein requirement of Korat chickens in this period was 18% CP because birds fed the 18% CP diet showed the beneficial effect on growth performance, such as the improvement in FCR, EER and PER and the lowest feed cost per kg of BWG. A reduction of BWG in low-protein (16-17% CP) and high-protein (19-20% CP) diets would associate with the alternation of amino acid content in diets. Birds fed with low-protein diets (16-17% CP) may receive inadequacy of nitrogen or amino acids, whereas high-protein diets (19-20% CP) may supply excess protein or amino acids for birds (Sklan and Noy, 2003; Awad et al., 2015). Thus, these birds had poorer PER, EER and FCR values, since the excess amino acids were deaminated and excreted in the form of uric acid leading to lower protein deposition (Kamran et al., 2004; Baéza et al., 2012). Moreover, these birds may divert the energy that would be used for tissue deposition to eliminate the imbalance of amino acids, and hence less energy is available for their growth (MacLeod, 1997; Chen et al., 1999).

4.5.4 Period 9-12 wk of age

The effects of dietary protein on growth performance and feed cost of Korat chickens in this period are shown in Table 4.8. There were significant differences ($P < 0.05$) in BW, BWG, ADG, and protein intake among treatments. The results showed a similar trend as those in the periods 0-3, 3-6 and 6-9 wk of age. As the dietary protein increased from 15 to 19%, the BW, BWG, ADG and protein intake were increased. However, there were no significant differences in diets containing 18 to 19% CP. Furthermore, the Korat chickens fed 18% CP diet had the highest BW, BWG and ADG. The protein intake was increased by 21.51%, with increasing dietary protein levels from 15 to 19%. Birds fed with low-protein diets had a higher PER than those fed with high-protein diets ($P < 0.05$), and this finding was similar to those in the periods 0-3, 3-6 and 6-9 wk of age (Table 4.8). All experimental diets had similar amino acid to protein ratios. The essential to total amino acid ratios also represent in the optimal ranges of 0.57, 0.58, 0.58, 0.58 and 0.59 in diets containing 15, 16, 17, 18 and 19% CP, respectively. This result was supported by the BUN values, in which the birds fed with low-protein diets had a lower BUN value than those fed with high-protein diets. This observation was in agreement with the findings of Cheng et al. (1997); Aletor et al. (2000); Nguyen and Bunchasak (2005); Widyaratne and Drew (2011) and Gheorghe et al. (2013), who reported a significant increase in PER with a reduction in the dietary protein content. A decreased BWG in Korat chickens fed

15-17% CP diets was probably due to insufficient quantities of amino acid for the growth. The best growth performance was obtained at 18% CP regarding other parameters such as BW, BWG, ADG, FCR, feed cost per kg of BWG and EER.

Interestingly, the increase in dietary protein levels can improve FCR ($P < 0.05$) due to an increased BW without alterations in FI. This result was in accordance with many previous studies (Sterling et al., 2002; Kingori et al., 2003; Zaman et al., 2008; Niu et al., 2009; Baéza et al., 2012; Gheorghe et al., 2013; Malomo et al., 2013). Moreover, increasing dietary protein levels positively resulted in improved EER ($P < 0.05$). This observation was probably due to the high-protein diets (18-19% CP) supplied an adequate amount or a proper ratio of amino acid to achieve the growth and high-efficiency energy utilization (Niu et al., 2009).

Table 4.8 Effects of dietary protein on growth performance and feed cost of Korat chickens in the period 9-12 wk of age.

Items	Level of CP					SEM	*P*-value
	15%	16%	17%	18%	19%		
FI, g/bird	1,574	1,613	1,582	1,572	1,509	23.48	0.0604
BW 9-wk-old, g/bird	1,077	1,076	1,088	1,074	1,068	5.21	0.1332
BW 12-wk-old, g/bird	1,527^{b}	1,550^{ab}	1,575^{a}	1,583^{a}	1,551^{ab}	13.30	0.0472
BWG, g/bird	450.26^{b}	474.10^{ab}	479.24^{ab}	508.82^{a}	483.26 ^{ab}	11.79	0.0313
ADG, g/bird/day	21.44^{b}	22.58^{ab}	22.82^{ab}	24.23^{a}	23.01^{ab}	0.56	0.0313
FCR, g of feed/g of BWG	3.51^{a}	3.41^{a}	3.31^{ab}	3.10^{b}	3.13^{b}	0.08	0.0028
Feed cost/BWG, Baht/kg	50.95	50.96	50.80	48.76	50.52	1.16	0.6381
Protein intake, g/bird	244.07^{c}	269.68^{b}	279.22^{b}	294.47^{a}	296.58^{a}	4.22	0.0001
PER, g/g	1.84^{a}	1.76^{ab}	1.71^{b}	1.73^{ab}	1.64^{b}	0.04	0.0187
ME intake, kcal/bird	5,037	5,162	5,061	5,029	4,829	75.12	0.0604
EER, %	8.94^{b}	9.19^{b}	9.46^{ab}	10.12^{a}	10.04^{a}	0.22	0.0025
BUN, mg/dL	2.05	2.06	2.07	2.11	2.14	0.25	0.9986

$^{a, b, c}$Means within each row with different superscripts are significantly different ($P < 0.05$).

The FI and ME intake were unaffected by protein levels, but they tended to increase with decreasing dietary protein levels (P = 0.0604). However, feed cost per kg of BWG and BUN values of chickens did not show any significant differences among treatments ($P > 0.05$) (Table 4.8).

Based on the results of this period, it can be seen that the optimum dietary protein level of Korat chickens was 18% CP. The current observation indicates that the birds fed a 18% CP diet showed the most efficient results, like the improvement in FCR, EER and PER and the lowest feed cost per kg of BWG. Low-protein diets (15-17% CP) may not supply nitrogen or amino acid for the muscle protein synthesis in a proper balance, and thus result in a reduction of the protein retention or BWG. Conversely, high-protein diet (19% CP) may also offer an excess protein or amino acid than Korat chickens' requirement (Sklan and Noy, 2003; Kamran et al., 2008; Awad et al., 2015). Therefore, more energy is required in order to deaminate the excess protein (amino acids), and hence less energy is available for growth (MacLeod, 1997; Chen et al., 1999). This result also supports our hypothesis that birds had poorer FCR and EER values.

4.5.5 Broken-line regression analysis for estimating protein requirement

The result for estimating protein requirement of Korat chickens based on broken-line model analyses in the periods 0-3, 3-6, 6-9 and 9-12 wk of age are presented in Table 4.9. In the current experiment, the estimated protein requirement of Korat chickens from 0-3 and 3-6 wk of age for optimal BWG were 21.26 and 20.45%, respectively and the regression equations were $y = 229.00 - 5.5508 \times (21.26 - x)$ [$P < 0.01$, $R^2 = 0.48$] and $y = 505.50 - 15.994 \times (20.45 - x)$ [$P < 0.01$, $R^2 = 0.75$] for the aged 0-3 and 3-6 wk, respectively (Table 4.9). The daily protein requirement of

Korat chickens for the aged 0-3 and 3-6 wk were 4.32 and 10.21 g/bird/d, respectively. However, the requirement for the FCR was not estimated for both periods because the data did not conform to the regression model.

Table 4.9 Protein requirement of Korat chickens based on broken-line model analyses in the periods 0-3, 3-6, 6-9 and 9-12 wk of age.

Items	Regression equations[1]	Estimated Requirement[1]	SE	*P*-value	R^2
0-3 wk					
BWG	y = 229.00 – 5.5508 × (21.26 – x)	21.26	0.50	0.0001	0.48
FCR	NE[2]				
3-6 wk					
BWG	y = 505.50 – 15.994 × (20.45 – x)	20.45	0.33	0.0001	0.75
FCR	NE				
6-9 wk					
BWG	y = 557.70 – 34.844 × (18.00 – x)	18.00	0.71	0.0001	0.56
FCR	y = 2.6050 + 0.1900 × (18.04 – x)	18.04	0.41	0.0001	0.50
9-12 wk					
BWG	y = 496.00 – 14.489 × (17.94 – x)	17.94	1.36	0.0165	0.26
FCR	y = 3.1267 + 0.1332 × (18.03 – x)	18.03	0.73	0.0003	0.45

[1]The linear broken-line model is y = l + u × (r − x), where y = BWG or FCR; x = dietary protein level (%); r = Requirement of dietary protein; l = the response at x = r; and u = the steepness of the curve. In this model, y = l when x > r.

[2]NE = Not estimated because data did not conform to the regression model.

In the period 6-9 wk of age, the protein requirement of Korat chickens for optimal BWG and FCR were 18.00 and 18.04%, respectively, and the daily protein requirement of Korat chickens was 12.59 g/bird/d. The regression equations predicted the protein requirement for optimal BWG and FCR were y = 557.70 – 34.844 ×

(18.00 – x) [$P < 0.01$, $R^2 = 0.56$] and y = 2.6050 + 0.1900 × (18.04 – x) [$P < 0.01$, $R^2 = 0.50$], respectively (Table 4.9). While the protein requirement of Korat chickens from 9 to 12 wk of age for optimal BWG and FCR were 17.94 and 18.03%, respectively, and the daily protein requirement of Korat chickens was 13.46 g/bird/d. The regression equations predicted the protein requirement for optimal BWG and FCR were y = 496.00 – 14.489 × (17.94 – x) [$P < 0.02$, $R^2 = 0.26$] and y = 3.1267 + 0.1332 × (18.03 – x) [$P < 0.01$, $R^2 = 0.45$], respectively (Table 4.9). However, the coefficient of determination (R^2) of regression equations used to predict the protein requirement for optimal BWG was very low, which was the weakness of a non-linear relationship between dietary protein levels (x : independent variable) and BWG (y : dependent variable) due to high variances within the treatments. As the coefficient of determina-tion is often used as a measure of the correctness of a model; that is, how well a regression model will fit the data, the coefficient of determination can have values of $0 \leq R^2 \leq 1$, in which the good model means that R^2 is close to one (Kaps and Lamberson, 2009). Normally, the values of BWG are expressed as a function of the values of dietary protein levels. Therefore, the application of this regression equation for estimating a function of dependency between variables and prediction of future measurements or means of BWG using new measurements of the dietary protein levels should be diagnosed and aware of this value for possible elimination.

Nevertheless, the protein requirement of Korat chickens is different from those of other breeds or genetic of Thai indigenous crossbred as proposed by Vorachantra and Tancho (1996); Tangtaweewipat et al. (2000); Pingmuang et al. (2001); Polsiri, (2001) and Tananchai et al. (2001), in which those protein requirements were expressed in a range of 18-21% CP of the diet during the period 0-6 wk of age and in a range of

15-18% CP of the diet in the period 6-12 wk of age. When compared with the protein requirements between Korat chickens and broilers, this appears to be logical that the Korat chickens would require lower protein than broilers (23% CP of the diet) in the period 0-3 wk of age, whereas the requirement in aged 3-6 wk was higher than that of broilers (20% CP of the diet), but was similar to those of broilers (18% CP of the diet) in the period 6-8 wk of age (NRC, 1994). In case of daily protein requirement, the broiler chickens required a higher protein than Korat chickens, about 2.23 to 2.65 times in all periods (9.64 vs. 4.32, 24.70 vs. 10.21 and 33.30 vs. 12.59 g/bird during the periods 0-3, 3-6 and 6-9 wk of age, respectively). Although the daily protein requirement of Korat chickens is quite low, FI of this strain was also lower than that of broilers, approximately 2 to 3 times. Therefore, feed formulation for Korat chickens is needed to formulate in high nutrient density in order to meet their requirements.

In addition, the different levels of protein requirement for the optimum growth performance in the different genotypes of chicken breeds may be related to differences in the growth rate, body compositions and daily protein or amino acid requirements from amounts deposited or utilized by the chickens in each day (Scott et al., 1982; NRC, 1994). Moreover, each of chicken breed has its different efficiency in digestion, nutrient absorption and metabolism of absorbed nutrients resulting in different amino acid requirement (NRC, 1994; Klasing, 1998; Zhao et al., 2009). Magala et al. (2012) also reported that nutrient requirements of chickens were influenced by body size and growth rate, in which large size birds tended to require more dietary nutrients than the smaller size counterparts. Additionally, a previous study suggested that slowly growing birds require less protein than fast-growing broilers (Morris and Njuru, 1990). The protein requirements of Korat chickens per g of BWG in the periods 0-3, 3-6, 6-9 and 9-12 wk of age were 0.40, 0.43, 0.47 and 0.56 g, respectively while the requirements in broilers aged 0-3, 3-6 and 6-9 wk were 0.33, 0.41 and 0.55 g/g of BWG, respectively (NRC, 1994).

In the research report herein, when considering in the ME to protein ratio (ME:CP), there is a nearly ratio of the ME to protein for both breeds in all periods. The optimum ME to protein ratios of Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age were 140, 154, 178 and 178, respectively while the optimum ME to protein ratios of broiler chicken in the periods 0-3, 3-6 and 6-8 wk of age were 139, 160 and 178, respectively (NRC, 1994). Moreover, it is interesting to note that the protein requirement of Korat chickens decreased with age. This is because old birds required lower protein. This result was also similar to those reported by Baéza et al. (2012) and NRC (1994) in which dietary protein requirements of ducks and chickens decreased as the birds grow older.

4.6 Conclusion

The results of the present study suggested that the protein requirements of Korat chickens from 0 to 3 and 3 to 6 wk of age for optimal BWG were 21.26 and 20.45% or 4.32 and 10.21 g/bird/d when dietary ME was 2,978 and 3,151 kcal/kg, respectively. The protein requirements of Korat chickens from 6 to 9 wk of age for optimal BWG and FCR were 18.00 and 18.04%, respectively or about 12.59 g/bird/d when dietary ME was 3,200 kcal/kg. Finally, the protein requirements of Korat chickens from 9 to 12 wk of age for optimal BWG and FCR were 17.94 and 18.03%, respectively or about 13.46 g/bird/d when dietary ME was 3,200 kcal/kg.

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CHAPTER V

THE STUDY OF NUTRIENT UTILIZATION AND APPARENT METABOLIZABLE ENERGY OF DIETS FOR KORAT CHICKENS

5.1 Abstract

The objective of this study was to determine the nutrient digestibility and utilization and apparent metabolizable energy (AME) in Korat chickens by using the total excreta collection method. A total of fifteen male Korat chickens were used at 11-d-old, 32-d-old, 53-d-old and 74-d-old in the experimental periods 0-3, 3-6, 6-9 and 9-12 wk of age, respectively. In each period, all birds were randomly allotted to individual cages and fed with the diets contained metabolizable energy and protein levels which were chosen from chapter III and IV for 11 d (11-21, 32-42, 53-63 and 74-84 d of age, respectively). On the first 7 d, the chickens were adjusted to the cage and diet (adaptation period) and total excreta was collected on the last 4 days of each period. Results showed that the apparent digestibility of dry matter (DM) were 66.87, 70.32, 71.38 and 71.40% in the periods 0-3, 3-6, 6-9 and 9-12 wk of age, respectively. The average percentages of N retention were 59.00, 57.16, 53.20 and 52.55% in the periods 0-3, 3-6, 6-9 and 9-12 wk of age, respectively. The determined AME values were similar to the calculated AME in all periods. The calculated AME values of Korat chicken diets in the periods of 0-3, 3-6, 6-9 and 9-12 wk of age were 2,978,

3,150, 3,200 and 3,200 kcal/kg, respectively while the determined AME values of diets were 3,027, 3,171, 3,231 and 3,238 kcal/kg, respectively and the determined AME_n values of diets were 3,009, 3,154, 3,217 and 3,225 kcal/kg, respectively.

Key words : growth performance, Korat chicken, protein, requirement

5.2 Introduction

In poultry diets, metabolizable energy (ME) is commonly accepted and extensively used to measure or describe the available energy values of feedstuffs and poultry diets, as well as energy requirement is usually expressed in this unit (Pirgozliev et al., 2001; Lopez and Leeson, 2007). The formulation of diets with accurate ME, digestibility and other nutrient contents evaluation of diets requires reliable methods to obtain these values (Sales and Jenssens, 2003). In general, two methods of rapid bioassays for determining ME and digestibility in poultry are total excreta collection or partial excreta collection methods. This requires a preliminary period and a collection period to be long enough to reduce negligible terms in the errors of irregular excreta collection (Sales and Jenssens, 2003; Dourado et al., 2010). However, the total excreta collection method is the most frequently and applicably used to determine AME and digestibility values in chicken diets by quantifying feed intake and total excreta for a collection period (Dourado et al., 2010). Therefore, it is important to determine nutrient digestibility and utilization and AME in Korat chickens.

5.3 Objective

The objective of this experiment was to determine nutrient digestibility and utilization and AME of diets in Korat chickens by using the total excreta collection method.

5.4 Materials and methods

All experiments were conducted according to principles and guidelines approved by the Animal Care and Use Committee of Suranaree University of Technology.

5.4.1 Bird

In this study, a total of fifteen male Korat chickens were used at 11-d-old (average initial BW = 114.43 ± 3.46 g), 32-d-old (average initial BW = 486.64 ± 20.85 g), 53-d-old (average initial BW = 974.93 ± 44.35 g) and 74-d-old (average initial BW = 1,400.95 ± 154.49 g) in the experimental periods 0-3, 3-6, 6-9 and 9-12 wk of age, respectively. All birds were randomly allotted to individual cages.

5.4.2 Experimental diet

There were four diets which were divided into 4 periods (0-3, 3-6, 6-9 and 9-12 wk of age). The dietary ME and protein levels of each period were formulated based on the results from the chapter III and chapter IV. The dietary ME and protein content in the periods 0-3, 3-6, 6-9 and 9-12 wk of age were 2,978 kcal/kg, 21.26%; 3,150 kcal/kg, 20.45%; 3,200 kcal/kg, 18.00% and 3,200 kcal/kg, 18.00%, respectively. All experimental diets were formulated to meet or exceed the nutrient requirement for broiler recommended specification by NRC (1994), except ME and protein content. The digestible amino acid (lysine, methionine, threonine and tryptophan) content of the diets was calculated based on the digestibility value of feedstuffs (NRC, 1994; Ajinomoto, 1998). Crystalline amino acids (lysine, methionine and threonine) were added to achieve the essential amino acid requirements. All diets were provided in mash form. Feed ingredients and compositions of the experimental diets in the periods 0-3, 3-6, 6-9 and 9-12 wk of age are shown in Table 5.1. The protein digestibility of corn, soybean meal, extracted rice bran, full-fat soybean, cassava pulp and meat meal were 87.0, 91.0, 77.7, 87.0, 46.0 and 81.0%, respectively.

5.4.3 Nutrient digestibility and utilization and apparent metabolizable energy determination

The determination of nutrient digestibility and utilization and apparent metabolizable energy (AME) were evaluated by using the total excreta collection method (Lopez and Leeson, 2005; Dourado et al., 2010; Hasanzadeh Seyedi et al., 2013). The experimental period was divided into 4 phases : 0-3, 3-6, 6-9 and 9-12 wk of age. Fifteen 11-d-old, 32-d-old, 53-d-old and 74-d-old male Korat chickens were randomly allotted to individual cages (length 37 cm, width 21 cm, and height 41 cm) with wire floors, where individual feed consumption and BW were recorded. Each cage was equipped with a box feeder and a nipple drinker. Birds were offered the experimental diets in mash form. Feed and water were available *ad libitum* and lighting was continuous for 24 h. The amount of feed intake and excreta output of individual were weighed and recorded daily in each period.

Table 5.1 Compositions of the experimental diets for Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age (as-fed basis).

Items	Periods (wk of age)	0-3	3-6	6-9	9-12
	ME (kcal/kg)	2,978	3,151	3,200	3,200
	CP (%)	21.26	20.45	18.00	18.00
Ingredient					
Corn		45.40	47.72	52.92	51.90
Soybean meal, 44% CP		27.78	28.25	21.30	21.54
Extracted rice bran		7.08	5.09	6.96	6.65
Rice bran oil		3.70	5.99	5.85	5.95
Full-fat soybean		4.00	1.50	1.00	1.00
Cassava pulp		3.00	3.00	4.00	5.00
Meat meal, 60% CP		6.00	6.00	6.00	6.00
Calcium carbonate, $CaCO_3$		0.90	0.71	0.60	0.60
Monocalcium phosphate, $Ca(H_2PO_4)_2$		0.69	0.60	0.35	0.34
DL-methionine		0.34	0.20	0.11	0.11
L-lysine		0.06	0.02	0.03	0.03
L-threonine		0.12	0.10	0.11	0.11
Salt		0.43	0.32	0.27	0.27
Premix[1]		0.50	0.50	0.50	0.50
Calculated composition, %					
Digestible CP[2]		18.65	17.97	15.69	15.69
Calcium		1.00	0.90	0.80	0.80
Available phosphorus		0.48	0.46	0.39	0.39
Digestible lysine		1.11	1.03	0.89	0.89
Digestible methionine		0.64	0.49	0.38	0.38
Digestible methionine + cystine		0.90	0.74	0.60	0.60
Digestible threonine		0.80	0.76	0.68	0.68
Digestible tryptophan		0.25	0.24	0.20	0.20
Analyzed composition, %					
DM		91.07	91.19	91.45	91.47
CP		22.21	20.66	18.61	18.56
CF		4.30	4.13	4.00	4.09
Price, Baht/kg		16.79	16.67	15.65	15.63

[1]Premix (0.5%) provided the following (per kg of diet) : vitamin A, 15,000 IU; vitamin D_3, 3,000 IU; vitamin E, 25 IU; vitamin K_3, 5 mg; vitamin B_1, 2 mg; vitamin B_2, 7 mg; vitamin B_6, 4 mg; vitamin B_{12}, 25 mg; pantothenic acid, 11.04 mg; nicotinic acid, 35 mg; folic acid, 1 mg; biotin, 15 µg; choline chloride, 250 mg; Cu, 1.6 mg; Mn, 60 mg; Zn, 45 mg; Fe, 80 mg; I, 0.4 mg; Se, 0.15 mg.

[2]The values were calculated on the basis of the digestible CP values of the individual ingredients (Rostagno, 2011). The digestible CP values of experimental diets in the periods 0-3, 3-6, 6-9 and 9-12 wk of age were 87.70, 87.90, 87.18 and 87.18%, respectively.

The birds in each period were fed with the experimental diets for 11 d (11-21, 32-42, 53-63 and 74-84 d of age). The first 7 d enabled the chickens to adapt themselves to the cage and feeds (adaptation period). Total excreta was collected on the last 4 consecutive days of each period (18-21, 39-42, 60-63 and 81-84 d of age) at 08:00 am. During the 4 d excreta collection, the excreta was sprayed with 5% HCl. Feathers and scales were carefully removed to avoid the contamination, and then the excreta was stored in zip-lock plastic bags at −20°C immediately after being collected each day in order to prevent microbial breakdown. Excreta samples were homogenized and dried in a forced-air draft oven at 55°C for 48-72 h, and then ground through a 1 mm screen and analyzed for chemical composition. Feed and excreta samples were pooled to make the representative samples for proximate analyses. Dry matter was determined by hot air oven at 100-105°C for 3 h. Nitrogen was analyzed by Kjeldahl method (AOAC, 1990). Gross energy was determined by an adiabatic oxygen bomb calorimeter (IKA® Werke bomb calorimeter; C 5000, GMBH & Co., Staufen, Germany) and using benzoic acid as a calibration standard (AOAC, 1990).

5.4.4 Calculation

The apparent digestibility of DM of the diets was calculated using the following formula (DM basis).

$$= \left[\frac{(\text{FI} \times \text{DM of diet}) - (\text{Excreta output} \times \text{DM of excreta})}{(\text{FI} \times \text{DM of diet})}\right] \times 100$$

The percentage of N retention of the diets was calculated using the following formula (DM basis).

$$= \left[\frac{(\text{FI} \times \text{N of diet}) - (\text{Excreta output} \times \text{N of excreta})}{(\text{FI} \times \text{N of diet})}\right] \times 100$$

The AME and nitrogen corrected apparent metabolizable energy (AME_n) values of the diets were calculated using the following formula (DM basis). Correction to zero N retention (NR) was made using 8.22 kcal/g of retained nitrogen (Hill and Anderson, 1958).

$$\text{AME diet (kcal/kg)} = \frac{[(\text{FI} \times \text{GE of diet}) - (\text{Excreta output} \times \text{GE of excreta})]}{\text{FI}}$$

AME_n diet (kcal/kg)

$$= \frac{[(\text{FI} \times \text{GE of diet}) - (\text{Excreta output} \times \text{GE of excreta}) - (\text{NR} \times 8.22)]}{\text{FI}}$$

where NR = (FI × N of diet) − (Excreta output × N of excreta)

5.4.5 Experimental location

The experiment was conducted at Suranaree University of Technology's Poultry Farm, the Center for Scientific and Technological Equipment Building 10, Suranaree University of Technology.

5.4.6 Experimental period

The experiment was done from March 2015 to June 2015.

5.5 Results and discussion

The average values of nutrient utilization and AME of diets for Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age are shown in Table 5.1. The apparent digestibility of DM were 66.87, 70.32, 71.38 and 71.40% in the periods 0-3, 3-6, 6-9 and 9-12 wk of age, respectively. These values were quite similar to the apparent DM digestibility of corn-soybean basal diet in broilers at the age of 3 wk, which was 70.3% (Mountzouris et al., 2010) and 69.9% (Pekel et al., 2015). Moreover, the results in this study indicated that DM digestibility increased with the age of birds (Kato et al., 2011) since adult birds have a better capability of digestion and absorption by the activity of enzyme and gastrointestinal tract development than the young birds (Denbow, 2015). Since extracted rice bran and cassava pulp were involved in the diets, this could make the digestible protein percentage (87.18-87.90%, mean = 87.49 ± 0.36%) to be lower than corn-soybean basal diets (89.85-90.08%, mean = 89.93 ± 0.11%), approximately 2.44%. Based on the results of this study, further applications should be concerned about the protein digestibility of feedstuffs in the feed formulation in order to achieve the precision protein requirement.

Table 5.2 Nutrient utilization and AME values of diets[1] for Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age.

Items	**Periods (wk of age)**			
	0-3	**3-6**	**6-9**	**9-12**
Apparent digestibility of DM, %	66.87[2]	70.32	71.38	71.40
N retention, %	59.00	57.16	53.20	52.55
AME, kcal/kg	3,027	3,171	3,231	3,238
AME_n, kcal/kg	3,009	3,154	3,217	3,225

[1]The optimal dietary ME and protein levels of Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age were 2,978 kcal/kg, 21.26%; 3,150 kcal/kg, 20.45%; 3,200 kcal/kg, 18.00% and 3,200 kcal/kg, 18.00%, respectively.

[2]Data were mean of 15 replications (n = 15 birds) in each period. Average daily feed intake (ADFI) of Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age were 23.76, 45.68, 70.85 and 81.71 g/bird/day, respectively.

The percentages of N retention of diet conducted in Korat chickens was similar to broiler chickens (Lopez and Leeson, 2005). The average percentages of N retention of diet for Korat chickens were 59.00, 57.16, 53.20 and 52.55% in the periods 0-3, 3-6, 6-9 and 9-12 wk of age, respectively (Table 5.1). In broilers received a corn-soybean basal diet, the average percentages of N retention were 59.40, 57.00 and 51.00% at 2, 4 and 6 wk of age, respectively (Lopez and Leeson, 2005) while the N retention decreased with an increased in the age of birds. However, the percentages of N retention depend on the nutrient digestibility, protein level and amino acid balance in diets, which could reflect the relative abundance or inadequacy of amino acids (Gou et al., 2016). Therefore, chicken diets should supply the sufficient amount of N and the correct ratios of essential- and non- essential amino acid as well as sufficient quantities and qualities must also be available for protein synthesis (Sklan and Noy, 2003; Awad et al., 2015). Because amino acids are the building blocks of protein, but the excess protein (amino acids) will be deaminated and excreted along with the unabsorbed N, dietary amino acids and endogenous origin in the form of uric acid, ammonia and urea (Goldstein and Skadhauge, 2000), the growth rate is reduced and uric acid levels are increased in the blood (Klasing, 1998). In addition, the goal of feed formulation is to increase the percentage of N retention and to reduce the N excretion, without affecting the growth performance and welfare (Gou et al., 2016). Therefore, the chicken diets should be formulated based on high nutrient digestibility of feedstuffs and focused on optimizing an ideal protein or amino acid pattern (Dari et al., 2005; Widyaratne and Drew, 2011). Moreover, if the diet contains high nutrient digestibility of feedstuffs, it can decrease the protein level in diets with or without supplement synthetic amino acids. Furthermore, the fortification of amino acids may result in a better economic return for the industry and lessen environmental pollution (Pesti, 2009).

The determined AME values were similar as compared to the calculated AME in all periods. The calculated AME values of Korat chicken diets in the periods of 0-3, 3-6, 6-9 and 9-12 wk of age were 2,978, 3,150, 3,200 and 3,200 kcal/kg, respectively while the determined AME values of diets were 3,027, 3,171, 3,231 and 3,238 kcal/kg, respectively, and the determined AME_n values of diets were 3,009, 3,154, 3,217 and 3,225 kcal/kg, respectively.

5.6 Conclusion

The apparent DM digestibility of diets for Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age were ranging from 66.87 to 71.40%. The average percentages of N retention for Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age were in the range between 59.00 and 52.55%. In addition, the determined AME and AME_n values were ranging from 3,009 to 3,238 kcal/kg, which were close to the calculated AME in each experimental period.

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CHAPTER VI

OVERALL CONCLUSION AND IMPLICATION

6.1 Conclusion

This study aimed to investigate the ME and protein requirements of Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age.

The first experiment was conducted to evaluate the ME requirement of Korat chickens from 0 to 12 wk of age (Chapter III). As dietary ME is essential for the growth performance of the Korat chickens, and it has been shown to affect the chickens' FI in the way that the birds will adjust their consumption according to the dietary energy levels. When the dietary ME level increased, FI was decreased whereas FCR was improved. In addition, the dietary energy ranging between 2,750 and 3,200 kcal of ME/kg had no significant effect on BW or BWG, and this suggests that Korat chickens still consume diets to meet their energy need. In this study, it can be concluded that the ME requirements of Korat chickens in the period 0-3 wk of age for the optimal FCR of Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age were 2,978, 3,151, 3,200 and 3,200 kcal/kg, respectively. At the same time, the daily ME requirement of Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age were 59, 152, 209 and 249 kcal/bird/d, respectively. Therefore, the optimum dietary ME levels play a crucially important and critical role in the FI, nutrient metabolism and subsequent growth performance of the chickens. However, if the energy density of the diet is of insufficient quantities, it also resulted in deficiencies in other nutrients in addition to energy, whereas excessive ME content in diets caused increasing deposition of abdominal fat and carcass fat in birds.

The second experiment was conducted to evaluate the protein requirements of Korat chickens from 0 to 12 wk of age (Chapter IV). As the dietary protein level has a major effect on the growth performance, the increasing dietary protein levels resulted in an increased BWG. It can be concluded that the protein requirements of Korat chickens from 0 to 3 and 3 to 6 wk of age for the optimal BWG were 21.26 and 20.45% or 4.32 and 10.21 g/bird/d when dietary ME were 2,978 and 3,151 kcal/kg, respectively. The protein requirements of Korat chickens from 6 to 9 wk of age for optimal BWG and FCR were 18.00 and 18.04%, respectively or about 12.59 g/bird/d when dietary ME was 3,200 kcal/kg. The protein requirements of Korat chickens from 9 to 12 wk of age for optimal BWG and FCR were 17.94 and 18.03%, respectively or about 13.46 g/bird/d when dietary ME was 3,200 kcal/kg. Based on the present study, it can be suggested that the optimum ME to protein ratios of Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age were 140, 154, 178 and 178, respectively.

The third experiment was conducted to determine the nutrient digestibility and utilization and apparent metabolizable energy (AME) of diets for Korat chickens by using the total excreta collection method. The apparent digestibility of dry matter for Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age were ranging from 66.87 to 71.40%. The percentages of N retention for Korat chickens in the periods 0-3, 3-6, 6-9 and 9-12 wk of age were in the range between 59.00 and 52.55%. In addition, the determined AME and AME_n values were ranging from 3,009 to 3,238 kcal/kg, which were similar to the calculated AME in each experimental period.

However, these results based on the protein digestibility coefficients were 87.70, 87.90, 87.18 and 87.18% in the periods 0-3, 3-6, 6-9 and 9-12 wk of age, respectively. Consequently, further applications should be concerned about the protein digestibility of feedstuffs in the feed formulation in order to achieve the precision protein requirement. In addition, the study of ME and protein requirements of Korat chickens should determine the ME and nutrient digestibility of feed and feed ingredients in Korat chickens.

6.2 Implication

Based on the current study on the energy and protein requirements of Korat chickens, farmers, feed manufacturers and nutritionists can apply this database to formulate the diets for Korat chickens and other 50% indigenous crossbred chickens. Since this nutrient requirements were performed based on an optimization of the growth performance, but not for carcass quality and characteristics, the further research is required to consider about this matter. Moreover, the future research should also pay attention to the relationship between the dietary energy and protein contents or dietary energy and amino acid contents on growth performance and carcass quality.

In generally, the protein requirement of chickens is a requirement for amino acids. Therefore, the future production of Korat chickens on a commercial scale is required to rationalize amino acid requirements from 0 to 12 wk of age, especially limiting amino acids, such as methionine and lysine, and this can make the feed formulation with more precision. The next research should be conducted to determine the partitioning of ME requirements between maintenance and production. In addition, this information can be used to apply according to the type of feedstuffs available locally or some by-products from agricultural processing factories or alternative feedstuffs as a feed of Korat chickens.

BIOGRAPHY

Mr. Prapot Maliwan was born on 5th June 1972 in Nakhon Si Thammarat, Thailand. In 1991, he graduated from Benjamarachutit high school, Nakhon Si Thammarat. In 1995, he obtained his Bachelor's degree in Animal Science from the Department of Animal Science, Faculty of Natural Resources, Prince of Songkla University, Songkhla. In 2000, he received his a Master of Science in Animal Science (Animal Nutrition) from the Faculty of Graduate School, Prince of Songkla University, Songkhla. He has been working as a lecturer at the Department of Animal Science, Faculty of Agriculture, Rajamangala University of Technology Srivijaya, Nakhon Si Thammarat since 2000. In 2012, he was awarded got a scholarship by the Ministry of Science and Technology for his Doctor of Philosophy (Ph.D. degree) study in Animal Production Technology at the School of Animal Production Technology, Institute of Agricultural Technology, Suranaree University of Technology, Nakhon Ratchasima. During his doctoral study, he had an opportunity to go abroad for training in the nutrition section at the Department of Farm Animal Health, Faculty of Veterinary Medicine, Utrecht University, Utrecht, The Netherlands for 5 months (from 29th May to 31st October 2016). During his Ph.D. study, he has published one article "**Maliwan, P.**, Khempaka, S., and Molee, W. (2017). Evaluation of various feeding programmes on growth performance, carcass and meat qualities of Thai indigenous crossbred (50%) chickens. **S. Afr. J. Anim. Sci.** 47(1): 16-25."