Asian-Aust. J. Anim. Sci.
Vol. 20, No. 12 : 1865 - 1873
December 2007

www.ajas.info

Effects of Dietary Metabolizable Energy and Lysine on Carcass Characteristics and Meat Quality in Arbor Acres Broilers*

M. Y. Tang, Q. G. Ma, X. D. Chen and C. Ji**

National Lab of Animal Nutrition, College of Animal Science and Technology
China Agricultural University, Beijing, 100094, China

ABSTRACT : An experiment was performed to evaluate the effects of dietary metabolizable energy (ME) and lysine on carcass characteristics and meat quality in Arbor Acres (AA) broilers from 1 to 56 days of age. A total of 2,970 1-d-old male broiler chicks were randomly allocated to nine dietary treatments (three ME levels in combination with three lysine levels), and dietary ME and lysine concentrations were formulated by varying corn, soybean meal, tallow, and L-lysine sulfate concentrations. Live body weight (BW), carcass weight (CW), dressing percent, breast muscle weight (BMW), yield of breast muscle, muscle color (CIE L*, a*, and b*), pH values 45 min and 24 h postmortem (pH_{45}, and pH_{24}), meat shear force value (SFV), and water loss rate (WLR) were evaluated. Results showed that live body weight and dressing percent increased ($p<0.05$) as dietary energy increased. Higher dietary lysine content improved breast muscle weight. Neither carcass weight nor yield of breast muscle was affected by dietary energy or lysine content. Higher ME increased the b* value ($p = 0.067$) and pH_{24} value ($p<0.05$), whereas it decreased SFV ($p<0.05$) and WLR ($p = 0.06$). Only water loss rate was influenced ($p<0.01$) by dietary lysine, which was higher in broilers from the high lysine diet as compared to those from medium or low lysine diets. The pH_{45} value and L* value of breast muscle were not affected by ME or lysine. Significant interaction of dietary ME and lysine was found on a* value of breast muscle. These results indicated that dietary ME and lysine had important effects on breast muscle growth and meat quality, however their effects were different. Different concentrations of dietary ME and lysine might be considered to improve meat quality. (**Key Words :** Metabolizable Energy, Lysine, Carcass Trait, Meat Quality, Broiler)

INTRODUCTION

Poultry selection, aiming to reduce breeding costs by improving production of poultry, has progressed continually since the early 1970s and resulted in a very large increase in growth rate of chickens. At the same time, the growth, structure or overall metabolism of muscle are also modified by such selection, probably resulting in modifications affecting technological and sensory characteristics of meat (Santoso, 2002; Remignon and Bihan-Duval, 2003).

Nowadays, poultry quality, which is defined by a combination of multiple factors, has become a primary focus for producers, packers, processors, retailers and consumers. Muscle color and texture are always the two most important factors that influence meat quality. Fletcher et al. (2000) stated that cooked product appearance was significantly associated with raw meat color. Moreover, it is suggested that lightness values could be used as an indicator of poultry breast muscle quality for evaluating the incidence of the PSE-like (pale, soft, and exudative) condition (Barbut, 1993; Owens et al., 2000). Meat pH, tenderness and water holding capacity are attributes of muscle texture that have been studied most extensively. Meat pH is determined by muscle glycogen content and its degradation rate. A rapid pH drop results in earlier onset of rigor and greater degree of rigor shortening, which determines the tenderness of meat (Khan, 1974). Muscle contraction is also controlled by the glycogen reserves ante-mortem and their breakdown rate postmortem. Meanwhile, rapid glycogen breakdown results in increased acidification, and at this pH value, usually the isoelectric point of muscle, most proteins in the myofibril become denatured and can precipitate. The relaxed proteins decrease their capacity to hold water which is characterized by high water loss rate (WLR). Muscle glycogen pools might be manipulated through diets and the

* Financially supported by National Basic Research Program of China (Project No: 2004CB11750-).

** Corresponding Author: Cheng Ji. Tel: +86-10-62732774, Fax: +86-10-62732774, E-mail: jicheng@cau.edu.cn

Received December 22, 2006; Accepted June 11, 2007

Table 1. Dietary ME and lysine levels for Arbor Acres broilers in different growing phases

Diets[1]	Age (d)					
	1 to 21		22 to 42		43 to 56	
	ME (MJ/kg)	Lysine (%)	ME (MJ/kg)	Lysine (%)	ME (MJ/kg)	Lysine (%)
LL	12.96	1.0	12.96	0.9	12.96	0.75
LM	12.96	1.1	12.96	1.0	12.96	0.85
LH	12.96	1.2	12.96	1.1	12.96	0.95
ML	13.38	1.0	13.38	0.9	13.38	0.75
MM	13.38	1.1	13.38	1.0	13.38	0.85
MH	13.38	1.2	13.38	1.1	13.38	0.95
HL	13.79	1.0	13.79	0.9	13.79	0.75
HM	13.79	1.1	13.79	1.0	13.79	0.85
HH	13.79	1.2	13.79	1.1	13.79	0.95

[1] LL to HH represented nine diets with different energy and lysine concentrations.

LL = Low energy low lysine; LM = Low energy medium lysine; LH = Low energy high lysine; ML = Medium energy low lysine; MM = Medium energy medium lysine; MH = Medium energy high lysine; HL = High energy low lysine; HM = High energy medium lysine; HH = High energy high lysine.

rate of glycolysis was reduced in pigs fed a muscle glycogen reducing diet (Rosenvold et al., 2003).

Dietary composition and nutrient content are potent regulators of muscle development and metabolism (Grizard et al., 1995, 1999). Studies of dietary factors on meat quality were focused on vitamins and trace minerals. Decreased shear force values were obtained by injecting $CaCl_2$ into the muscle of lambs (Carpenter et al., 1997; Clare et al., 1997). D'souza et al. (1998) reported that supplementing Mg to diets 5 days before slaughter increased pH value and decreased water drip loss. Addition of Mg to diets increased the redness of the *longissimus thoracis* muscle of growing-finishing pigs (Apple et al., 2000). Other studies reported that Cr and Fe had different effects on tenderness, water drip loss, and color of poultry meat (Edens, 1997; Ruiz et al., 2000). Dietary composition and/or feed additives have been shown to affect muscle color of pigs (Rosenvold et al., 2001; Stoller et al., 2003), sheep and cattle (Brandt et al., 1992; Boleman et al., 1996; Geay et al., 2001), and meat tenderness of cows (Boleman et al., 1996) and beef steers (Bruce et al., 1991). Conjugated linoleic acid decreased breast muscle redness of broilers (Du and Ahn, 2002). Deficiency in lysine reduced body growth and had an effect on the development of the pectoralis major muscle and the sartorius muscle in growing chickens (Tesseraud et al., 1996a, b).

Despite the relatively important effect of metabolizable energy and lysine on the performance of broilers (Sanz et al., 2000; Ettle et al., 2003; Urynek and Buraczewska, 2003; Hidalgo et al., 2004; Noy and Sklan, 2004; Lopez and Leeson, 2005; Aftab et al., 2007), data concerning the effect of nutrition, such as ME, lysine and their interaction effects, on these muscle attributes of poultry were seldom available (Moran and Bilgili, 1990; Tesseraud et al., 2001; Smith et al., 2002). The purpose of the present experiment was to determine the effects of dietary ME, lysine and their interactions on carcass characteristics and meat quality (pH, color, water loss rate, and meat shear force value), and to determine the optimum ME and lysine concentrations for better meat quality in Arbor Acres broilers.

MATERIALS AND METHODS

Animals and diets

In order to evaluate the effects of dietary ME and lysine on carcass characteristics and meat quality in AA broilers, a 3×3 (three levels of ME (low, medium, and high) and three levels of lysine (low, medium, and high)) factorial experiment was conducted. A total of 2,970 1-d-old AA broilers were randomly allocated to nine dietary treatments with five replicates of 66 birds per replicate pen, each equipped with a raised-wire floor. There was no significant difference for initial body weight (BW, 35.63±0.78 g) across treatment groups. Broilers were vaccinated for Newcastle disease and infectious bronchitis disease at the hatchery, at 7 and 21 days of age, respectively. All broilers were housed in an environmentally controlled house with temperature maintained at approximately 35°C during the first week post-hatch, then decreased gradually to 25°C for the duration of the trial. Birds received a 24 h lighting regime during the first three days post-hatch, and 23 h lighting with 1 h darkness from 4 days of age onwards. Pens were enlarged whenever needed to provide enough room for normal growth of broilers. Feed and water were provided *ad libitum* during the whole experiment period.

In the present study, nine corn-soybean meal-based diets comprising three levels of ME in combination with three levels of lysine were formulated (LL, LM, LH, ML, MM, MH, HL, HM, and HH were symbols for diets with different concentrations of ME and lysine). All nutrient contents except for ME and lysine were formulated to meet or exceed the NRC (1994) recommendations. Dietary ME and lysine concentrations of the different experimental diets are presented in Table 1. From 1 to 21 days of age, broilers were fed diets contained 12.96, 13.38, and 13.79 MJ of ME/kg in combination with 1.0, 1.1, and 1.2% lysine,

Table 2. Composition and nutrient content of basal diets[1] for broilers in different growing phases

Diets[2]	Age (d)								
	1 to 21			22 to 42			43 to 56		
	LL	ML	HL	LL	ML	HL	LL	ML	HL
Ingredients (%)									
Corn	55.3	53.0	50.8	62.1	59.3	58.2	67.8	65.6	63.3
Soybean meal	20.9	20.9	21.0	21.3	20.3	17.0	12.1	12.9	12.6
Peanut meal	7.0	7.0	6.6	4.1	4.7	6.0	10.3	8.5	9.2
Extruded soybean	2.0	2.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0
Corn gluten meal	5.2	5.6	6.0	2.5	2.5	2.9	1.0	1.9	1.9
Fish meal	3.2	3.2	3.3	2.0	2.0	3.3	0.9	1.1	1.1
Animal tallow	2.2	4.1	6.1	1.8	4.0	5.5	1.1	3.1	5.0
Limestone	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.4	1.4
Dicalcium phosphate	1.4	1.4	1.4	1.4	1.4	1.4	1.0	1.1	1.1
Peptide additive	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Salt	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
DL-methionine									
Premix[3]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total	100	100	100	100	100	100	100	100	100
Calculated composition									
ME (MJ/kg)	12.96	13.38	13.79	12.96	13.38	13.79	12.96	13.38	13.79
Crude protein (%)	23.00	23.00	23.00	21.00	21.00	21.00	19.00	19.00	19.00
Crude fat (%)	4.62	4.62	4.62	4.77	4.77	4.77	4.85	4.85	4.85
Calcium (%)	1.08	1.08	1.08	0.97	0.97	0.97	1.07	1.07	1.07
Total phosphorus (%)	0.66	0.66	0.66	0.62	0.62	0.62	0.54	0.54	0.54
Available phosphorus (%)	0.56	0.56	0.56	0.54	0.54	0.54	0.42	0.42	0.42
Lysine[4] (%)	1.00	1.00	1.00	0.90	0.90	0.90	0.75	0.75	0.75

[1] The medium and high lysine diets were formulated by replacing limestone with L-lysine H_2SO_4, respectively.
[2] LL, ML, and HL represented basal diets with different ME and low lysine concentrations formulated for broilers in 3 growing periods.
LL = Low energy low lysine; ML = Medium energy low lysine; HL = High energy low lysine.
[3] The vitamin and mineral premix contained per kg of diet: Vitamin A, 14,711 IU; Vitamin D_3, 1,409 IU; Vitamin E, 16 IU; B_1, 1.1 mg; B_2, 8.1 mg; B_6, 4 mg; B_{12}, 2 mg; folic acid, 1 mg; pantothenic acid, 11.3 mg; niacin, 60 mg; biotin, 10 mg; manganese, 65 mg; zinc, 55 mg; iron 0.3 mg; copper, 6 mg; iodine, 1 mg; selenium 0.3 mg.
[4] The lysine contents in diets were analyzed values.

respectively. Diets for broilers from 22 to 42 days of age contained 12.96, 13.38, and 13.79 MJ of ME/kg each in combination with 0.9, 1.0, and 1.1% lysine, respectively. Diets containing 12.96, 13.38, and 13.79 MJ of ME/kg in combination with 0.75, 0.85, and 0.95% lysine, respectively, were fed to birds from 43 to 56 days of age. Diet LL, ML, and HL were basal diets, and the concentrations of lysine in diet LM and LH, diet MM and MH, and diet HM and HH were adjusted by adding L-lysine sulfate to the three basal diets, respectively. The composition and nutrient content of basal diets formulated for broilers in different growing phases are shown in Table 2.

Sample collection

At the end of the experiment, two birds with body weights close to the mean were selected from each pen. Feed and water were withdrawn 12 h prior to slaughter. The birds were humanely slaughtered and carcasses harvested. Breast muscle from both sides of the carcass were skinned and deboned for carcass traits, muscle color (L*, a*, b*), pH value, tenderness and water loss rate measurements.

Measurements

Carcass characteristics : Live body weight, carcass weight, and weight of breast muscle from both sides of the carcass were measured. Carcass weight was defined as the weight with feather-scalded, eviscerated carcass (with head, neck, blood, and hocks removed) (Dilger et al., 2006). The dressing percent (carcass weight relative to live body weight) and yield of breast muscle (breast muscle weight relative to carcass weight) was calculated.

Muscle pH : At 45 min and 24 h after slaughter, the breast muscle pH was tested at a depth of 2.5 cm below the surface using a Model PHB-10B meter (Shanghai Kang-Yi Instrument Co. LTD., Shanghai, China). All pH measurements were conducted on the anterior end of the right breast. The pH meter was standardized by a two-point method against standard buffers of pH 4.0 and pH 7.0.

Muscle color : The CIE L* (lower values indicate darker color), a* (larger positive values indicate more red color), and b* (higher value indicates more yellow color) values (CIE, Commission Internationale de l'Eclairage, 1976) were obtained 5 min after slaughter from breast muscle, using a hand-held color difference meter (SC-80C,

Table 3. Effects of dietary ME and lysine on live body weight, carcass weight, breast muscle weight, yield of breast muscle and dressing percent of 56 day-old broilers

	Live body weight (g)	Carcass weight (g)	Breast muscle weight (g)	Breast muscle yield[1] (%)	Dressing percent[2] (%)
ME[3]					
L	2,684[a]	1,929	476.89	24.99	69.42[a]
M	2,757[b]	1,940	464.44	23.98	70.49[ab]
H	2,771[b]	1,965	471.56	23.56	71.73[b]
SEM[5]	21.20	17.44	7.36	0.47	0.50
Lysine[4]					
L	2,722	1,921	443.78[a]	23.86	70.49
M	2,735	1,951	479.78[b]	24.14	70.72
H	2,756	1,962	489.33[b]	24.54	70.42
SEM[5]	21.20	17.44	7.36	0.47	0.50
	----- Probability value -----				
ME	0.012	0.338	0.505	0.101	0.010
Lysine	0.513	0.239	0.001	0.599	0.907
ME×lysine	0.817	0.929	0.207	0.200	0.391

[1] Breast muscle weight relative to carcass weight.
[2] Carcass weight relative to live body weight.
[3] L, M, and H represented concentrations of dietary ME. L = Low; M = Medium; H = High.
[4] L, M, and H represented concentrations of dietary lysine. L = Low; M = Medium; H = High.
[5] Pooled Standard Error of the Mean.
[a, b] Means with different superscripts differ significantly ($p<0.05$).

Kangguang apparatus Co. LTD., Beijing, China), with an illuminant D65 and 10° standard observer. Five particular spots of muscle free of hemorrhagic, ecchymotic lesions or any other abnormal discoloration were measured on each muscle (Fletcher, 1999).

Shear force value : A 12.7 mm (diameter) core was removed from the anterior end of each fillet with attached sampler. The cores were boiled in a temperature-controlled bath to an internal temperature of 70°C. Upon reaching the desired internal temperature, the cores were removed. Each sample was sheared perpendicular to the grain of the muscle fiber using a 25-kg load cell and crosshead speed of 5 mm/s with a Digital Meat Tenderness Meter of Model C-LM3 (Northeast Agricultural University, Harbin, China). Maximum force measured to cut the cores was expressed as kilogram force (kg.f). For each cooked muscle, the core was sheared in 2 locations and the average of the maximum forces was used for data analysis.

Water loss rate : Water-holding capacity, expressed as water loss rate, was measured by applying a load of 2.25 kg on the fillet core. The released water weight was calculated as the difference between the weight of intact fillet and the pressed fillet.

Statistical analysis

The pen was used as experimental unit. Data were analyzed by the GLM procedure of SAS software (SAS Institute, 1998) for a randomized complete block with a factorial treatment design with dietary ME, lysine, and interaction as main effects. The factorial treatment arrangement consisted of three levels of dietary ME and three levels of dietary lysine. If differences in treatment means were detected, the least significant difference (LSD) was applied to separate means. A significance level of $p<0.05$ was used during analysis and other significance levels were also specified whenever necessary.

RESULTS

The effects of dietary ME and lysine content on carcass traits are presented in Table 3. Dietary energy affected live body weight and dressing percent. As expected, live body weight of broilers increased with the increase of dietary energy. Body weight of broilers fed medium and high energy content was significantly higher ($p<0.05$) than those fed the low energy diet. Dietary ME had the same effects on dressing percent. The broilers fed high energy diets had higher ($p<0.05$) dressing percent than those fed low energy diets. Live body weight and dressing percent were not influenced by dietary lysine. Broilers fed medium and high lysine diets had higher ($p<0.05$) breast muscle weight than those fed low lysine diets whereas dietary energy had no significant impact on the weight of breast muscle. Carcass weight and breast muscle yield were not affected by dietary energy or lysine. There was no interaction effect on any of the parameters.

Table 4 shows the effects of dietary ME and lysine on muscle color (L*, a*, b*), pH value, shear force value and water loss rate. Dietary ME had no significant effects on the breast muscle L* and a* values, though the b* value increased ($p = 0.067$) with increasing ME. Dietary lysine had no influence on the color of breast muscle. A significant

Table 4. Effects of dietary ME and lysine on the color (L*, a*, b*), pH value 45 min and 24 h postmortem, shear force value (SFV) and water loss rate (WLR) of breast muscle of 56 day-old broilers

ME[1]	Lysine[2]	L*	a*	b*	pH_{45}	pH_{24}	SFV (kg.f)	WLR (%)
L	L	49.84	3.42[a]	10.02	6.17	5.63[ab]	2.09[abc]	31.46[a]
	M	49.17	4.77[ab]	9.37	6.16	5.54[a]	2.46[abc]	35.09[b]
	H	50.79	4.17[ab]	9.07	6.13	5.64[ab]	2.52[bc]	39.52[c]
M	L	51.73	6.00[b]	11.67	6.07	5.76[ab]	1.70[abc]	32.36[a]
	M	53.85	2.18[a]	10.71	6.20	5.80[b]	2.45[ab]	35.03[ab]
	H	52.85	2.77[a]	10.39	6.13	5.88[b]	2.61[c]	37.10[bc]
H	L	51.17	3.87[ab]	11.37	6.17	5.86[b]	1.54[a]	31.07[a]
	M	55.71	3.33[a]	11.68	6.06	5.84[b]	1.63[ab]	30.63[a]
	H	51.90	3.92[ab]	10.45	6.10	5.74[ab]	1.97[abc]	34.97[ab]
SEM[3]		0.66	0.25	0.31	0.05	0.04	3.20	2.10
	ME							
	L	49.93	4.12	9.49	6.15	5.61[a]	2.36[b]	35.36[b]
	M	52.81	3.65	10.93	6.13	5.81[b]	2.25[a]	34.83[a]
	H	52.93	3.71	11.17	6.11	5.82[b]	1.71[a]	32.23[a]
	SEM[3]	1.15	0.44	0.54	0.02	0.04	0.26	3.54
	Lysine							
	L	50.91	4.43	11.02	6.14	5.75	1.78	31.63[a]
	M	52.91	3.42	10.59	6.14	5.73	2.18	33.58[a]
	H	51.84	3.62	9.97	6.12	5.76	2.36	37.20[b]
	SEM[3]	1.15	0.44	0.54	0.02	0.04	0.26	3.52
	----------	----------	----------	----------	Probability value	----------	----------	----------
ME		0.116	0.701	0.067	0.352	0.001	0.043	0.060
Lysine		0.480	0.231	0.376	0.682	0.889	0.092	0.001
ME×lysine		0.635	0.018	0.963	0.065	0.397	0.858	0.527

[1] L, M, and H represented concentrations of ME. L = Low; M = Medium; H = High.
[2] L, M, and H represented concentrations of lysine. L = Low; M = Medium; H = High.
[3] Pooled Standard Error of the Mean.
[a, b, c] Means with different superscripts differ significantly (p<0.05).

interaction was found on the a* value of breast muscle ($p<0.05$). This result indicated that differences of a* value between different lysine levels in medium energy diets were significantly greater than differences between lysine levels in low and high energy diets.

The pH value of breast muscle 45 min postmortem was not affected by dietary treatments. However, dietary energy and lysine content had significant effects on pH value 24 h postmortem, shear force value and water loss rate (Table 4). The pH_{24} value increased with the increment of ME content ($p<0.01$), which was higher in birds fed medium and high ME diets than in those fed a low energy diet. Dietary lysine had no influence on pH_{24}. The breast fillets from broilers fed low ME diets had higher ($p<0.05$) SFV than those fed medium or high ME diets, whereas dietary lysine had no significant ($p>0.05$) effect on the tenderness of breast fillets. In this experiment, WLR was measured to evaluate water-holding capacity of muscle. Higher WLR meant lower water-holding capacity. The WLR of breast muscle was affected by dietary ME and lysine concentration. The WLR of breast muscle from boilers fed low ME diets were higher ($p = 0.06$) compared with those fed medium or high ME diets. Water-holding capacity decreased as dietary lysine concentration increased, and was significantly lower ($p<0.01$) in broilers fed high lysine diets when compared to those fed low or medium lysine diets. No interaction effect was obtained on pH_{45}, pH_{24}, shear force value and water loss rate.

DISCUSSION

Although an inadequacy of any nutrient has repercussions for the yield of meat or perhaps quality, only a few are of importance in poultry production. In general, these nutrients are energy, protein and phosphorus (Moran, 1999). Effects of dietary energy on the performance of broilers have been studied extensively (Yalcin et al., 1998; Hidalgo et al., 2004; Shyam Sunder et al., 2007) and showed that increasing dietary energy resulted in greater body weight, which was consistent with the present results. High energy levels are linked to high performance while reduction in dietary energy is not always associated with negative effects. Moran (1997) reported carcass quality and skinless-boneless meat yield of male broilers were not impaired when dietary fat was replaced with corn. This result accords with the present experiment. Increasing dietary energy improved body weight, while carcass weight did not suffer from low energy diets. Body fat may account for the increase in body weight of broilers fed high energy diets and carcass weight was not affected by energy.

Sonaiya et al. (1990) showed that male broilers receiving high energy diets had higher carcass weight. These different results might be due to the different breeds of poultry and environmental temperatures used in these experiments. The effect of the dietary energy on dressing percent was supported by Leclercq and Escartin (1987), who stated that increasing dietary energy led to faster growth rate and higher dressing percentage. In the present experiment, dietary energy had no effect on breast meat weight, though Nahashon et al. (2005) reported that breast meat weights of birds fed diets containing 3,150 kcal ME/kg were higher than those of birds fed 3,050 kcal ME/kg diets.

It is well known that dietary amino acids have important effects on carcass characteristics of broilers (Dozier et al., 2000; Gong et al., 2005; Lohakare, et al., 2005). Moran and Bilgili (1990) and Acar et al. (1991) reported live body weight and chilled carcass were not affected by dietary lysine, whereas Tesseraud et al. (1999, 2001) stated that lysine deficiency reduced the performance as well as muscle weights, and breast meat weight decreased when feeding low density of dietary lysine to chicks at 50 d of age (Kidd et al., 1998). Breast meat yield decreased significantly as lysine content decreased from 1.05% to 0.85% (Moran and Bilgili, 1990; Acar et al., 1991). Some studies reported lysine had no influence on breast and leg muscle weights (Rostagno and Pack, 1995). In our study, only breast muscle weight increased with incremental dietary lysine content.

Glycogen content and its depletion rate *post mortem* determines pH decline of muscle (Lister et al., 1970), and glycogen in muscle could be manipulated by dietary composition (Rosenvold et al., 2003). Generally, muscle pH has been associated with lots of meat quality attributes, such as meat color, tenderness, water-holding capacity and other characteristics of muscle. Color is one of the most important quality attributes of poultry muscle or meat product for consumer acceptance. Mugler and Cunningham (1972) reviewed many factors influencing poultry meat color, such as bird sex, age, strain and processing procedures. However, limited studies were available expatiating nutritional aspects and their effects on meat quality and the PSE condition. Smith et al. (2002) reported that wheat-based diets increased broiler breast lightness (L*) and yellowness (b*) and decreased redness (a*) compared to milo- and corn- based diets. Extra dietary supplementation of tryptophan reduced incidence of PSE meat (Adeola and Ball, 1992). Boulianne and King (1995, 1998) reported that pale fillet had significantly greater lightness value, less redness and greater yellowness, whereas dark fillets had lower lightness and yellowness. In the present study, higher ME increased the b* value of breast muscles whereas, lysine had contrasting effects on b* value of breast muscle such that higher lysine concentration decreased muscle yellowness. The functioning mechanism of energy and lysine on the color of muscle remains unclear, and whether the effect was due to pigments present in feed ingredients or changes in protein metabolism resulting from dietary lysine content needs further study. El Rammouz et al. (2004) reported ultimate pH (24 h postmortem) was significantly correlated with lightness ($r = -0.37$) and yellowness ($r = -0.36$). Livingston and Brown (1981) reported higher muscle pH resulted in darker breast meat. Dark fillets had significantly lower lightness, higher redness, lower yellowness, and higher pH values (Boulianne and King, 1995, 1998; Allen et al., 1997). These findings were confirmed by Yang and Chen (1993). The above results were consistent with the present research, in which increased lightness was associated with higher yellowness and decreased redness.

Much research has been conducted to study the factors influencing meat tenderness and water-holding capacity (Fletcher, 2002). Genetic stock and selection (Smith, 1963), age, sex, location (Castaneda et al., 2005), pre- and post-slaughter chilling (Alvarado and Sams, 2000) and *post-mortem* metabolism (Skarovsky and Sams, 1999) were factors affecting quality of muscle. About 88 to 95% of water in the muscle is held intracellularly within the space between actin and myosin filaments (Ranken, 1976; Offer and Knight, 1988). Water-holding capacity determines the juiciness, flavor and tenderness of meat (Wood, 1993). Lactic acid accumulation and the decline in pH *post mortem* result in protein denaturation and an overall decrease in muscle water-holding capacity. On the other hand, divalent cations in the sarcoplasm, during the rigor mortis period, bind to the reactive groups on adjacent protein chains, reducing the electrostatic repulsion between negatively charged groups that maintain their separation (Wismer-Perdersen, 1986). This reaction reduces the space available for water to be retained intramuscularly. Rosenvold et al. (2003) reported that a higher digestible energy diet induced a reduction in total glycogen stores, which resulted in a higher ultimate pH value. This may account for the lower water loss rate and resultant higher tenderness of breast muscle from birds fed a high energy diet in the present experiment. Another attribute of energy to tenderness of muscle is intramuscular fat. The decrease in shear force value with dietary energy might be due to increased muscular fat content and altered glucose metabolism by decreasing the translocation or expression of glucose transporter-4 (Clarke, 2000). Lyon et al. (2004) also reported that breast fillets from wheat-fed birds required more force to shear compared with breasts from corn-fed birds.

It is clear that dietary lysine content affects the performance and carcass characteristics of broilers. Relatively little research has been conducted to study the density of dietary lysine on the meat quality of broilers. Apple et al. (2004) reported that lysine content had no effect on the pH, drip loss, firmness score and a* value of LM in pigs, and increased the L* value and decreased the b* value. Cameron et al. (1999) found that lower lysine density produced redder and more yellow pork meat than higher density of dietary lysine. No influence of lysine on ultimate pH, shear force value and meat color was observed in this study, whereas increasing dietary lysine content significantly decreased water-holding capacity in the breast muscle. However, the relationship between muscle lysine metabolism, protein turnover and muscle water-holding capacity needed further study.

According to the results obtained in the present study, dietary ME and lysine had significant effects on carcass characteristics and meat quality. These parameters responded to dietary ME and lysine in different ways. Therefore, higher body weight and dressing percentage would be obtained by feeding a higher level of dietary ME to broilers, higher lysine density would produce more breast meat and medium dietary energy and lysine level would produce more tender meat.

REFERENCES

Acar, N., E. T. Moran, Jr. and S. F. Bilgili. 1991. Live performance and carcass yield of male broilers from two commercial strain crosses receiving rations containing lysine below and above the established requirement between six and eight weeks of age. Poult. Sci. 70:2315-2321.

Adeola, O. and R. O. Ball. 1992. Hypothalamic neurotransmitter concentrations and meat quality in stressed pigs offered excess dietary tryptophan and tyrosine. J. Anim. Sci. 70:1888-1894.

Aftab, U., M. Ashraf, A. S. Mumtaz and Z. R. Jiang. 2007. Lysine requirement of broiler chickens fed low-density diets under tropical conditions. Asian-Aust. J. Anim. Sci. 20:939-943.

Allen, C. D., S. M. Russell and D. L. Fletcher. 1997. The relationship of broiler breast meat color and pH to shelf-life and odor development. Poult. Sci. 76:1042-1046.

Alvarado, C. Z. and A.R. Sams. 2000. Rigor mortis development in turkey breast muscle and the effect of electrical stunning. Poult. Sci. 79:1694-1698.

Apple, J. K., C. V. Maxwell, B. deRodas, H. B. Watson and Z. B. Johnson. 2000. Effect of magnesium mica on performance and carcass quality of growing-finishing swine. J. Anim. Sci. 78:2135-2143.

Apple, J. K., C. V. Maxwell, D. C. Brown, K. G. Friesen, R. E. Musser, Z. B. Johnson and T. A. Armstrong. 2004. Effects of dietary lysine and energy density on performance and carcass characteristics of finishing pigs fed ractopamine. J. Anim. Sci. 82:3277-3287.

Barbut, S. 1993. Color measurements for evaluating the pale soft exudative (PSE) occurrence in turkey meat. Food Res. Int. 26:39-43.

Boleman, S. J., R. K. Miller, M. J. Buyck, H. R. Cross and J. W. Savell. 1996. Influence of realimentation of mature cows on maturity, color, collagen solubility, and sensory characteristics. J. Anim. Sci. 74:2187-2194.

Boulianne, M. and A. J. King. 1995. Biochemical and color characteristics of skinless boneless pale chicken breast. Poult. Sci. 74:1693-1698.

Boulianne, M. and A. J. King. 1998. Meat color and biochemical characteristics of unacceptable dark-colored broiler chicken carcasses. J. Food. Sci. 63:759-762.

Brandt, R. T. Jr., G. L. Kuhl, R. E. Campbell, C. L. Kastner and S. L. Stroda. 1992. Effects of steam-flaked sorghum grain or corn and supplemental fat on feedlot performance, carcass traits, longissimus composition, and sensory properties of steers. J. Anim. Sci. 70:343-348.

Bruce, H. L., R. O. Ball and D. N. Mowat. 1991. Effects of compensatory growth on protein metabolism and meat tenderness of beef steers. Can. J. Anim. Sci. 71:659-668.

Cameron, N. D., J. C. Penman, A. C. Fisken, G. R. Nute, A. M. Perry and J. D. Wood. 1999. Genotype with nutrition interactions for carcass composition and meat quality in pig genotypes selected for components of efficient lean growth rate. Anim. Sci. 69:69-80.

Carpenter, C. E., M. B. Solomon, G. D. Snowder, N. E. Cockett and J. R. Busboom. 1997. Effects of electrical stimulation and conditioning, calcium chloride injection and aging on the acceptability of callipyge and normal lamb. Sheep Goat Res. J. 13:127-134.

Castaneda, M. P., E. M. Hirschler and A. R. Sams. 2005. Early postmortem carcass trim effects on the tenderness of broiler breast fillet. Poult. Sci. 84:951-954.

Clare, T. L., S. P. Jackson, M. F. Miler, C. T. Elliott and C. B. Ramcey. 1997. Improving tenderness of normal and callipyge lambs with calcium chloride. J. Anim. Sci. 75:377-385.

Clarke, S. D. 2000. Polyunsaturated fatty acid regulation of gene transcription: a mechanism to improve energy balance and insulin resistance. Br. J. Nutr. 83(Suppl. 1):59-66.

Dilger, R. N., C. Martinez Amezcua, P. B. Pillai, J. L. Emmert, C. M. Parsons and D. H. Baker. 2006. Effect of Reciprocating dietary lysine fluctuations on chick growth and carcass yield. Poult. Sci. 85:1226-1231.

Dozier, W. A., E. T. Moran, Jr. and W. T. Kidd. 2000. Response of fast- and slow- feathering male broilers to dietary threonine during 42 to 56 days of age. J. Applied Poult. Res. 9:460-467.

D'Souza, D. N., R. D. Warner, B. J. Leury and F. R. Dunshea. 1998. The effect of dietary magnesium aspartate supplementation on pork quality. J. Anim. Sci. 76:104-109.

Du, M. and D. U. Ahn. 2002. Effect of dietary conjugated linoleic acid on the growth rate of live birds and on the abdominal fat content and quality of broiler meat. Poult. Sci. 81:428-433.

Edens, F. W. 1997. Potential for organic selenium to replace selenite in poultry diets. Zootecn. Int. 20:28-31.

El Rammouz, R., R. Babilé and X. Fernandez. 2004. Effect of ultimate pH on the physicochemical and biochemical characteristics of turkey breast muscle showing normal rate of postmortem pH fall. Poult. Sci. 83:1750-1757.

Ettle, T., D. A. Roth-Maier and F. X. Roth. 2003. Effect of apparent ileal digestible lysine to energy ratio on performance of finishing pigs at different dietary metabolizable energy levels. J. Anim. Physiol. Anim. Nutr. 87:269-279.

Fletcher, D. L. 1999. Broiler breast meat color variation, pH and meat texture. Poult. Sci. 78:1323-1327.

Fletcher, D. L. 2002. Poultry meat quality. Worlds Poult. Sci. J. 58:131-145.

Fletcher, D. L., M. Qiao and D. P. Smith. 2000. The relationship of raw broiler breast meat color and pH to cooked meat color and pH. Poult. Sci. 79:784-788.

Geay, Y., D. Bauchart, J.-F. Hocquette and J. Culioli. 2001. Effect of nutritional factors on biochemical, structural and metabolic characteristics of muscles in ruminants, consequences on dietetic value and sensorial qualities of meat. Reprod. Nutr. Dev. 41:1-26.

Gong, L. M., C. H. Lai, S. Y. Qiao, D. F. Li, Y. X. Ma and Y. L. Liu. 2005. Growth performance, carcass characteristics, nutrient digestibility and serum biochemical parameters fed low-protein diets supplemented with various ratios of threonine to lysine. Asian-Aust. J. Anim. Sci. 18:1164-1170.

Grizard, J., B. Picard, D. Dardevet, M. Balage and C. Rochon. 1999. Regulation of muscle growth and development. In Protein Metabolism and Nutrition (Ed. G. E. Lobley, A. White and J. C. MacRae). EAAP Publ. 96, Wageningen, Netherlands, pp. 177-201.

Grizard, J., D. Dardevet, I. Papet, L. Mosoni, P. Patureau-Mirand, D. Attaix, I. Tauveron, D. Bonin and M. Arnal. 1995. Nutrient regulation of skeletal muscle protein metabolism in animals. The involvement of hormones and substrates. Nutr. Res. Rev. 8:67-91.

Hidalgo, M. A., W. A. Dozier, III, A. J. Davis and R. W. Gordon. 2004. Live performance and meat yield responses of broilers to progressive concentrations of dietary energy maintained at a constant metabolizable energy-to-crude protein ratio. J. Appl. Poult. Res. 13:319-327.

Khan, A. W. 1974. Relation between isometric tension, postmortem pH decline and tenderness of poultry breast meat. J. Food Sci. 39:393-395.

Kidd, M. T., B. J. Kerr, K. M. Halpin, G. W. Meward and C. L. Quarles. 1998. Lysine levels in starter and grower finisher diets affect broiler performance and carcass traits. J. Appl. Poult. Res. 7:351-358.

Leclercq, B. and R. Escartin. 1987. Further investigations on the effects of metabolisable energy content of diet on broiler performances. Archiv für Geflügelkunde. 51:93-96.

Lister, D., R. A. Sair, J. A. Will, G. R Schmidt, R. G. Cassens, W. G. Hoekstra and E. J. Briskey. 1970. Metabolism of striated muscle of 'stress-susceptible'pigs breathing oxygen or nitrogen. Am. J. Physiol. 218:102-107.

Livingston, D. J. and W. D. Brown. 1981. The chemistry of myoglobin and its reactions. Food Technol. 35:244-252.

Lohakare, J. D., J. Y. Choi, J. K. Kim, J. S. Yong, Y. H. Shim, T.-W. Hahn and B. J. Chae. 2005. Effects of dietary combinations of vitamin A, E and methionine on growth performance, meat quality and immunity in commercial broilers. Asian-Aust. J. Anim. Sci. 18:516-523.

Lopez, G. and S. Leeson. 2005. Utilization of metabolizable energy by young broilers and birds of intermediate growth rate. Poult. Sci. 84:1069-1076.

Lyon, B. G., D. P. Smith, C. E. Lyon and E. M. Savage. 2004. Effects of diet and feed withdrawal on the sensory descriptive and instrumental profiles of broiler breast fillets. Poult. Sci. 83:275-281.

Moran, E. T. Jr. 1997. Response of broilers to added dietary fat and pellet quality. In Proceedings of the 11th European Symposium on Poultry Nutrition, Faaborg, Denmark, pp. 7-10.

Moran, E. T. Jr. 1999. Live production factors influencing yield and quality of poultry meat (Ed. R. I. Richardson and G. C. Mead). Poult. Meat Sci. CABI, UK, pp. 179-195.

Moran, E. T. Jr. and S. F. Bilgili. 1990. Processing losses, carcass quality, and meat yields of broiler chickens receiving diets marginally deficient to adequate in lysine prior to marketing. Poult. Sci. 69:702-710.

Mugler, D. J. and F. E. Cunningham. 1972. Factors affecting poultry meat color - a review. World's Poult. Sci. J. 28(4):400-406.

Nahashon, S. N., N. Adefope, A. Amenyenu and D. Wright. 2005. Effects of dietary metabolizable energy and crude protein concentrations on growth performance and carcass characteristics of French guinea broilers. Poult. Sci. 84:337-344.

National Research Council. 1994. Nutrient Requirements of Poultry. 9th rev. edn. Natl. Acad. Press, Washington, DC.

Noy, Y. and D. Sklan. 2004. Effects of metabolizable energy and amino acid levels on turkey performance from hatch to marketing. J. Appl. Poult. Res. 13:241-252.

Offer, G. and P. Knight. 1988. The structural basis of water-holding in meat. General principles and water uptake in meat processing. In Developments in Meat Science. Elsevier Applied Science Publishing Co., Inc., New York, NY, pp. 63-171.

Owens, C. M., N. S. Matthews and A. R. Sams. 2000. The use of halothane gas to identify turkeys prone to developing pale, exudative meat when transported before slaughter. Poult. Sci. 79:789-795.

Ranken, M. D. 1976. The water holding capacity of meat and its control. Chem. Ind. 18:1052-1057.

Rémignon, H. and E. L. Bihan-Duval. 2003. Meat quality problems associated with selection for increased production. In Poultry Genetics, Breeding and Biotechnology (Ed. W. M. Muir and S. E. Aggrey). CABI publishing, UK.

Rosenvold, K., B. Essén-Gustavsson and H. J. Andersen. 2003. Dietary manipulation of pro- and macroglycogen in porcine skeletal muscle. J. Anim. Sci. 81:130-134.

Rosenvold, K., J. S. Petesen, H. N. Laerke, S. K. Jensen, M. Therkildsen, A. H. Karlsson, H. S. Moller and H. J. Anderse. 2001. Muscle glycogen stores and meat quality as affected by strategic finishing feeding of slaughter pigs. J. Anim. Sci. 79:382-391.

Rostagno, H. S. and M. Pack. 1995. Growth and breast meat responses of different broiler strains to dietary lysine. In Proceedings of the 10th European Symposium on Poultry Nutrition, Antalya, Turkey, pp. 260-262.

Ruiz, J. A., A. M. Perez-Vendrell and E. Esteve-Garcia. 2000. Effect of dietary iron and copper on performance and oxidative stability in broiler leg meat. Br. Poult. Sci. 41:163-167.

Santoso, U. 2002. Effects of early feed restriction on breast and leg meat composition and plasma lipid concentration in unsexed broiler chickens reared in cages. Asian-Aust. J. Anim. 15:1475-1481.

Sanz, M., A. Flores and C. J. Lopez-Bote. 2000. The metabolic use of energy from dietary fat in broilers is affected by fatty acid saturation. Br. Poult. Sci. 41:61-68.

SAS Institute Inc. 1998. SAS/STAT User's Guide: Statistics. Version 7.0. SAS Institute Inc., Cary, North Carolina.

Shyam Sunder, G., Ch. Vijaya Kumar, A. K. Panda, M. V. L. N. Raju, S. V. Rama Rao, N. C. S. Gopinath and M. R. Reddy. 2007. Restriction of metabolizable energy in broiler growers and its impact on grower and breeder performance. Asian-Aust. J. Anim. Sci. 20:1258-1265.

Skarovsky, C. J. and A. R. Sams. 1999. Tenderness, moisture loss and post-mortem metabolism of broiler pectoralis muscle from electrically stimulated and air chilled carcases. Br. Poult. Sci. 40:622-625.

Smith, D. P., C. E. Lyon and B. G. Lyon. 2002. The effect of age, dietary carbohydrate source, and feed withdrawal on broiler breast fillet color. Poult. Sci. 81:1584-1588.

Smith, J. H. 1963. Relation of body size to muscle cell size and number in the chicken. Poult. Sci. 42:283-290.

Sonaiya, E. B., M. Ristic and F. W. Klein. 1990. Effect of environmental temperature, dietary energy, age and sex on broiler carcase portions and palatability. Br. Poult. Sci. 31:121-128.

Stoller, G. M., H. N. Zerby, S. J. Moeller, T. J. Baas, C. Johson and L. E. Watkins. 2003. The effect of feeding ractopamine (Paylean) on muscle quality and sensory characteristics in three diverse genetic lines of swine. J. Anim. Sci. 81:1508-1516.

Tesseraud, S., E. Le Bihan-Duval, R. Peresson, J. Michel and A. M. Chagneau. 1999. Response of chick lines selected on carcass quality to dietary lysine supply: Live performance and muscle development. Poult. Sci. 70:80-84.

Tesseraud, S., N. Maaa, R. Peresson and A. M. Chagneau. 1996a. Relative responses of protein turnover in three different skeletal muscles to dietary lysine deficiency in chicks. Br. Poult. Sci. 37:641-650.

Tesseraud, S., R. Peresson, J. Lopes and A. M. Chagneau. 1996b. Dietary lysine deficiency greatly affects muscle and liver protein turnover in growing chickens. Br. J. Nutr. 75:853-865.

Tesseraud, S., S. Temin, E. Le Bihan-Duval and A. M. Chagneau. 2001. Increased responsiveness to dietary lysine deficiency of pectoralis major muscle protein turnover in broilers selected on breast development. J. Anim. Sci. 79:927-933.

Urynek, W. and L. Buraczewska. 2003. Effect of dietary energy concentration and apparent ileal digestible lysine: Metabolizable energy ratio on nitrogen balance and growth performance of young pigs. J. Anim. Sci. 81:1227-1236.

Wismer-Perdersen, J. 1986. Chemistry of animal tissues: Water. In the Science of Meat and Meat Products (Ed. J. F. Price and B. S. Schweigert). Food and Nutrition Press, Inc. Westport, CN, pp. 141-154.

Wood, J. D. 1993. Consequences of changes in carcass composition on meat quality. In Recent Development in Pig Nutrition (Ed. D. J. A. Cole, W. Haresign and P. C. Garnsworthy). Nottingham University Press, Nottingham, UK, pp. 20-29.

Yalcin, S., S. Özkan, Z. AcikgÖz and K. Özkan. 1998. Influence of dietary energy on bird performance, carcase parts yields and nutrient composition of breast meat of heterozygous naked neck broilers reared at natural optimum and summer temperatures. Br. Poult. Sci. 39:633-638.

Yang, C. C. and T. C. Chen. 1993. Effect of refrigerated storage, pH adjustment, and marinade on color of raw and microwave cooked chicken meat. Poult. Sci. 72:355-362.