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Effects of Hot Environment and Dietary Protein Level on Growth Performance and Meat Quality of Broiler Chickens

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ABSTRACT : This study was conducted to determine the effect of hot environment and dietary crude protein level (CP) on performance, carcass characteristics, meat visual quality, muscle chemical composition and malondialdehyde (MDA) concentration of tissues in broilers. Two hundred and sixteen 21-d old Arbor Acre broilers were used in a 4×3 factorial arrangement and randomly reared in 4 environmental chambers and fed on 3 diets with different CP levels for 3 weeks. The results showed: (1) when air temperature (AT) rose to 33°C, average daily feed intake, average daily gain, carcass weight, right breast meat weight, left thigh and drumstick meat weight decreased ($p<0.05$) and feed conversion rate decreased ($p<0.05$), but the ratio of carcass to live weight and of left thigh and drumstick meat weight to carcass weight increased ($p<0.05$). (2) There were significant differences in pH and shear force in breast meat, and shear force, L* and a* in thigh meat ($p<0.01$ or 0.05) among hot environments. Dietary CP level tended to affect breast meat pH and pH and L* of thigh meat ($p<0.06$ or 0.09). Compared to the normal temperature (22°C), low temperature (15°C) and hot humid (AT 33°C, relative humidity (RH) 80%) treatments significantly ($p<0.05$) decreased the tenderness of thigh meat. L* and a* value in thigh meat under high temperature treatments, regardless of RH, were higher ($p<0.05$) than those under normal temperature. (3) Protein content in breast and thigh meat of broilers fed under high temperature (33°C) was lower ($p<0.05$) than that under 22°C, but fat content had an adverse change. High temperature (33°C) increased the moisture of breast meat significantly ($p<0.05$). Protein content in breast meat increased significantly ($p<0.05$), in which fat content had an adverse change ($p<0.05$), when the dietary protein rose. (4) MDA concentration in liver and breast meat under hot humid (AT 33°C, RH 80%) treatment increased markedly ($p<0.05$). (5) High humidity could sharpen the bad effect of high temperature on performance, carcass yield and choice cuts, crude protein and moisture content in breast meat. It was concluded that a hot environment could affect the performance and meat quality of broiler chicks more significantly than CP level and that high humidity would aggravate the bad influence of high temperature on the broiler. (**Key Words :** Hot Environment, Dietary Protein Level, Performance, Meat Quality, Broiler)

INTRODUCTION

High environmental temperature is one of major concerns for broiler producers in many countries of the world, especially in the hot and humid tropics. Many studies have been conducted to investigate the effect of thermal environment and dietary nutrient level on the growth performance of broilers. Since the broiler have no sweat glands and are fully covered with feathers, the thermoregulations are challenged under hot weather. The reduced feed intake, body weight gain and feed conversion ratio are believed as the result of adaptive responses to the high environmental temperatures (Teeter et al., 1985; Leenstra and Cahaner, 1991; Baziz et al., 1996). Furthermore, the high humidity will aggravate the bad influence of high temperature on the broiler (Yahav et al., 1995; Gu et al., 1999; Lin et al., 2005a, b). Lin et al. (2005a,b) reported that humidity could affect the thermoregulation of broiler chickens by redistributing heat within the body at high, low and even thermoneutral temperatures, high humidity above 60% impaired the heat transmission from body core to the surrounding at high temperature. At hot environment, the chemical composition of chicken is changed (Leenstra and Cahaner, 1991; Geraert et al., 1996) and meat sensory quality is decreased by heat stress (Osman et al., 1989; Northcutt et al., 1994; Li, 1999). The oxidative damage of tissues induced by heat stress is

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Table 1. Composition and nutrient levels of trial diets

	Diet I	Diet II	Diet III
Ingredients (%)			
Corn	65.40	60.89	56.47
Soybean meal	26.35	30.20	34.11
Fish meal (imported)	3.00	3.00	3.00
Soybean oil	2.30	3.00	3.50
Dicalcium phosphate	0.95	0.95	0.95
Limestone meal	1.25	1.20	1.20
Salt	0.30	0.30	0.30
Vitamin premix[1]	0.025	0.025	0.025
Mineral premix[2]	0.20	0.20	0.20
Choline chloride (50%)	0.11	0.11	0.11
Chlortetracycline (15%)[3]	0.067	0.067	0.067
Methionine	0.05	0.06	0.07
Nutrient level (%)			
Metabolizable energy (Mcal/kg)	3.0	3.0	3.0
Crude protein[4]	18.67	20.00	21.33
Calcium[4]	0.91	0.90	0.91
Available phosphorus[4]	0.35	0.35	0.35
Lysine[4]	0.97	1.04	1.12
Lysine/crude protein	0.052	0.052	0.053
Methionine	0.38	0.41	0.43
Methionine+cystine	0.68	0.73	0.77

[1] Supplied per kg of dietary DM: Vitamin A, 10,300 IU; Vitamin D_3, 2,160 ICU; Vitamin E, 36 IU; Vitamin K_3, 10 mg; Thiamine, 6 mg; Riboflavin, 10 mg; Vitamin B_6, 2.3 mg; Vitamin B_{12}, 12 ug; D-pantothenic acid, 50 mg; Niacin, 10 mg.
[2] Supplied per kg of dietary DM: Cu, 80 mg; Fe, 100 mg; Zn, 75 mg; Mn, 100 mg; I, 0.45 mg; Se, 0.3 mg.
[3] Chlortetracycline was used for prophylactic purpose.
[4] Analyzed values.

one of the possible reasons (Sandercock et al., 2001; Lin et al., 2006b).

The nutrient requirements of broiler chickens are different as the environmental temperature changes. As protein has the highest heat increment, diets with low protein level were recommended in order to reduce heat production in broiler chickens under heat stress (Musharaf and Latshaw, 1999). However, some findings have demonstrated that diets with low concentrations of crude protein worsen the performance and affected chemical composition of carcass cuts of broilers strongly when the birds were reared under heat stress (Alleman and Leclerq, 1997; Furlan et al., 2004; Gonzalez-Esquerra and Leeson, 2005). Furthermore, many trials were carried out for evaluating the performance of broilers chickens reared under heat stress conditions and fed high protein diets and showed an improvement in bird performance (Temim et al., 1999; Temim et al., 2000). Han and Baker (1993) reported that amino acid requirement of female broiler increased under heat stress. Baghel and Pradhan (1991) indicated that increasing dietary protein level could heighten the deposition of metabolic energy and the synthesis of protein in broiler under torrid condition. Hence, whether high or low dietary crude protein level should be provided to broilers fed under hot thermal condition still is an interesting problem. We hypothesized that the adverse effect of hot environment on broiler chickens will be aggravated by high dietary protein level.

The aim of this study was to investigate the effect of hot environment and dietary protein level (CP) on the growth performance, carcass and cuts output, and meat quality of broiler chickens. The tissue oxidative status of broiler chickens was also evaluated.

MATERIALS AND METHODS

Animals and treatments

Experimental chicks (male Arbor Acres broiler chicks) of one day old were fed under the routine management till 21 days old. Then, two hundred and sixteen 21 days old with similar body weight (Mean±SE: 775±4 g, $p>0.05$) in good condition, were randomly allocated into 36 units (cages) each with 6 birds/unit, equally reared in 4 environmental chambers each controlled at air temperature (AT) 15°C and relative humidity (RH) 50% (I), AT 22°C and RH 50% (II), AT 33°C and RH 50% (III), and AT 33°C and RH 80% (IV), with the precision of ±1°C for AT and ±5% for RH, and fed on 3 diets each containing the crude protein level of 18.7%, 20.0%, 21.3% and with similar ratio of lysine to protein (Table 1). That is, there were 18 broiler chicks of 3 cages fed on one of the trial diets in each chamber. The experiment lasted for three weeks and ended when the broiler were 42 days old.

The chicks of each unit were kept in a cage of 60 cm×80 cm. Ventilation of environmental chambers could keep out ammonia the chicks discharged and maintained odorless during the experiment. The light regime was 23L:1D and the intensity of illumination was 5 to 10 Lux. Broilers had free access to diet (as mash) and water during rearing period. The feces were cleared out every two days in order to keep air environment good in the chambers.

Measurement

Body weight and feed consumption were measured weekly and the feed conversion rate was calculated. At day 42, two birds with mean body weight were obtained from each cage. Then the birds were electrically stunned (200 Hz, 2.5 s, 100 mA) in water bath, slaughtered by exsanguination from the cervical vein and de-feathered according to standard industry practices. Carcass weight was obtained after bleeding and defeathering. The right breast meat, left thigh meat and drumstick, and abdominal fat were harvested and weighed after evisceration. The organ weight was expressed as gram or the ratio to live weight or carcass

Table 2. Effects of hot environment and dietary crude protein level on performance of broiler in 21-42 days

	Hot environment				SEM_{HE}	CP (%)			SEM_{CP}	p value		
	I	II	III	IV		18.7	20.0	21.3		HE	CP	HE×CP
The first week												
ADFI (g/bird)	88.5[a]	89.4[a]	69.3[b]	63.4[c]	1.32	77.4	76.2	79.4	1.14	<0.01	NS	NS
ADG (g/bird)	55.8[b]	60.9[a]	43.7[c]	44.0[c]	0.93	52.2	50.3	50.9	0.81	<0.01	NS	NS
Feed/gain	1.59[a]	1.47[b]	1.59[a]	1.49[b]	0.03	1.49[b]	1.56[a]	1.56[a]	0.02	0.01	0.06	NS
The second week												
ADFI (g/bird)	158.6[a]	164.4[a]	121.1[b]	104.6[c]	3.33	139.8	135.9	135.7	2.88	<0.01	NS	NS
ADG (g/bird)	68.3[b]	78.5[a]	43.2[c]	33.0[d]	2.16	56.0	53.9	57.4	1.87	<0.01	NS	0.06
Feed/gain	2.36[c]	2.10[c]	2.84[b]	3.23[a]	0.10	2.67	2.70	2.54	0.09	<0.01	NS	NS
The third week												
ADFI (g/bird)	172.4[a]	177.6[a]	110.1[b]	62.5[c]	4.67	128.4	129.3	134.2	4.04	<0.01	NS	NS
ADG (g/bird)	82.9[a]	74.3[a]	34.0[b]	23.0[c]	3.04	49.9	57.4	53.4	2.63	<0.01	NS	NS
Feed/gain	2.10[b]	2.40[b]	3.36[a]	3.27[a]	0.18	2.91	2.64	2.80	0.16	<0.01	NS	NS
The three weeks												
ADFI (g/bird)	139.8[a]	143.8[a]	100.1[b]	76.8[c]	2.03	115.2	113.8	116.4	1.76	<0.01	NS	NS
ADG (g/bird)	69.0[a]	71.3[a]	40.5[b]	33.6[c]	1.33	52.7	54.2	53.9	1.15	<0.01	NS	NS
Feed/gain	2.02[b]	1.99[b]	2.57[a]	2.68[a]	0.06	2.36	2.29	2.30	0.05	<0.01	NS	NS

HE = Hot environment, CP = Crude protein.

SEM_{HE} and SEM_{CP} each is pooled standard error of mean for hot environment and dietary crude protein level.

I = air temperature (AT) 15°C and relative humidity (RH) 50%; II = AT 22°C and RH 50%; III = AT 33°C and RH 50%; IV = AT 33°C and RH 80%.

ADG = Average daily gain, ADFI = Average daily feed intake.

[a, b, c, d] Means within the same treatment with different superscripts differ significantly ($p<0.05$) and NS is non-significant.

The number of replicates is 9 for HE and 12 for CP.

weight (%).

The color measurements of lightness (L* value), redness (a* value), yellowness (b* value) were conducted with TC-PIIG all-automatic spectrocolorimeter (Beijing Aoyike Instruments Co., China). The meat pH value was measured directly with PH213 meter (Hanna Instruments, the United Kingdom). Warner-Bratzler shear force was measured by C-LM3 digital tenderometer (Dongbei Agricultural University, China).

The contents of moisture, crude protein, crude ash, crude fat and cholesterol in breast and thigh meat were measured (GB/T 9695.15-1988, GB/T 5009.5-1985, GB/T 9695.18-1988, GB 9695.7-1988 and GB/T 9695.24-1990) and were expressed on a fresh weight basis. The malondialdehyde (MDA) content was determined with commercial thiobarbituric acid reactive substances assay kit (Nanjing Jiancheng Bioengineering Institute, Nanjing, China).

Statistical analysis

Two-way ANOVA model was used to analyze the main effect of thermal environment, diet and the interaction between environment and diet (General Linear Model of SPSS11.5). Means were considered significantly different when $p<0.05$.

RESULTS

Effects of hot environment and diet on performance of broiler were shown in Table 2. Hot environment had significant effect on average daily feed intake (ADFI), average daily gain (ADG) and feed conversion ratio (FCR) for the first, the second, the third and all the three weeks of the experimental period ($p<0.01$ or $p = 0.01$). When AT rose to 33°C and RH was 50% or 80%, ADFI and ADG decreased significantly ($p<0.05$) for all the trial period. At high temperature combined with high RH (80%), ADFI and ADG decreased further. Simultaneously FCR decreased significantly under high AT (33°C) and/or high RH (80%) ($p<0.05$) for the second, the third and the three weeks of the experimental period. However, the performance had no marked change during the experimental period when AT was lower than normal temperature (22°C) ($p>0.05$). Dietary protein had no significant effect on ADFI, ADG and FCR ($p>0.05$) except that increasing CP level had a trend to depress FCR during the first week of the trial ($p = 0.06$). There was no interaction of hot environment and CP on ADFI, ADG and FCR ($p>0.05$).

Table 3 showed live weight, the yield in carcass and choice cuts of broilers slaughtered at 42 d of age. Hot environment had significant effects on live weight, carcass weight and its ratio to live weight, right breast meat weight and its ratio to carcass weight, left thigh and drumstick meat weight and its ratio to carcass weight, and abdominal fat weight ($p<0.01$). When live weight, the yields in carcass and meat cuts were expressed as gram, there were marked deceases as AT rose to 33°C ($p<0.05$). The relative parameters of breast cuts also declined but the ratio of

Table 3. Effects of hot environment and dietary crude protein level on carcass quality of broiler at 42 days

	HE				SEM_{HE}	CP			SEM_{CP}	p value		
	I	II	III	IV		18.7	20.0	21.3		HE	CP	HE×CP
Live weight (g)	2,234[a]	2,289[a]	1,718[b]	1,509[c]	24.2	1,930.6	1,923.7	1,957.9	20.97	<0.01	NS	0.06
Carcass weight												
g	2,023[a]	2,045[a]	1,556[b]	1,377[c]	22.5	1,748.4	1,734.8	1,767.0	19.44	<0.01	NS	NS
%[1]	90.6[a]	89.3[b]	90.6[a]	91.3[a]	0.33	90.7	90.3	90.3	0.28	<0.01	NS	NS
Right breast meat weight												
g	155.4[a]	159.1[a]	106.0[b]	97.4[b]	4.41	126.4	130.5	131.6	3.82	<0.01	NS	NS
%[2]	7.7[a]	7.8[a]	6.8[b]	7.0[b]	0.21	7.1	7.4	7.4	0.18	<0.01	NS	NS
Left thigh and drumstick meat weight												
g	176.0[a]	181.6[a]	147.4[b]	133.8[c]	3.66	158.3	161.5	159.3	3.17	<0.01	NS	NS
%[2]	8.7[b]	8.9[b]	9.5[a]	9.7[a]	0.18	9.2	9.4	9.1	0.15	<0.01	NS	0.09
Abdominal fat weight												
g	31.3[a]	29.6[a]	27.5[a]	21.4[b]	2.11	28.6	25.6	28.1	1.82	<0.01	NS	NS
%[1]	1.4	1.3	1.6	1.4	0.10	1.5	1.3	1.4	0.09	NS	NS	NS

HE = Hot environment, CP = Crude protein.

SEM_{HE} and SEM_{CP} each is pooled standard error of mean for hot environment and dietary crude protein level.

I = Air temperature (AT) 15°C and relative humidity (RH) 50%; II = AT 22°C and RH 50%; III = AT 33°C and RH 50%; Ⅳ = AT 33°C and RH 80%.

[1] %: of live weight; [2] %: of uneviscerated carcass weight.

[a, b, c] Means within the same treatment with different superscripts differ significantly ($p<0.05$) and NS is non-significant.

The number of replicates is 18 for HE and 24 for CP.

carcass weight to live weight and of left thigh and drumstick meat weight to carcass weight increased ($p<0.05$) as hot environment exceeded comfort zone. Absolute weight of abdominal fat remarkably decreased only when high AT was combined with high RH. No significant effects of CP were found on the carcass quality and its cuts ($p>0.05$). There were no interactions of hot environment and CP on live weight, carcass and cuts indices ($p>0.05$). However, as CP level was lower or higher than the suitable protein level (herein 20%), the difference in the trend for live weight was found, which decreased under low temperature treatment (15.0°C) but rose under AT 22°C, RH 50% and AT 33°C, RH 50% (Figure 1).

Effects of hot environment and CP on chemical composition of chicken were showed in Table 4. The contents of crude protein, crude fat, moisture in breast meat and of crude protein, crude fat and crude ash in thigh meat were found to have significant differences among hot environment treatments ($p<0.01$ or $p\leq0.05$). As AT rose to 33°C combined with or without high RH, crude protein content of breast and thigh decreased markedly ($p<0.05$). However, crude fat content of breast and thigh increased when hot environment was lower or higher than comfort zone ($p<0.05$). An increase in moisture content was found only from breast meat but not from thigh meat as AT rose to 33°C ($p<0.05$). Increased crude protein content ($p<0.01$) and decreased crude fat content ($p<0.05$) in breast meat

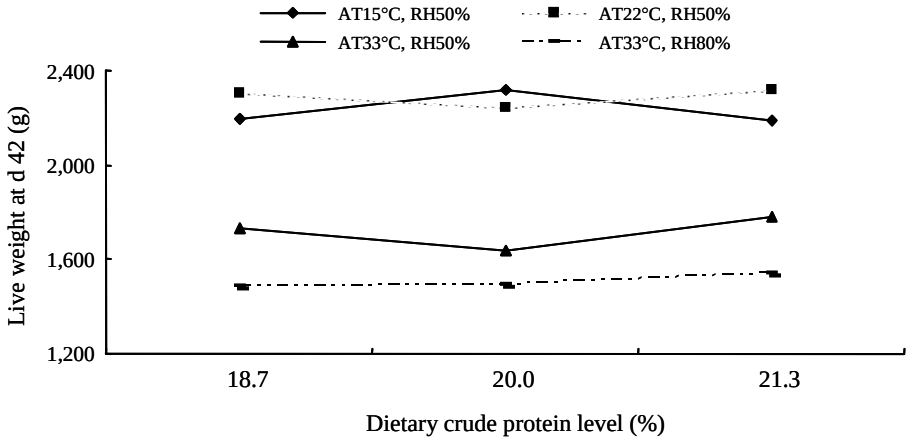

Figure 1. The interaction of hot environment and dietary crude protein level on live weight of d 42. AT = Air temperature; RH = Relative humidity. The number of replicates is 6 for each datum (also see Table 3).

Table 4. Effects of hot environment and dietary crude protein level on primary chemical composition of meat in broiler of 42 days

	HE				SEM_{HE}	CP			SEM_{CP}	p value		
	I	II	III	Ⅳ		18.7	20.0	21.3		HE	CP	HE×CP
Breast meat												
Crude protein (%)	24.9^{a}	24.4^{a}	23.6^{b}	22.7^{c}	0.26	23.3^{b}	23.9^{ab}	24.5^{a}	0.22	<0.01	<0.01	NS
Crude fat (%)	1.5^{a}	0.8^{c}	1.2^{ab}	1.0^{bc}	0.12	1.2^{ab}	1.3^{a}	0.9^{b}	0.1	<0.01	0.02	NS
Moisture (%)	72.0^{c}	72.0^{c}	73.5^{b}	75.0^{a}	0.35	73.5^{a}	73.2^{ab}	72.6^{b}	0.3	<0.01	0.09	NS
Crude ash (%)	1.4	1.5	1.5	1.6	0.09	1.5^{b}	1.4^{b}	1.7^{a}	0.08	NS	0.08	NS
Cholesterol (mmol/100 g)	0.7	0.6	0.7	0.4	0.10	0.5	0.6	0.7	0.09	NS	NS	NS
Thigh meat												
Crude protein (%)	20.9^{a}	20.7^{a}	20.0^{b}	20.0^{b}	0.2	20.2	20.5	20.5	0.17	<0.01	NS	0.09
Crude fat (%)	4.3^{a}	3.2^{b}	4.5^{a}	4.0^{a}	0.28	4.0	4.0	4.0	0.25	0.01	NS	NS
Moisture (%)	75.0	74.4	74.4	75.1	0.37	74.6	74.9	74.5	0.32	NS	NS	NS
Crude ash (%)	1.1^{b}	1.2^{ab}	1.3^{a}	1.2^{ab}	0.05	1.2	1.2	1.2	0.04	0.05	NS	NS
Cholesterol (mmol/100 g)	0.4	0.8	0.4	0.4	0.16	0.5	0.5	0.6	0.14	NS	NS	NS

HE = Hot environment, CP = Crude protein.

SEM_{HE} and SEM_{CP} each is pooled standard error of mean for hot environment and dietary crude protein level.

I = Air temperature (AT) 15°C and relative humidity (RH) 50%; II = AT 22°C and RH 50%; III = AT 33°C and RH 50%; Ⅳ = AT 33°C and RH 80%.

$^{a, b, c}$ Means within the same treatment with different superscripts differ significantly ($p<0.05$) and NS is non-significant.

The number of replicates is 18 for HE and 24 for CP.

Table 5. Effects of hot environment and dietary crude protein level on physical characteristics of chicken at 42 days

	HE (°C)				SEM_{HE}	CP (%)			SEM_{CP}	p value		
	I	II	III	IV		18.7	20.0	21.3		HE	CP	HE×CP
Breast meat												
pH	6.1^{c}	6.2^{ab}	6.3^{a}	6.2^{bc}	0.04	6.2^{ab}	6.3^{a}	6.2^{b}	0.03	<0.01	0.06	NS
shear force (kg)	3.7^{a}	2.3^{b}	2.7^{b}	2.7^{b}	0.20	3.1	2.8	2.7	0.17	<0.01	NS	NS
L* value	42.4	42.2	43.3	44.3	0.70	42.8	43.6	42.7	0.61	NS	NS	NS
a* value	22.0	20.4	19.7	24.7	1.74	21.4	20.6	23.1	1.51	NS	NS	0.09
b* value	5.7	4.8	5.1	4.0	0.77	4.8	5.2	4.7	0.66	NS	NS	NS
Thigh meat												
pH	6.2^{b}	6.2^{ab}	6.4^{a}	6.2^{ab}	0.05	6.3^{ab}	6.3^{a}	6.2^{b}	0.04	0.06	0.09	NS
shear force (kg)	2.5^{a}	1.7^{b}	1.8^{b}	2.2^{a}	0.12	2.1	2.1	2.0	0.11	<0.01	NS	NS
L* value	41.7^{b}	42.5^{b}	46.6^{a}	43.9^{ab}	1.02	44.9^{a}	44.2^{ab}	41.8^{b}	0.89	<0.01	0.06	0.10
a* value	24.0^{ab}	21.4^{b}	19.1^{b}	27.4^{a}	1.96	22.0	21.7	25.2	1.70	0.03	NS	NS
b* value	6.4	4.4	5.8	7.2	0.91	5.8	5.5	6.5	0.78	NS	NS	0.09

HE = Hot environment, CP = Crude protein.

SEM_{HE} and SEM_{CP} each is pooled standard error of mean for hot environment and dietary crude protein level.

I = Air temperature (AT) 15°C and relative humidity (RH) 50%; II = AT 22°C and RH 50%; III = AT 33°C and RH 50%; IV = AT 33°C and RH 80%.

$^{a, b, c}$ Means within the same treatment with different superscripts differ significantly ($p<0.05$) and NS is non-significant.

The number of replicates is 18 for HE and 24 for CP.

were found when CP rose to 21.3%. Besides, no significant changes in the other chemical composition parameters evaluated were found as CP changed ($p>0.05$) though moisture in breast meat had a trend to decrease ($p = 0.09$) and crude ash in breast meat had a trend of bell-shaped change ($p = 0.08$) as CP rose.

There were significant differences in pH and shear force of breast meat and shear force, L* value and a* value of thigh ($p<0.01$ or $p<0.05$) among hot environment treatments (Table 5). Shear force of breast increased but pH of breast had opposite response ($p<0.05$) when hot environment was lower than comfort zone. For thigh meat, shear force and a* value increased under both AT 15°C, RH 50% and AT 33°C, RH 80%, but L* value increased only under AT 33°C, RH 50% ($p<0.05$). CP and hot environment ×CP had no effects on most determined physical characteristics although pH of breast meat and L* value of thigh meat tended to change as CP rose ($p = 0.06$).

Analysis of variance for two factors showed that hot environment had significant effects on MDA content in liver ($p<0.05$) and breast meat ($p<0.01$) but in thigh meat ($p>0.05$) and that no marked influences on MDA content in the tissues evaluated were found by CP level and the interaction of hot environment and CP level ($p>0.05$) (Table 6). MDA content in liver and breast meat increased significantly under high AT combined with high RH ($p<0.05$).

Table 6. Effect of hot environment and dietary energy on tissue malondialdehyde content of broiler of 42 days

	HE (°C)				SEM_{HE}	CP (%)			SEM_{CP}	p value		
	I	II	III	IV		18.7	20.0	21.3		HE	CP	HE×CP
Malondialdehyde content (nmol /mg protein)												
Liver	0.6^{b}	1.2^{ab}	1.0^{b}	2.3^{a}	0.41	1.2	0.9	1.7	0.35	0.04	NS	NS
Breast meat	0.6^{b}	0.6^{b}	0.6^{b}	1.3^{a}	0.16	0.8	0.6	0.9	0.14	0.01	NS	NS
Thigh meat	2.2	1.9	1.4	1.7	0.44	1.9	1.5	2.0	0.38	NS	NS	NS

HE = Hot environment, CP = Crude protein.

SEM_{HE} and SEM_{CP} each is pooled standard error of mean for hot environment and dietary crude protein level.

I = Air temperature (AT) 15°C and relative humidity (RH) 50%; II = AT 22°C and RH 50%; III = AT 33°C and RH 50%; IV = AT 33°C and RH 80%.

[a, b] Means within the same treatment with different superscripts differ significantly ($p<0.05$) and Ns is non-significant.

The number of replicates is 18 for HE and 24 for CP.

DISCUSSION

When hot environment, the combination of air temperature and humidity, exceeds the thermal comfort zone, broiler will encounter heat stress which inevitably results in a negative impact on the performance and carcass quality (Austic, 1985; Howlider and Rose, 1987; Leenstra and Cahaner, 1991; Borges et al., 2004). In accordance with the previous reports, the result of the present study indicated that the growth performance was decreased by heat exposure. Moreover, the result suggested that the adverse effect of high temperature was augmented by high humidity. Lin et al. (2005a, b) reported that humidity interfered the heat dissipation of broiler chickens at high temperature. The disturbed thermobalance should be responsible, at least partially, for the decreased growth performance of heat-stressed broilers.

In the present study, the decreased carcass weight and breast meat was in line with the result of Howlider and Rose (1989), who reported that the broilers rearing under high temperature environment had less yield of carcass weight, especially of breast. Although the absolute weights of both breast and thigh meat were all decreased by heat exposure, the relative weight of breast meat to carcass weight (% BW) was significantly lower in hot environment treatments while the opposite was true for the thigh. This result indicated that the growth of breast was suppressed more severely relative to body weight and the development of thigh was suppressed to a less extent than body weight, suggesting that the growth of breast is more sensitive to hot environment. Lin et al. (2006a) reported that when the broiler chickens were subjected to corticosterone treatment, the development of breast muscle tissue was suppressed more severely than body weight and thigh muscle tissue. Hence, the effect of corticosterone in heat-stressed broiler chickens could not be excluded.

The protein contents of both breast and thigh meat were reduced by hot environment, consistent with previous reports (Geraert et al., 1996; Tankson et al., 2001). Tankson et al. (2001) reported that heat exposure resulted in the reductions in BW, carcass weight and protein content. The present result further illustrated that the reduced protein contents in breast and thigh muscles tissues were the main contributor. The stress effect induced by glucocorticoid is one of the underlying mechanisms (Tankson et al., 2001).

Baziz et al. (1996) reported that the heat-stressed broilers had higher level of abdominal fat (% BW) compared to the *ad libitum* control chickens rearing under normal temperature. In line with this result, although the chickens in hot environment showed a reduction in absolute abdominal fat weight, the relative weight of fat to body weight was not changed significantly by heat treatment compared to control chickens. As the broiler chickens rearing in hot temperature had higher abdominal fat compared to the pair-fed chickens (Baziz et al., 1996), the result suggested that hot environment would facilitate the development of abdominal fat.

Besides the thermal environment, dietary crude protein level can affect growth performance and carcass composition of broiler. Many researches reported that low dietary crude protein content could lower carcass yield in broiler and increase body fat deposition, especially the abdominal fat (Aletor et al., 2000; Furlan et al., 2004). Furlan et al. (2004) summarized that there was a reduction in the protein and an increase in the crude fat content of breast, drumstick+thigh and wings from broiler fed low protein diets, with these effects being more strongly observed when the birds were raised under heat stress. High dietary protein level could reduce the adverse effect of thermal environment on performance of broilers (Baghel and Pradhan, l991; Han and Baker, 1993). In the present study, an increase in the crude protein content and a reduction in crude fat content of breast were also found from broiler fed on high CP diet. However, no significant effect of dietary protein level on chemical components of thigh meat was detected. On one hand, the fact that the dietary protein treatment had no large scope enough in the present study could be possible reason and on the other hand, the thigh meat composition had less response to the dietary CP level than the breast meat.

Li (1999) reported that breast meat from broilers suffered from heat stress had higher shear force value.

However, the present result showed that the Warner-Bratzler shear force values of thigh meat increased significantly under hot humid environment, suggesting that the rearing environment of high temperature and humidity could decrease the tenderness of chicken. Furthermore, we also found broiler fed under 15°C environment had higher shear force in breast and thigh meats compared to the normal condition (22°C). The underlying mechanism needs to be investigated further.

High temperature in rearing condition or acute heat stress before slaughtering could significantly decrease pH of chicken muscle (Mccurdy et al., 1996; Sandercock et al., 2001). McKee and Sams (1997) reported that the seasonal heat stress turkeys exhibited a faster pH decline by 15 min post-mortem and were also paler in color. In addition, the heat stress birds had a higher frequency of abnormal birds than controls when birds were grouped as normal (L*<53) or abnormal (L*>53). Owens et al. (2000) found that the halothane-susceptible birds had significantly lower muscle pH (0 h), higher L* values at 2 h postmortem and higher incidence of PSE compared with halothane-unsusceptible birds in the large breast muscle yield strain raised under heat stress before slaughtering. For halothane-unsusceptible birds, heat stress birds had significantly lower muscle pH (0 h and 2 h) and significantly higher L* values at 2 h postmortem compared with comfort ambient temperature controls in the rapid overall growth strain. These results suggested that heat stress could contribute to the development of PSE meat, in which affecting extent was associated with stress sensitivity of birds and the strains selected. This study further approved the previous researches and also found that the decreasing degree of visual meat quality was related to the intensity of heat stress environment. The pH of breast meat or thigh meat declined or had a trend to decline only when AT rose to 33°C and RH to 80%. The decrease of pH in meat might have some correlation with PSE meat, which had higher L* value and lower a* value (Li, 1999). However, in our experiment, L* and a* in breast meat had no marked change, and L* value and a* in thigh meat increased for the broilers fed under hot or hot humid environment. The reason for such difference may be that the broiler suffered by heat stress for three weeks could acquire some thermal acclimation mechanisms and the physiological responses and metabolic status acutely modulated with great extent soon after the exposure became to restore. This view was supported by the studies in broilers suggesting that heat stress could induce the metabolic changes (Lin et al., 2006b) and in men indicating that acclimation to humid heat could be in favor of the restore of physiological balance (Buono et al., 1998).

Animal can keep the balance between the oxidation and antioxidant defence by the physiological and metabolic regulation for body homeostasis systems under the common condition. However, such balance may be disturbed by stressful and clinical conditions (Dröge, 2002), causing lipid peroxidation (LPO) and oxidative damages to cell and tissue (Slater, 1984). Lin et al. (2006b) reported the elevated body temperature could induce the metabolic changes that were involved in the induction of oxidative stress. The oxidative stress should be considered as part of the stress response of broiler chickens to heat exposure. Aoyagi et al. (1997) found that chicks to heat exposure had lower antioxidant defence capacity, higher lipid peroxidation level and lifted thiobarbituric acid reacting substances concentration in plasma and liver. In this study, an increase of MDA level in liver and breast meat was observed in the very hot environment treatment, indicating the cellular damage caused by the combination of high temperature and high humidity. The result that MDA level in thigh meat had no significant change, suggesting the tissue specificity.

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