Effect of dietary energy and protein content on growth and carcass traits of Pekin ducks

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ABSTRACT A study was conducted to determine the influence of dietary energy and protein concentrations on growth performance and carcass traits of Pekin ducks from 15 to 35 d of age. In experiment 1, 14-d-old ducks were randomly assigned to 3 dietary metabolizable energy (11.8, 12.8, and 13.8 MJ/kg) and 3 crude protein concentrations (15, 17, and 19%) in a 3 × 3 factorial arrangement (6 replicate pens; 66 ducks/pen). Carcass characteristics were evaluated on d 28, 32, and 35. In Experiment 2, 15-d-old ducks (6 replicate cages; 6 ducks/cage) were randomly allotted to the 9 diets that were remixed with 0.5% chromic oxide. Excreta were collected from d 17 to 19, and ileal digesta was collected on d 19 to determine AME_n and amino acid digestibility. In Experiment 1, there were interactions ($P < 0.05$) between dietary metabolizable energy and crude protein (CP) on body weight (BW) gain and feed intake, wherein BW gain increased more to increasing dietary CP as dietary metabolizable energy increased. However, feed intake was only influenced by dietary crude protein at 11.8 MJ ME/kg and not 12.8 or 13.8 MJ/kg. As dietary CP increased from 15 to 19%, breast meat yield increased by 10.8% on d 35 ($P < 0.01$). Conversely, increasing metabolizable energy from 11.8 to 13.8 MJ/kg increased dressing percentage, breast skin, and subcutaneous fat, but decreased breast meat yield (% but not weight) on d 35 ($P < 0.01$). In Experiment 2, the determined AME_n for diets formulated to contain 11.8, 12.8, or 13.8 MJ ME/kg were 11.66, 12.68, and 13.75 MJ/kg, respectively; determined standardized ileal digestible Lys was 0.95, 1.00, and 1.21% for diets formulated to contain 15, 17, or 19% crude protein, respectively. The best body weight gain and feed conversion ratio was obtained when ducks were fed a high dietary AME_n (13.75 MJ/kg) and high CP (19%, 1.21% SID Lys). These results provide a framework for subsequent modeling of amino acid and energy inputs and the corresponding outputs of growth performance and carcass components.

Key words: carcass traits, crude protein, duck, metabolizable energy, standardized ileal digestibility

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INTRODUCTION

Determination of nutrient requirements of different types of poultry is necessary to efficiently use the genetic potential of these birds for specific production goals (Pym, 1990). Dietary nutrient density is the most critical nutritional factor in commercial production, not only because it has a significant effect on growth performance, carcass quality, and health of poultry, but also because of economic inputs and outputs (Scott, 2002; Sterling et al., 2005; Brickett et al., 2007). Similar to chickens, ingredients supplying dietary energy and amino acids **(AA)** represent most of the diet cost for meat ducks. Therefore, providing diets formulated to contain AME and AA at optimum concentrations to meat ducks may increase profits by decreasing feed cost and/or increasing meat yield. Xie et al. (2010) reported that the AME requirement of White Pekin ducklings from 1 to 21d of age for optimal feed to gain ratio **(FCR)** was 12.63MJ/kg when dietary protein was 20.5% (1.1% lysine). The AME requirements of White Pekin ducks from 15 to 42d of age for optimal body weight (**BW**) gain and FCR was 12.57 and 12.67 MJ/kg when dietary protein was 18% (0.9% lysine), respectively, and abdominal fat increased when dietary AME was above 11.29MJ/kg (Fan et al., 2008). Sritiawthai et al. (2013) observed dietary 18% crude protein (**CP**) and 11.29 MJ ME /kg were the appropriate concentrations for improved feed efficiency and presented the best final BW and FCR from 1 to 14 d of age in Cherry Valley ducks. A significant interaction between protein and energy indicated the importance of a

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balanced calorie: protein **(C:P)** ratio to achieve optimum performance and carcass traits in broilers. Seaton et al. (1978) observed an increase in carcass fat and a decrease in moisture with an increase in the dietary energy level, and this fat was usually considered to be waste product when broilers were processed further, which indicated an economic loss for poultry producers. However, few studies have determined the interaction effects of dietary energy and CP or amino acid density on performance and carcass traits in Pekin ducks from 14 to 35d of age.

Moreover, the optimal processing age for meat ducks under various plans for nutrition to provide guidelines to optimize ration cost, performance, and carcass yield has yet to be determined. Murawska (2012) observed that the weight of lean meat, the most valuable component of duck, increased until the end of rearing, from 35.8 g in 1-wk-old birds to 1,047 g at 8 wk, and breast muscle weight increased 188-fold over 8 wk. A significant increase in the weight of skin and subcutaneous fat was observed until wk 7. Research has shown that carcass characteristics can be altered through manipulation of dietary protein or energy in broilers (Niu et al., 2009). The world meat duck production is increasing, which emphasizes the need for knowledge about responses to nutrients for feed formulations to allow best possible meat production. Therefore, comparing carcass traits of ducks under different ages to market weight with various nutrient profiles can provide substantial information to model nutrient input and carcass trait outcomes. However, this information is limited in the duck. Therefore, the objectives of this study were to determine the influence of dietary metabolic energy (**ME**) and CP concentration on performance and secondly to determine functional changes of carcass traits for varying ME and CP density at three different ages.

MATERIALS AND METHODS

All procedures and protocols were approved by Purdue University Animal Care and Use Committee.

Bird Management

In Experiment **(Exp.)** 1, 3,564 one-d-old Peking ducklings were fed a standard diet containing 12.72MJ/kg ME, 24% CP, 1.33% Lys, 0.7% Met, 0.9% Thr, and 0.5% Trp from 1 to 14 d of age. At d14, ducks were randomly allotted to 54 floor pens of 66 birds each so that ducklings had a similar initial BW in each pen. The floor pens were equipped with feeder, nipple drinker, and raised plastic floors. The environmental temperature and humidity were kept at 29°C and 60%, respectively, during 1 to 14 d. Afterward, the temperature was kept at 24°C.

In Exp. 2, 324 fifteen-d-old ducks were randomly allotted to 9 dietary groups in a randomized complete block design. Each treatment had 6 replicate cages with 6 ducks per replicate cage.

Dietary Treatments

In Exp.1, birds were randomly assigned to 9 dietary treatments in a 3 × 3 factorial arrangement with CP, and ME as the main effects. These diets were formulated to contain 11.8, 12.8, or 13.8 MJ ME/kg of diet each in combination with 15, 17, or 19% CP, respectively, and were fed from 14 to 35 d of age (Table 1). All diets kept the same ratio of Lys, Met, Thr, Trp, and Arg to dietary CP. The analyzed nitrogen **(N)** content and AA composition of the 9 diets is presented in Table 2. Each dietary treatment was replicated 6 times and fed in pellet form. Feed and water were provided for ad libitum consumption.

Exp.2 was a subsequent digestibility study of diets fed in Exp.1. Chromic oxide (0.5%) was mixed into the diets after grinding. On d 15, the birds were grouped by BW and randomly allotted to 9 dietary groups in a randomized complete block design. Between 17 and 19 d of age, the collection pans were placed under the cage, and excreta collection was done daily for 3 d. Excreta was collected and analyzed for DM, Cr, N, and energy to calculate AME and AMEn. On d 19, ileal digesta was gently rinsed with distilled water into plastic containers. The collected ileal samples from 6 birds within a cage were pooled and stored in a freezer at −20°C for subsequent analyses of DM, Cr, and AA to calculate apparent AA digestibility.

Measurements

In Exp.1, BW and feed consumption were determined at 21, 28, and 35 d. Mortality was recorded as it occurred, and the weights of dead birds were used to adjust F/G. The caloric and crude protein conversion were calculated by the formula: Dietary ME density (Mcal/kg) × Feed intake(kg) ÷ BW gain (kg), and Dietary CP concentration (g/kg) × Feed intake(g) ÷ BW gain (kg), respectively. At 28, 32, and 35 d of age, 4, 6, and 6 birds from each replicate were randomly selected for evaluation of carcass traits, respectively. Feed was withdrawn 4 h before processing. Birds selected for processing were weighed and placed in transportation coops. These birds were weighed, euthanized after electrical stunning by exsanguination, defeathered, eviscerated, and weighed again to obtain carcass weight (without neck and feet), breast meat weight and breast skin, and subcutaneous fat weight after the carcasses were stored on ice overnight. Carcass yield was determined as the carcass weight in relation to BW and expressed as percentage of BW (%), whereas breast meat and breast skin and subcutaneous fat yield were expressed as percentages of the carcass weight.

For Exp. 2, the chemical analyses of dietary and ileal digesta nitrogen and AA composition the methods de-

Table 1. Feed ingredients and chemical composition of the experimental diets on an as-feed basis.

Item	11.8 (MJ/Kg)			12.8 (MJ/Kg)			13.8 (MJ/Kg)		
	15.0%	17.0%	19.0%	15.0%	17.0%	19.0%	15.0%	17.0%	19.0%
Ingredient (%)									
Corn	48.54	46.12	52.67	55.00	55.45	51.65	55.95	48.38	44.49
Soybean Meal,48% CP	13.65	19.33	27.57	15.80	21.32	27.49	17.57	21.90	29.25
Wheat	9.06	9.64	5.95	6.87	4.57	–	2.19	2.68	–
Bakery Meal	6.67	4.91	–	6.67	6.67	6.67	6.67	8.33	8.33
Wheat Middlings	8.33	6.21	–	–	–	–	–	–	–
Wheat Red Dog	8.33	8.33	8.33	8.33	5.00	5.78	5.83	6.48	4.58
Animal-Vegetable Oil Blend	–	–	–	2.12	1.99	3.33	6.69	7.26	8.36
Calcium Carbonate	2.81	2.93	2.78	2.76	2.63	2.62	2.64	2.63	2.61
Monocalcium Phosphate (21%)	1.01	0.99	0.99	1.09	1.07	1.02	1.10	1.06	1.02
L-Lysine, HCl	0.43	0.36	0.38	0.40	0.34	0.41	0.37	0.35	0.37
Methionine Hydroxy Analog(MHA)	0.25	0.27	0.35	0.25	0.27	0.36	0.25	0.27	0.36
L-Threonine	0.04	–	0.02	0.03	–	0.02	0.02	–	–
NaCl	0.39	0.42	0.50	0.20	0.20	0.20	0.20	0.18	0.18
Choline Chloride	0.14	0.13	0.11	0.15	0.14	0.12	0.16	0.14	0.12
Vitamin-Mineral Premix[1]	0.35	0.35	0.35	0.35	0.35	0.34	0.35	0.35	0.34
Total (kg)	100	100	100	100	100	100	100	100	100
Calculated Composition (%)									
ME(MJ/kg)	11.81	11.81	11.81	12.77	12.77	12.77	13.83	13.83	13.83
Crude Protein(CP)%	15.00	17.00	19.00	15.00	17.00	19.00	15.00	17.00	19.00
Calcium	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33
Total Phosphorus	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
ME:CP (Ratio)	188	165	148	203	181	160	220	196	170

[1]The vitamin-mineral premix was formulated to meet or exceed NRC (1994) nutrient recommendations for growing ducks for vitamins and trace minerals. The premix also contained 0.1% mold inhibitor, phytase (final dietary concentration of 1,000FYT/kg), xylanase, and β-glucanase (final dietary concentration of 1,100 and 100 units/kg, respectively).

Table 2. Analyzed nitrogen content and amino acid composition of the experimental diets (as-fed basis).

Item	11.8 (MJ/Kg)			12.8 (MJ/Kg)			13.8 (MJ/Kg)		
	15.0%	17.0%	19.0%	15.0%	17.0%	19.0%	15.0%	17.0%	19.0%
Nitrogen, g/kg	2.48	2.76	3.14	2.52	2.82	3.25	2.53	2.84	3.30
Dispensable Amino Acid, g/kg									
Aspartic Acid	1.33	1.50	1.90	1.37	1.54	1.84	1.42	1.55	1.89
Alanine	0.80	0.85	0.97	0.79	0.85	0.93	0.80	0.83	0.95
Cysteine	0.25	0.26	0.30	0.25	0.26	0.30	0.25	0.25	0.27
Glutamic Acid	2.78	3.02	3.56	2.85	3.09	3.44	2.86	3.07	3.61
Glycine	0.65	0.70	0.82	0.65	0.69	0.82	0.65	0.69	0.81
Proline	0.95	1.01	1.14	0.97	1.05	1.15	0.98	1.03	1.17
Serine	0.65	0.71	0.85	0.66	0.71	0.81	0.68	0.73	0.85
Tyrosine	0.56	0.64	0.74	0.57	0.62	0.71	0.58	0.62	0.71
Indispensable Amino Acid, g/kg									
Arginine	0.94	1.02	1.28	0.95	1.04	1.23	0.97	1.05	1.26
Histidine	0.39	0.42	0.50	0.39	0.42	0.50	0.40	0.42	0.49
Isoleucine	0.60	0.66	0.82	0.62	0.69	0.81	0.63	0.68	0.83
Leucine	1.33	1.42	1.67	1.33	1.46	1.63	1.37	1.43	1.67
Lysine	1.03	1.15	1.33	1.06	1.16	1.31	1.09	1.15	1.31
Methionine	0.22	0.24	0.27	0.22	0.24	0.27	0.24	0.23	0.26
Phenylalanine	0.76	0.82	0.99	0.77	0.85	0.98	0.80	0.84	1.00
Threonine	0.50	0.53	0.65	0.51	0.56	0.66	0.53	0.57	0.67
Tryptophan	0.19	0.22	0.26	0.20	0.22	0.22	0.20	0.22	0.25
Valine	0.71	0.77	0.93	0.72	0.79	0.90	0.73	0.77	0.91
Total AA	15.15	16.47	19.52	15.42	16.82	19.02	15.75	16.67	19.53
MHA[1]	0.29	0.27	0.24	0.29	0.25	0.26	0.30	0.25	0.26
Total AA:N[2]	6.11	5.97	6.22	6.12	5.94	5.85	6.23	5.87	5.92

[1]MHA: Methionine Hydroxy Analog.

[2]Total AA:N = the content of total AA of diet/Nitrogen content of diet.

scribed by Kong and Adeola (2013) were used, and the data of the basal endogenous N and AA losses (BEL, mg/kg of DM intake) in ducks and standardized ileal digestibility (**SID**; %) of N and AA were calculated according to Kong and Adeola (2013).

Statistical Analysis

Data were analyzed by two-way ANOVA using the GLM procedure of SAS software (SAS Institute, 2006). The model included the main effects of dietary

Table 3. The effect of dietary ME and CP concentration on growth performance of ducks in Exp. 1.

Item ME (MJ/kg)	CP (%)	35d BW (kg)	14–35d BWG (kg)	FI (kg)	F/G (g/g)	Caloric Conversion[1]	Crude Protein Conversion[2]
11.8	15	$3.02^{3,d,e}$	$2.22^{d,e}$	4.27^{a}	1.93^{a}	5.44	28.9
11.8	17	$3.08^{b,c}$	$2.29^{b,c}$	$4.12^{a,b}$	1.80^{b}	5.09	27.0
11.8	19	$3.15^{a,b}$	$2.32^{a,b}$	4.02^{b}	$1.73^{b,c,d}$	4.89	26.0
12.8	15	2.92^{f}	2.10^{f}	$3.74^{d,c}$	$1.78^{b,c}$	5.45	26.7
12.8	17	$3.11^{a,b,c}$	$2.30^{a,b,c}$	3.82^{c}	$1.66^{f,e,d}$	5.09	24.9
12.8	19	$3.13^{a,b}$	$2.31^{a,b}$	$3.78^{d,c}$	$1.64^{f,e}$	5.01	24.6
13.8	15	$2.97^{e,f}$	$2.16^{e,f}$	3.65^{d}	$1.70^{c,b,d}$	5.59	25.4
13.8	17	$3.05^{d,c}$	$2.24^{d,c}$	$3.70^{d,c}$	$1.65^{f,e,d}$	5.46	24.8
13.8	19	3.18^{a}	2.37^{a}	$3.74^{d,c}$	1.58^{f}	5.22	23.7
SEM		0.02	0.02	0.05	0.03	0.09	0.46
Main Effect Means							
11.8		3.08	2.28	4.14^{a}	1.82^{a}	5.14^{a}	27.3^{a}
12.8		3.05	2.24	3.78^{b}	1.69^{b}	5.18^{a}	25.4^{b}
13.8		3.06	2.25	3.70^{b}	1.64^{b}	5.42^{b}	24.6^{b}
	15	2.97^{a}	2.16^{a}	3.89	1.80^{a}	5.49^{a}	27.0^{a}
	17	3.08^{b}	2.28^{b}	3.88	1.71^{b}	5.21^{b}	25.6^{b}
	19	3.15^{b}	2.33^{b}	3.85	1.65^{c}	5.04^{c}	24.7^{c}
Source of Variation		Probability					
ME		0.38	0.14	<0.0001	<0.0001	0.0011	<0.0001
CP		<0.0001	<0.0001	0.64	<0.0001	<0.0001	<0.0001
ME*CP		<0.05	<0.01	<0.05	0.54	0.69	0.55

[a–f]Means within a column and under each main effect with no common superscripts differ at $P < 0.05$.

[1]The caloric conversion was calculated by the formula: Caloric conversion (Mcal ME/kg weight gain) = Dietary ME density (Mcal/kg) × Feed intake (kg) ÷ weight gain (kg).

[2]The crude protein conversion was calculated by the formula: crude protein conversion (g CP/kg weight gain) = Dietary CP concentration (g/kg) × Feed intake (kg) ÷ weight gain (kg).

[3]Means represent 6 pens per treatment of 66 ducks per pen.

energy concentration, dietary CP concentration, and their interaction. The pen was the experimental unit. The means showing significant treatment differences at $P \leq 0.05$ in ANOVA were then compared using Fisher's protected least significant difference procedure and an alpha level of 0.05 was considered significant. All data were tested for normality using the UNIVARIATE procedure and common variance using the GLM procedure.

RESULTS

Growth Performance, Caloric and Crude Protein Conversion

The effects of dietary ME and CP concentration on growth performance are given in Table 3. There were interactions between dietary CP and ME on BW at 35d ($P < 0.05$), BW gain ($P < 0.01$), and FI ($P < 0.05$). The BW gain responded more to dietary CP as ME increased (interaction of CP by ME < 0.01). Conversely, dietary CP only influenced feed intake at 11.8 MJ/kg but did not influence intake at 12.8 or 13.8 MJ/kg. The interaction of ME by CP was not significant for FCR; however, there were main effects on ME and CP ($P \leq 0.0001$). The FCR was 0.18 higher from birds fed the 11.8 versus 13.8 MJ/kg, but there was no difference between the 12.8 MJ/kg and 13.8 MJ/kg ME diet. Ducks fed 13.8 MJ ME/kg of diet had the higher caloric conversion ($P < 0.01$) compared to ducks fed 11.8 MJ/kg and 12.8MJ/kg ME of diet, whereas ducks fed 13.8 MJ ME/kg of diet had the lower CP conversion ($P < 0.01$) compared with ducks fed 11.8MJ/kg ME of diet. Dietary CP incrementally reduced FCR and caloric and crude protein conversion of ducks as it increased from 15 to 19%.

The effects of dietary ME and CP concentration on growth performance during 14 to 21 d, 21 to 28 d and 28 to 35 d are presented in Figures 1 and 2, respectively. While dietary energy concentration did not result in a difference in BW during the study, it dramatically decreased feed intake between 28 and 35 d of age ($P < 0.05$). Compared to ducks fed 11.8 MJ ME/kg of diet, ducks fed 12.8 or 13.8 MJ ME /kg of diet ate 24.8% and 28.9% less feed, respectively, from 28 to 35 d of age. During the whole study period, dietary CP concentration did not drive feed intake, but ducks fed 15% CP had a lower daily BW gain ($P < 0.05$) from 14 to 21 d and 21 to 28 d compared with ducks fed 17% and 19% CP. Moreover, dietary CP concentration had no dramatic effect on daily BW gain from 28 to 35d (108, 110, and 111g BWG for 15, 17, and 19% CP). However, the 15% CP diet resulted in a 110 and 180 g lighter BW at 35 d versus those fed 17 or 19%, respectively, with no difference in cumulative feed intake. During 28 to 35 d, dietary ME and CP concentration had a significant interactive effect ($P < 0.05$) on ADFI and daily BW gain, whereas ducks fed 13.8 MJ ME/kg and 15% CP of diet had the lowest feed intake and daily BW gain among all treatments.

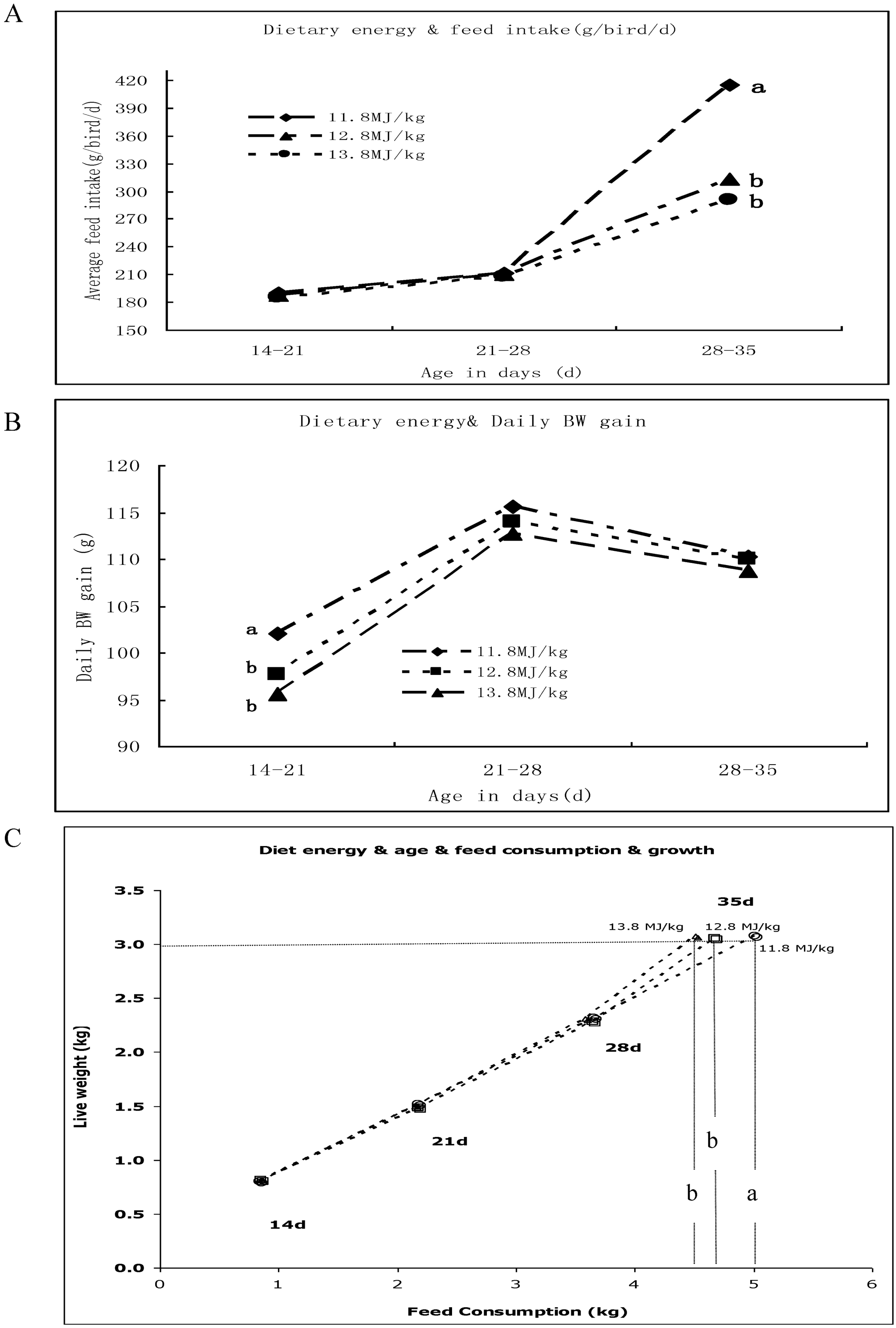

Figure 1. Effect of dietary energy concentration on growth performance of ducks of 21, 28, and 35 d of age. A: Effect of dietary energy on average daily feed intake; B: Effect of dietary energy on daily BW gain; C: Effect of dietary energy on cumulative feed consumption and BW gain. [a,b] Means within the same age with no common superscripts are significantly different ($P < 0.05$). SEM = 0.86, 0.89, and 1.43 for 14 to 21d, 21 to 28 d and 28 to 35 d daily BW gain, whereas SEM = 0.92, 1.59 and 3.72 for 14 to 21 d, 21 to 28 d and 28 to 35 d cumulative feed intake.

A

B

C

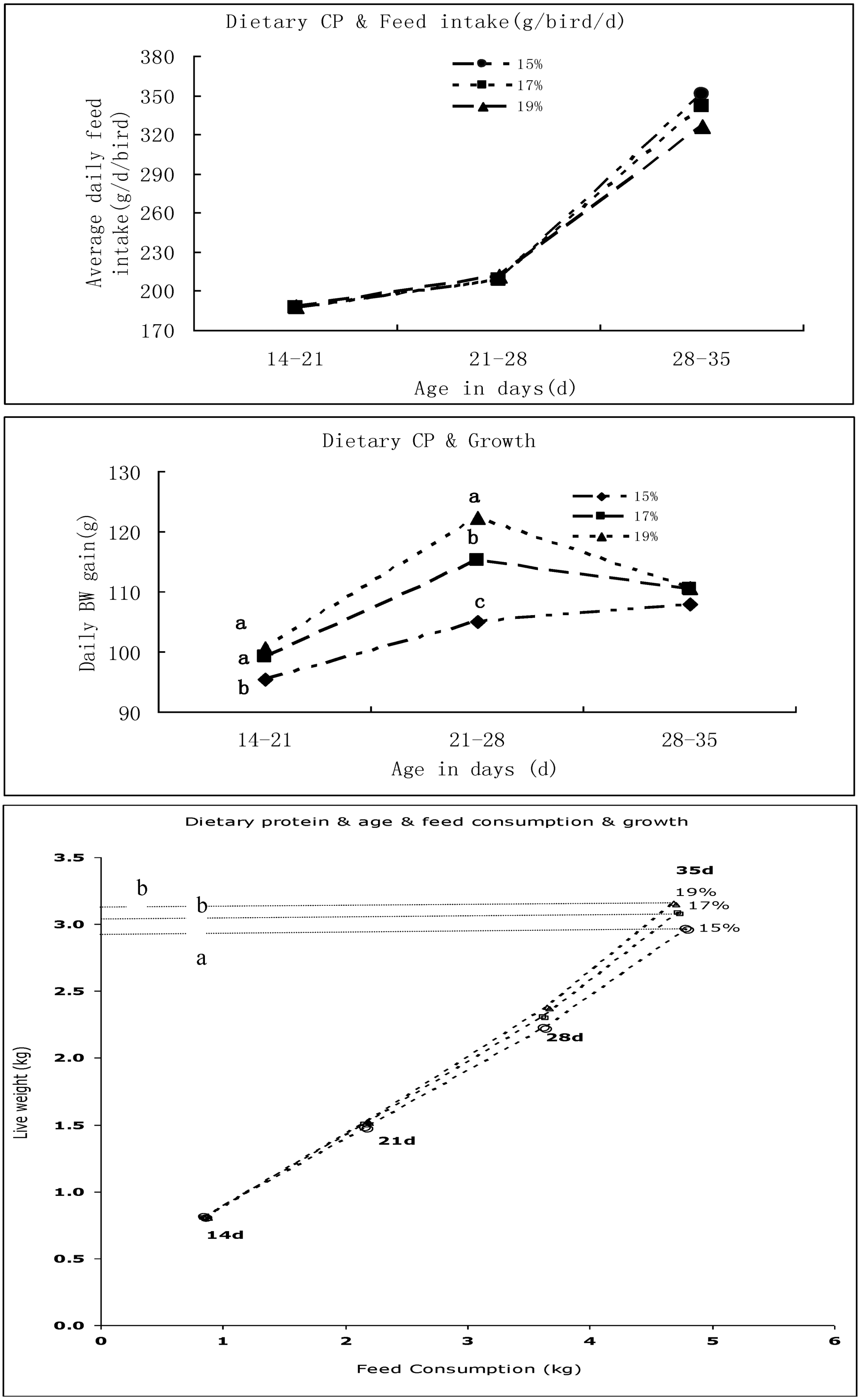

Figure 2. Effect of dietary CP concentration (%) on growth performance of ducks of 21, 28, and 35 d of age. A: Effect of dietary CP concentration on average daily feed intake; B: Effect of dietary CP concentration on daily BW gain; C: Effect of CP concentration on cumulative feed consumption and BW gain. [a,b,c] Means within the same age under each main effect with no common superscripts are significantly different ($P < 0.05$). SEM = 0.86, 0.89 and 1.43 for 14 to 21d, 21to 28d and 28 to 35d daily BW gain, whereas SEM = 0.92, 1.59 and 3.72 for 14 to 21d, 21 to 28d and 28 to 35d cumulative feed intake.

Table 4. The effect of dietary ME and CP on body weight and the weight of eviscerated carcass, breast skin, and subcutaneous fat, and breast meat at 28d, 32d, and 35d of age in Exp 1.

Item		Body Weight, kg			Eviscerated Carcass Weight, kg			Breast Skin and Fat Weight, g			Breast Meat Weight. g		
ME (MJ/kg)	CP (%)	28 d	32 d	35 d	28 d	32 d	35 d	28 d	32 d	35 d	28 d	32 d	35 d
11.8	15	2,300[1]	2,692[2]	3,003[3] ^{b,c}	1,447	1,687	1,936^{b,c,d}	102	109	127	182	275	360^{e,d}
11.8	17	2,380	2,880	2,983^{b,c,d}	1,494	1,810	1,919^{c,d}	100	116	118	207	318	371^{c,d}
11.8	19	2,423	2,826	3,095^{a,b}	1,532	1,790	2,010^{a,b,c}	98.4	100	117	222	336	417^{a}
12.8	15	2,234	2,670	2,849^{d}	1,412	1,686	1,853^{d}	104	117	121	174	265	319f
12.8	17	2,350	2,820	3,122^{a,b}	1,493	1,768	2,046^{a,b}	101	112	133	204	295	406^{a,b}
12.8	19	2,439	2,806	3,166^{a}	1,533	1,771	2,072^{a}	103	108	127	209	317	426^{a}
13.8	15	2,209	2,733	2,942^{d,c}	1,404	1,743	1,926^{b,c,d}	110	127	142	161	268	336^{e,f}
13.8	17	2,379	2,753	3,080^{a,b,c}	1,519	1,757	2,023^{a,b}	118	126	141	200	280	376^{b,c,d}
13.8	19	2,379	2,918	3,131^{a}	1,530	1,872	2,066^{a}	109	127	138	210	319	397^{a,b,c}
SEM		11.9	14.6	16.3	8.2	10.3	12.1	0.9	1.1	1.3	2.2	3.0	3.6
Main Effect Means													
11.8		2,368	2,800	3,028	1,491	1,762	1,955	100^{a}	108^{a}	122^{a}	204^{a}	310^{a}	387
12.8		2,341	2,766	3,046	1,479	1,742	1,990	103^{a}	114^{a}	127^{b}	196^{a,b}	293^{b}	382
13.8		2,322	2,802	3,051	1,484	1,791	2,005	112^{b}	127^{b}	140^{c}	190^{b}	289^{b}	385
	15	2,248^{a}	2,699^{a}	2,932^{a}	1,403^{a}	1,705^{a}	1,905^{a}	105	118^{a}	123	173^{a}	270^{a}	342^{a}
	17	2,370^{a}	2,818^{b}	3,062^{b}	1,502^{b}	1,778^{b}	1,996^{b}	106	118^{a}	131	204^{b}	298^{b}	384^{b}
	19	2,414^{b}	2,850^{b}	3,131^{b}	1,531^{b}	1,811^{b}	2,049^{b}	103	112^{b}	127	204^{b}	324^{c}	413^{c}
Source of Variation						Probability							
ME		0.33	0.56	0.68	0.82	0.11	0.14	< 0.0001	< 0.0001	< 0.0001	0.06	0.09	0.14
CP		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.36	0.03	0.47	< 0.0001	< 0.0001	< 0.0001
ME*CP		0.57	0.12	< 0.05	0.72	0.21	0.05	0.16	0.06	0.08	0.80	0.50	< 0.05

[a–f]Means within a column and under each main effect with no common superscripts differ at $P < 0.05$.

[1]Means represent 24 ducks per treatment.

[2,3]Means represent 36 ducks per treatment.

Table 5. Effect of dietary energy and protein content on the percentage of eviscerated carcass, breast skin and subcutaneous fat, and breast meat at 28 d, 32 d, and 35 d of age in Exp 1.

Item		Eviscerated Carcass Yield (%)[1]			Breast Skin and Fat Yield (%)[1]			Breast Meat Yield (%)[1]		
ME (MJ/kg)	CP (%)	28 d	32 d	35 d	28 d	32 d	35 d	28 d	32 d	35 d
11.8	15	62.96[2]	62.64[3]	65.22[4]	7.08^{d,c}	6.42^{c}	6.62	12.63	16.17	18.47
11.8	17	62.75	62.87	64.33	6.79^{d,e}	6.43^{c}	6.17	13.83	17.52	19.38
11.8	19	63.75	63.38	66.00	6.38^{f}	5.63^{d}	5.70	14.50	18.75	20.42
12.8	15	63.08	63.04	65.55	7.42^{b,c}	6.96^{b}	6.50	12.25	15.67	17.50
12.8	17	63.54	62.71	66.17	6.67^{f,e}	6.29^{c}	6.50	13.63	16.58	19.84
12.8	19	62.74	63.17	66.00	6.83^{d,e}	6.08^{c}	6.17	13.52	17.83	20.42
13.8	15	63.65	63.74	65.08	8.00^{a}	7.39^{a}	7.30	11.52	15.34	17.47
13.8	17	63.88	63.67	65.83	7.71^{a,b}	7.17^{a,b}	6.88	13.17	15.83	17.67
13.8	19	64.44	64.12	66.58	7.04^{d,e}	6.84^{b}	6.60	13.72	17.00	19.27
SEM		0.13	0.12	0.12	0.05	0.04	0.04	0.11	0.11	0.11
Main Effect Means										
11.8		62.99^{a}	62.92^{a}	64.52^{a}	6.75^{a}	6.19^{a}	6.23^{a}	13.65^{a}	17.29^{a}	19.35^{a}
12.8		63.13^{a,b}	62.97^{a}	65.30^{b}	6.97^{a,b}	6.44^{a}	6.39^{a}	13.13^{a,b}	16.69^{b}	19.30^{a}
13.8		64.00^{b}	63.84^{b}	65.63^{b}	7.57^{b}	7.13^{b}	6.92^{b}	12.83^{b}	16.08^{b}	18.43^{b}
	15	63.23	63.06	64.81	7.49^{a}	6.84^{a}	6.78^{a}	12.46^{a}	15.80^{a}	17.93^{a}
	17	63.39	63.08	65.08	7.06^{a,b}	6.63^{a}	6.51^{a,b}	12.82^{a}	16.63^{a}	19.23^{b}
	19	63.50	63.56	65.48	6.75^{b}	6.19^{b}	6.17^{b}	15.72^{b}	17.85^{b}	20.10^{b}
Source of Variation					Probability					
ME		0.004	0.002	0.0008	<0.0001	<0.001	<0.0001	0.0095	<0.001	0.0007
CP		0.74	0.20	0.17	<0.0001	<0.001	<0.0001	<0.0001	<0.001	<0.0001
ME*CP		0.38	0.91	0.89	<0.05	<0.05	0.13	0.62	0.59	0.16

[a–f]Means within a column and under each main effect with no common superscripts differ at $P < 0.05$.

[1]Eviscerated carcass yield (%) = Eviscerated carcass weight/BW*100%; Breast skin and fat yield (%) = Breast skin and fat weight/Eviscerated carcass weight * 100%; Breast meat yield (%) = Breast meat weight/Eviscerated carcass weight * 100%

[2]Means represent 24 ducks per treatment.

[3.4]Means represent 36 ducks per treatment.

Carcass Traits at 28, 32, and 35 d of Age

The effects of dietary ME and CP concentration on carcass weight and yield of ducks at 28, 32, and 35 d of age are reported in Tables 4 and 5, respectively. As dietary ME concentration increased, breast skin and fat weight and yield ($P < 0.01$), and eviscerated carcass yield ($P < 0.01$) increased, while breast meat yield ($P < 0.01$) decreased in ducks at 28, 32, and 35 d of age. Eviscerated carcass weight ($P < 0.01$), breast meat

Table 6. Effect of dietary energy and protein content on nutrient excretion and energy retention of ducks from 17 to 19 d of age in Exp. 2 (%).

Item ME(MJ/kg)	CP (%)	DM	Energy %	Nitrogen	AME MJ/kg	AMEn
11.8	15	70.13[1,e]	74.00[d]	73.48[d]	12.45	11.82
11.8	17	72.08[e,d,c]	75.68[d,c]	76.48[c]	12.39	11.65
11.8	19	73.21[d,b,c]	77.15[b,c]	79.63[a,b]	12.43	11.50
12.8	15	73.77[a,b,c]	77.36[b,c]	79.56[b]	13.42	12.68
12.8	17	71.47[e,d]	76.19[c]	79.36[b]	13.65	12.80
12.8	19	72.15[e,d,c]	76.03[c]	79.27[b]	13.49	12.56
13.8	15	75.31[a,b]	79.41[a]	80.57[a,b]	14.55	13.80
13.8	17	75.68[a]	79.97[a]	81.70[a]	14.58	13.71
13.8	19	73.31[b,d,c]	78.39[a,b]	80.96[a,b]	14.76	13.73
SEM		0.26	0.24	0.25	0.02	0.03
Main Effect Means						
11.8		71.75[a]	75.54[a]	76.37[a]	12.42[a]	11.66[a]
12.8		72.53[a]	76.56[a]	79.41[b]	13.52[b]	12.68[b]
13.8		74.85[b]	79.31[b]	81.08[b]	14.62[c]	13.75[c]
	15	72.96	76.80	77.74[a]	13.42	12.72[a]
	17	72.98	77.12	78.91[a,b]	13.43	12.61[a,b]
	19	72.87	77.12	79.89[b]	13.49	12.53[b]
Source of Variation				Probability		
ME		0.0001	0.0001	0.0001	<0.0001	<0.0001
CP		0.98	0.77	0.01	0.32	0.02
ME*CP		<0.01	<0.05	<0.01	0.07	0.16

[a–d]Means within a column and under each main effect with no common superscripts differ at $P < 0.05$.

[1]Means represent 6 cages per treatment of 6 ducks per cage.

weight and yield ($P < 0.01$) significantly increased, and breast skin and fat yield ($P < 0.01$) significantly decreased by increasing dietary CP from 15.0 to 19.0% in ducks at 28, 32, and 35 d of age. There were interactions between dietary CP and ME on breast meat weight ($P < 0.05$) in ducks at 35 d of age, but not at 28 or 32 d of age. Ducks at 35 d of age fed 12.8 MJ/kg ME had the heaviest breast meat within birds fed 17% or 19% CP of diet, but the lightest breast meat when fed 15% CP. Conversely, ducks fed 11.8 MJ/kg had the most breast meat among birds fed 15% CP.

Nutrient and Energy Retention and SID of Amino Acids

The effects of dietary ME and CP on excreta nutrient availability and SID of AA are shown in Tables 6 and 7, respectively. There were significant interactions ($P < 0.05$) between the ME and CP of the diet on excreta DM, energy, and nitrogen retention. The highest ME concentration significantly increased ($P < 0.01$) excreta DM, energy, nitrogen retention, and dietary AME and AME_n. Whereas the highest CP (19%)only increased the apparent nitrogen retention ($P < 0.01$), and decreased dietary AME_n concentration ($P < 0.01$). There were interactions ($P < 0.05$) between ME and CP of diet and SID of nitrogen, aspartic acid, serine, glycine, cysteine, valine, Thr, and Trp. The determined AME_n for diets formulated to contain 11.8, 12.8, or 13.8 MJ ME/kg were 11.66, 12.68, or 13.75 MJ/kg, respectively; while the determined standardized ileal digestible Lys were 0.95, 1.00, or 1.21% for diets formulated to contain 15, 17, or 19% CP, respectively.

DISCUSSION

In the current experiment, as dietary ME concentration increased, feed intake, FCR, and breast meat deposition decreased, whereas BW, and breast skin and fat deposition increased. The AME_n responses of White Pekin ducks from 15 to 35 d of age for the best BW gain and FCR was 13.75 MJ/kg when dietary protein was at the highest concentration (19%). These results were similar to Dozier et al. (2006), who evaluated diets varying in AME content fed to Ross×Ross 308 broilers from 1.5 to 3.9 kg and found that increasing AME of the diet from 13.46 to 13.84 MJ/kg decreased feed consumption and improved feed conversion by 0.08 in broilers subjected to low temperatures but limited breast meat yield. Fan et al. (2008) reported that as dietary energy increased from 10.87 to 12.96 MJ AME/kg (at a common 18% CP, 0.5% Met, 0.9% Lys), the daily BW gain of ducks increased significantly (64.6 vs 69.9 g), and the ADFI (190.4 vs 174.7 g) and FCR (2.95 vs 2.51) decreased significantly. In the same study when dietary AME was above 11.29 MJ/kg, abdominal fat (0.86% vs 1.65%) increased significantly, but did not affect breast and leg meat yield. Ducks fed on the highest energy diets had a better BW gain and FCR, which may have been due to relatively high nutrient utilization. In the current study, the excreta DM, energy and nitrogen retention increased with the increase of dietary ME concentration. In this study, the determined AME_n

Table 7. Standardized ileal digestibility of nitrogen and amino acids of ducks at 19 d of age in Exp. 2.

Item		Indispensable Amino Acid										Dispensable amino acid									
		Arg	His	Iso	Leu	Lys	Met	Phe	Thr	Trp	Val	Asp	Ala	Cys	Glu	Gly	Pro	Ser	Tyr	Total	N
ME (MJ/kg)	CP (%)										%										
11.8	15	86.15	81.82	79.69	84.49	85.11	84.31	82.47	70.93^{b}	78.07^{c}	77.71^{1,b}	76.79^{c}	80.59	73.42^{b}	85.83	73.33^{b}	82.05	75.88^{b}	81.76	79.01	74.92^{b}
11.8	17	94.02	91.25	90.60	91.61	93.69	93.47	91.33	85.57^{a}	90.55^{a}	89.56^{a}	88.08^{a,b}	90.55	86.66^{a}	93.10	86.25^{a}	90.87	88.30^{a}	91.01	89.83	87.92^{a}
11.8	19	93.37	90.11	89.08	89.92	91.52	91.38	89.92	82.82^{a}	87.35^{a,b,c}	88.3^{a}	86.72^{a,b}	88.79	84.21^{a}	91.83	84.01^{a}	89.37	86.29^{a}	89.31	87.95	84.54^{a}
12.8	15	94.09	91.02	90.66	91.62	93.04	92.99	91.53	84.19^{a}	90.18^{a,b}	89.63^{a}	87.27^{a,b}	90.27	85.79^{a}	93.13	85.65^{a}	91.09	87.90^{a}	91.08	89.44	86.77^{a}
12.8	17	90.54	86.32	85.30	86.94	89.00	88.64	86.94	77.07^{a,b}	83.95^{a,b,c}	84.21^{a,b}	81.81^{a}	85.36	80.39^{a,b}	89.28	78.87^{a}	86.78	82.08^{a}	86.68	84.14	80.97^{a,b}
12.8	19	94.07	91.29	90.61	91.1	92.52	92.86	91.12	84.13^{a}	87.55^{a,b,c}	89.44^{a}	88.00^{a}	89.95	86.58^{a}	92.68	86.39^{a}	90.66	87.40^{a}	90.79	89.36	87.29^{a}
13.8	15	93.00	90.31	88.97	90.51	91.92	91.58	90.64	83.28^{a}	88.46^{a,b}	88.35^{a}	86.69^{a,b}	89.25	86.52^{a}	92.16	84.71^{a}	90.47	87.73^{a}	90.03	88.69	85.59^{a}
13.8	17	79.05	81.04	81.07	80.69	80.00	80.35	80.80	80.00^{a,b}	80.50^{b,c}	81.54^{a,b}	80.87^{b,c}	81.35	81.49^{a,b}	79.12	80.54^{a}	81.53	82.00^{a,b}	81.54	81.73	81.40^{a,b}
13.8	19	92.47	89.2	87.91	88.93	90.8	89.11	89.12	79.86^{a,b}	85.57^{a,b,c}	86.27^{a}	84.99^{a,b}	87.19	80.60^{a,b}	90.91	82.72^{a}	88.56	85.61^{a}	88.27	86.54	83.95^{a}
SEM		1.04	1.34	1.11	1.17	1.13	1.13	1.58	1.08	1.61	1.12	1.00	1.08	1.02	1.49	1.09	1.03	1.04	1.06	1.03	1.00
Main Effect Mean																					
11.8		91.18	87.72	86.45	88.01	90.1	89.72	87.9	79.77	85.32	85.19	83.86	86.65	81.43	90.25	81.20	87.43	83.51	87.36	85.6	82.5
12.8		92.90	89.54	88.86	89.89	91.52	91.49	89.86	81.8	87.23	87.76	85.69	88.55	84.25	91.70	83.64	89.51	85.79	89.52	87.65	85.01
13.8		88.17	86.82	85.98	86.71	86.91	87.01	86.85	81.05	84.84	85.39	84.18	85.93	82.87	87.40	82.66	86.85	85.11	86.61	85.65	83.65
	15	91.08	87.72	86.44	88.21	90.03	89.63	88.21	79.47	85.57	85.23	83.58	86.70	81.91	90.37	81.23	87.87	83.84	87.62	85.71	82.42
	17	87.87	86.2	85.66	86.41	86.89	87.49	86.35	80.88	85	85.1	83.59	85.75	82.84	87.17	81.89	86.39	84.15	86.41	85.22	83.43
	19	93.30	90.17	89.2	89.98	91.61	91.12	90.05	82.27	86.82	88.00	86.57	88.65	83.79	91.81	84.37	89.53	86.43	89.45	87.95	85.26
Source of Variation											Probability										
ME		0.49	0.59	0.54	0.54	0.48	0.40	0.55	0.76	0.66	0.54	0.73	0.58	0.56	0.50	0.63	0.58	0.65	0.53	0.65	0.59
CP		0.40	0.34	0.41	0.47	0.47	0.55	0.42	0.61	0.80	0.45	0.38	0.52	0.77	0.44	0.44	0.51	0.53	0.52	0.52	0.51
ME*CP		0.28	0.09	0.08	0.13	0.23	0.19	0.12	<0.05	<0.05	<0.05	<0.04	0.08	<0.05	0.28	<0.05	0.12	<0.05	0.12	0.06	<0.05

[a–d]Means within a column and under each main effect with no common superscripts differ at $P < 0.05$.

[1]Means represent 6 cages per treatment of 6 ducks per cage.

for diets formulated to contain 11.8, 12.8, or 13.8 MJ ME/kg were 11.66, 12.68, or 13.75 MJ/kg, respectively. Increasing dietary energy can cause the deposition of excess abdominal or carcass fat in broilers (Summers et al., 1992; Ghaffari et al., 2007) and in Roman White geese (Min et al., 2007), which was in agreement with this study. However, some studies observed no significant effects of high-energy diets on breast meat yield of broilers (Leeson et al., 1996; Yalcin et al., 1998; Dozier et al., 2006) in contrast to the results of the present study.

It is known that the CP and amino acid (AA) status of a diet influences BW gain, carcass composition of broilers, and decreases in dietary CP can cause a decrease in carcass protein and an increase in carcass fat content. In the present study, dietary CP concentration and AA density affected BW and breast meat yield of ducks at 28, 32, and 35d of age, whereas ducks fed 19% CP had the highest BW, breast meat weight, and yield compared to ducks fed 15% and 17% CP. Farhat and Chavez (1999) observed that Pekin ducks on the high protein (23%) program had higher plasma IGF-I concentrations than ducks on either medium (19%) or low protein (17%) programs. Similar differences in the same study (Farhat and Chavez, 1999) were observed for the ultrasound measurements of breast muscle thickness, 8.42 vs 7.26 and 6.93 mm for high protein vs. medium and low protein programs, respectively; as well as for the Pectoralis muscle (weight as percentage of carcass weight), 14.38% vs 12.19% and 12.02% for high protein vs. medium and low protein programs, respectively.

A significant interaction between dietary ME and CP concentration on 35 d BW and breast meat yield indicated the importance of a balanced ME:CP ratio to achieve optimum performance (Jackson et al., 1982). Swatson et al. (2002) reported that poorer performance was observed for birds fed diets of low ME:CP ratios, which suggests that, when surplus protein is fed, the energy content should also be increased to ensure that sufficient energy is available for the efficient utilization of the dietary protein. This is in line with the result of the digestibility study in the current experiment, which revealed dietary ME and CP concentration had a significant interactive effect on DM, energy, and N availability. Ducks fed 13.8 MJ ME/kg and 17% CP of diet (ME:CP = 196) presented the best DM, energy and N availability, whereas ducks fed 11.8 MJ ME/kg and 15% CP of diet (ME:CP = 188) had the poorest DM, energy, and N availability, and FCR among all dietary treatments. High CP concentration and AA density of the diet resulted in lower caloric conversion (5.59 vs 5.21 and 5.04 Mcal ME/kg BW gain for 15% vs 17% and 19%). In other words, the 19% CP diet had the highest conversion of ME intake into BW gain compared to 17 and 15% CP of the diet. At the same time, the 19% CP diet had the highest conversion of CP intake into BW gain compared to 17 and 15% CP of diet (26.99 vs 25.59 vs 24.74 g CP/kg BW for 15% vs 17% vs 19%). This is why ducks fed 19% CP diet had the highest BW, BW gain, FCR, breast meat weight, and yield. In contrast, high dietary ME resulted in a higher caloric conversion (5.14 and 5.18 versus 5.42 MCal ME/kg BW for 11.8 and 12.8 MJ ME/kg versus 13.8MJ ME/kg). This suggests that the excess of ME intake caused by the diet with 13.8 MJ ME/kg was deposited as fat at lower CP intakes, which is metabolically less efficient than lean tissue accretion. Indeed, when breast meat, breast skin, and subcutaneous fat yield were evaluated, higher fat deposition and lower protein retention were observed in birds fed diets with 13.8MJ ME/kg. The reverse was true when the low-energy (11.8MJ ME/kg) and high-CP (19%) diet was fed, which promoted better conversion of ME into BW gain and led to less ME available for fat deposition. Those results were in agreement with the reports by Summers et al. (1965), Griffiths et al. (1977), and Rosebrough and Steele (1985), who observed in isocaloric diets, if crude protein concentration is decreased, there is an increase in ME:CP ratio, which results in fatter broiler carcasses.

In conclusion, growth performance and carcass characteristics can be regulated through manipulation of dietary protein or energy in ducks. The best BW gain and FCR were obtained when ducks were fed a high dietary AME_n (13.75 MJ/kg) and high CP (19%, 1.21% SID Lys). Considering the growth performance and carcass traits, the optimal dietary AME_n of ducks from 15 to 35d of age was 12.68 MJ/kg, and 19% CP (1.21% SID Lys). Additionally, due to observed changes in daily growth and carcass response, the 28 to 35 d ME:CP optima may be lower than that for 15 to 21, and 22 to28 d of age.

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