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Antioxidant capacity and meat quality of broilers exposed to different ambient humidity and ammonia concentrations

F.X. Wei[1,2], X.F. Hu[3], R.N. Sa[4], F.Z. Liu[1], S.Y. Li[2] and Q.Y. Sun[2]

[1]College of Animal Science and Technology, Northwest A&F University, Yangling, China
[2]Institute of Animal Husbandry and Veterinary Science, Henan Academy of Agricultural Sciences, Zhengzhou, China
[3]Henan Key Laboratory for Animal Immunology, Henan Academy of Agricultural Science, Zhengzhou, China
[4]State Key Laboratory of Animal Nutrition, Institute of Animal Sciences, Chinese Academy of Agricultural Sciences, Beijing, China

Corresponding authors: F.Z. Liu / S.Y. Li
E-mail: lfz811@163.com / lsy9617@aliyun.com

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ABSTRACT. To investigate the effect of humidity and ammonia on the antioxidative capacities and meat qualities of broilers, 192 broilers were divided into 2 groups: high (H, 70 ppm) and low (L, 30 ppm) ammonia concentration. These groups were divided into 30% (Treatment humidity, T) and 60% (Control humidity, C) humidity, giving 4 treatments: C+L, C+H, T+L, and T+H. Blood and muscle antioxidative capacities and meat quality were measured. In the H group, body weight (BW), average daily feed intake (ADFI), average daily weight gain (ADG), blood and muscle antioxidative capacities, and postmortem pectoral muscle a* of broilers were significantly decreased ($P < 0.05$), and pectoral muscle thiobarbituric acid reactive substance (TBARS) contents and drip losses, postmortem pectoral muscle b* ($P < 0.05$) and

L* (P = 0.054), and pectoral muscle shear forces (P = 0.075) increased. In the T condition, BW, ADFI, pectoral muscle superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px) activities, and pectoral muscle L* decreased (P = 0.053), and pectoral muscle shear forces and TBARS contents increased (P < 0.05). In the T+H group, BW, ADFI, ADG, blood antioxidative capacities, pectoral muscle SOD and GSH-Px activities, and postmortem pectoral muscle a* were significantly lower than those of the C+L group, but postmortem pectoral muscle TBARS contents and pectoral muscle drip losses and shear forces significantly increased (P < 0.05). These results revealed that T+H could significantly reduce growth performance, antioxidative capacities, and meat quality of broilers; T intensified these negative effects.

Key words: Ammonia; Relative humidity; Antioxidative capacity; Meat quality; Broiler

INTRODUCTION

With modern broilers growing more and more quickly at early growth stages, ambient and physiological stress factors gradually exert significant influences on their health and growth performance, thereby causing their death rate to increase, their growth rate to decrease, and their meat quality to deteriorate. This results in broiler farmers suffering economic losses on one hand, and broiler consumers facing health disadvantages resulting from deteriorated broiler meat on the other hand. Thus, it is necessary to pay great attention to related research. Usually, the concentrations of toxic gases such as ammonia, sulfureted hydrogen, and carbon dioxide, as well as their combination with humidity in poultry houses, are the main factors affecting environments. In poultry houses of many chicken farms, carbon dioxide concentrations are over-proof, particularly during the late period of broilers (Lacey et al., 2004). In recent years, global warming is evident, and arid and semi-arid scenarios appeared to be more severe in many regions where low atmospheric humidity could intensify harmful effects of such toxic gases, thus rendering animals susceptible to strong stress reactions and significantly decreasing their performance (Bottje and Harrison, 1985; Howlider and Rose, 1989; Mashaly et al., 2004).

There are incompletely consistent reports on humidity effects on broiler growth performance (Jones et al., 2005), but hardly any reports on the effects of humidity on chicken muscle quality. High-concentration ammonia is reported to be capable of decreasing the production capacity of domestic animals, but its effects on meat qualities were rarely reported (Charles and Payne, 1966; Kling and Quarles, 1974; Quarles and Kling, 1974; Reece et al., 1980, 1981; Caveny et al., 1981) Furthermore, most current relevant studies focus on investigating effects of individual ambient factors inside poultry houses on broilers, while few studies focus on effects of combinations of ambient factors inside poultry houses on broilers. In practice, effects of humidity and ammonia coexist, and the influences of ammonia on antioxidant capacity and meat qualities of broiler bodies at different humidities are rarely reported. Investigating antioxidant capacity and meat quality of broilers at different humidities can provide an important theoretical basis for controlling poultry-house environments and producing high-quality meat products. Hence, the objective of this study was to evaluate the effects of ambient ammonia and humidity on the antioxidant capacity and meat quality of broiler chickens.

MATERIAL AND METHODS

Experimental design and bird management

One hundred and ninety-two 21-day-old male Arbor Acres broiler chicks (purchased from Huadu Foodstuff Ltd. Co., and raised to 21 days old in a conventional poultry house) were chosen and randomly divided into 4 groups, and each of the groups was composed of 6 eight-broiler replicates. The average initial body weight (BW) of broilers did not significantly differ among the treatments ($P > 0.05$). The study adopted a 2 x 2-factorial design, and the treatments are listed in Table 1. The experiment lasted 3 weeks, from day 22 to 42.

Table 1. Experimental treatments.

Treatments	Relative humidity (%)	Ammonia concentration (ppm)
60%+30 ppm (C+L)	60	30
60%+70 ppm (C+H)	60	70
35%+30 ppm (T+L)	35	30
35%+70 ppm (T+H)	35	70

C and T = control and treatment humidity; L and H = low and high ammonia concentration.

The experiment was carried out in a programmed artificial climate chamber (PC) in the Key State Animal Nutrition Lab in China. The broilers were raised in 4 separate PCs during the experiment period, and the chambers were computer programmed to have the humidity and ammonia concentrations as required. The ammonia concentrations and humidity inside the chambers were separately measured with a multi-gas tester made in Germany and a hydrometer every 4 h, and the values were compared with those displayed on the computer. In each chamber, the temperature was kept at 25°-26°C. All birds were provided the same diet in the experimental period (Table 2). Water and feed were provided *ad libitum*, and feed intake and BW were recorded weekly. Birds were kept in 3-layer cages. The photoperiod was set at 24 L throughout the experimental period. Birds were vaccinated with the Newcastle disease and infectious bronchitis (ND-IB) combined vaccine by eye and nose dripping at 7 days. When they were 14 and 19 days old, they were vaccinated by drinking water with the infectious bursal disease vaccine, live virus (Strain B87). When they were 26 days old, they were vaccinated by drinking water with the ND-IB combined inactive vaccine.

Table 2. Ingredients and nutrient level of basal diet.

Ingredient	4-6 weeks (%)	Nutrient content	
Corn	61.19	ME, MJ/kg	12.55
Soybean meal	31.80	CP, %	19.96
Soybean oil	3.27	Ca, %	0.90
Monocalcium phosphate	1.65	Available P, %	0.40
Limestone	1.13	Lys, %	1.00
L-Lysine	0.08	Met, %	0.45
DL-methionine	0.15	Met+Cys, %	0.78
Salt	0.35		
50% Choline chloride	0.15		
Vitamin premix	0.02		
Trace element premix	0.20		

Multi-vitamin premix contains 125,000 IU VA, 2500 IU VD, 18.75 mg VE, 2.65 mg VK, 2 mg VB, 6 mg VB2, 2 mg VB6, 0.025 mg VB12, 0.0325 mg biotin, 1.25 mg folic acid, 12 mg pantothenic acid, and 50 mg niacin per kg. Trace element premix contains 10.35 mg I, 0.15 mg Se, 75 mg Zn, 8 mg Cu, 80 mg Fe, and 100 mg Mn per kg.

Sampling and sample preparation

When the broilers reached 42 days, 6 individuals were taken from each treatment, and their blood was sampled by wing venipuncture. Sera were prepared from the blood, and the superoxide dismutase (SOD) activity, total antioxidant capacity, and glutathione peroxidase activity (GSH-Px) were measured.

On day 42, 6 broilers were taken from each treatment and were killed after a 12-h fast and access to water *ad libitum*. Their pectoral muscles were separated, and the pH and drip losses of the pectoral muscles were measured. About 10 g left pectoral muscle was taken, sealed in a plastic bag, and stored at 4°C for thiobarbituric acid reactive substance (TBARS) measurement. At the same time, additional left pectoral muscle was taken and stored at -20°C to measure GSH-Px, SOD activity, and total antioxidant capacity.

Measured parameters and measurement methods

The GSH-Px, SOD activity, and total antioxidant capacity were measured with a test kit according to manufacturer instructions (NanJing JianCheng Bioengineering Institute). The TBARS content of pectoral muscles that were stored at 4°C was measured on the 1st, 3rd, 5th, and 7th days after slaughtering using the method of Jo and Ahn (1998).

The muscle pH was measured with a Hitachi acidometer that was directly stabbed into the pectoral muscle 45 min and 24 h after slaughtering ($pH_{45\ min}$ and $pH_{24\ h}$). Muscle color parameters [lightness (L*), redness (a*), and yellowness (b*)] of pectoral muscle were measured with a TC-PllG Automatic Colorimeter 45 min and 24 h after slaughtering.

To measure drip loss, after the broilers were slaughtered, their left pectoral muscles were separated, weighed (recorded as W1), sealed in plastic bags, and stored at 4°C in a refrigerator for 24 h. Then, they were dried with filter paper and weighed (and recorded as W2). The drip loss of the pectoral muscles could be calculated by the following formula: drip loss = 100% x (W1-W2) / W1.

The pectoral muscles that were used to measure the drip loss were used as the materials for the muscle shear force measurement. To measure the sheer force of pectoral muscle, the probe needle of a probe thermometer was stabbed into the central area of the pectoral muscle, and the muscle was heated in an 80°C water bath; when the temperature in the central area reached 74°C, the muscle was taken out of the water and cooled to room temperature. Then, the muscle was cut into 5 strips of 1 x 1 x 3 cm along the fiber direction, and the shear forces of the 5 strips were measured with the TMS-Pro Food Testing Instrument and averaged.

Statistical analysis

All of the data were analyzed by analysis of variance (ANOVA) using SPSS 16.0. Differences among treatment means were determined using a least significant difference test ($P = 0.05$), and all data are reported as average ± standard error.

RESULTS

Effect of ammonia and humidity on the performance of broilers

The growth performance of 42-day-old broilers exposed to different ambient humid-

ity and ammonia concentrations are shown in Table 3. The results show that humidity and ammonia concentrations inside a poultry house significantly affected BW and average daily feed intake (ADFI) of 42-day-old broilers ($P < 0.05$) and the average daily gain (ADG) was affected ($P = 0.072$), whereas the feed efficiency was not significantly affected ($P > 0.05$). No significant interactions in BW, ADFI, ADG, and feed efficiency were observed between humidity and ammonia ($P > 0.05$). However, BW, ADFI, and ADG of 42-day-old broilers exposed to 35% relative humidity and 70 ppm ammonia were significantly lower than those of birds exposed to 60% relative humidity and 30 ppm ammonia ($P < 0.05$).

Table 3. Effects of ambient humidity and ammonia concentrations on growth performance in broilers.

Treatments		Initial body weight (g)	Final body weight (g)	ADFI (g)	ADG (g)	F/G
60%+30 ppm (C+L)		715.88	2927.130[b]	181.69[b]	104.98[b]	1.72
60%+70 ppm (C+H)		721.40	2862.13[a,b]	173.62[a]	101.52[a,b]	1.71
35%+30 ppm (T+L)		718.50	2866.50[a,b]	175.11[a,b]	102.38[ab]	1.71
35%+70 ppm (T+H)		717.63	2813.93[a]	169.74[a]	99.39[a]	1.71
SE		3.80	12.18	1.13	0.61	0.01
P value	Ammonia (A)	0.763	0.028	0.009	0.018	0.186
	Humidity (H)	0.941	0.040	0.035	0.072	0.792
	A x H	0.679	0.802	0.559	0.853	0.978

[a,b]Values with different letters in the same column indicate significant difference ($P < 0.05$). ADFI = average daily feed intake; ADG = average daily gain; F/G = feed to gain ratio. For other abbreviations, see Table 1.

Effect of ammonia and humidity on SOD activities, total antioxidant capacities, and GSH-Px activities of broilers

The SOD activities, total antioxidant capacities and GSH-Px activities of broilers exposed to different humidity and ammonia concentrations are shown in Tables 4 and 5. At the high ammonia concentration, blood ($P < 0.01$) and muscle ($P < 0.05$) total antioxidant capacities of broilers decreased, and their blood SOD activities tended to decrease. At the low humidity, pectoral muscle SOD and GSH-Px activities of the broilers decreased ($P < 0.05$), and their blood GSH-Px activities tended to decrease.

Table 4. Effect of humidity and ammonia on blood antioxidant capacity of broilers (U/mL).

Treatments		SOD activity	T-AOC	GSH-PX activity
60%+30 ppm (C+L)		142.57	29.29[a]	394.64
60%+70 ppm (C+H)		134.23	23.00[b]	392.69
35%+30 ppm (T+L)		137.34	27.44[a,b]	364.67
35%+70 ppm (T+H)		132.61	21.97[b]	361.23
SEM		2.55	0.95	9.81
P value	Ammonia (A)	0.215	0.006	0.892
	Humidity (H)	0.510	0.456	0.133
	A x H	0.727	0.830	0.970

[a,b]Values with different letters in the same column indicate significant difference ($P < 0.05$). SOD = superoxide dismutase; T-AOC = total antioxidant capacity; GSH-Px = glutathione peroxidase activity. For other abbreviations, see Table 1.

The serum total antioxidant capacity and muscle SOD and GSH-Px activities of the broilers significantly decreased in the high ammonia and low humidity treatment (T+H) compared with the low ammonia and high humidity treatment (C+L) ($P < 0.05$).

Table 5. Effect of humidity and ammonia on pectoral muscle antioxidant capacity of broilers (U/mg pro).

Treatments		SOD activity	T-AOC	GSH-P_X activity
60%+30 ppm (C+L)		17.66[a]	0.31	41.48[a]
60%+70 ppm (C+H)		17.32[a,b]	0.30	29.98[b]
35%+30 ppm (T+L)		15.64[a,b]	0.30	32.80[b]
35%+70 ppm (T+H)		15.11[b]	0.28	29.61[b]
SE		0.46	0.02	0.89
P value	Ammonia (A)	0.637	0.671	0.001
	Humidity (H)	0.033	0.759	0.019
	A x H	0.917	0.869	0.030

[a,b]Values with different letters in the same column indicate significant difference ($P < 0.05$). For other abbreviations, see Tables 1 and 4.

Effect of ammonia and humidity on TBARS content in pectoral muscle of broilers

The pectoral muscle TBARS contents of the broilers exposed to different humidity and ammonia concentrations are presented in Table 6. At the high ammonia concentration, muscle TBARS tended to increase. Additionally, the pectoral muscle TBARS of the broilers was significantly affected when the pectoral muscles were stored for 5 days ($P < 0.05$), but this effect was not significant when the muscles were stored for 1, 3, and 7 days ($P > 0.05$). Pectoral muscle TBARS contents of the broilers were affected by humidity. At the low humidity, pectoral muscle TBARS contents increased when the muscles were stored for 5 and 7 days. Pectoral muscle TBARS contents of the broilers were higher in the high ammonia and low humidity treatment (T+H) than in the low ammonia control (C+L) when the pectoral muscles were stored for 5 and 7 days ($P < 0.05$). Figure 1 shows that the TBARS content increased linearly as the period of pectoral muscle storage increased.

Table 6. Effect of humidity and ammonia on TBARS content in pectoral muscle of broilers (mg/kg).

Treatments		TBARS			
		1st day after slaughtering	3rd day after slaughtering	5th day after slaughtering	7th day after slaughtering
60%+30 ppm (C+L)		0.14	0.28	0.42[a]	0.60[a]
60%+70 ppm (C+H)		0.14	0.28	0.46[b]	0.64[a,b]
35%+30 ppm (T+L)		0.14	0.28	0.47[b]	0.66[a,b]
35%+70 ppm (T+H)		0.15	0.28	0.49[c]	0.70[b]
SE		0.002	0.003	0.005	0.013
P value	Ammonia (A)	0.353	0.818	0.003	0.147
	Humidity (H)	0.616	0.774	0.004	0.039
	A x H	0.959	0.790	0.888	0.875

[a,b]Values with different letters in the same column indicate significant difference ($P < 0.05$). For other abbreviations, see Table 1.

Effect of ammonia and humidity on meat quality

The pH and drip losses in pectoral muscles of broilers exposed to different humidity and ammonia concentrations are presented in Table 7. Ammonia concentrations did not significantly affect the pectoral muscle pH of broilers ($P > 0.05$), but under high ammonia concentrations, the drip losses ($P < 0.01$) of their pectoral muscles significantly increased. The shear forces also increased, but the change was not significant ($P = 0.075$). At the low humidity, the shear forces of pectoral muscles increased, and the pH of their pectoral muscles

24 h after slaughtering and the drip losses tended to increase (P > 0.05). The drip losses and shear forces of the broilers were significantly higher in the high ammonia and low humidity treatment than in the low ammonia control (C+L) (P < 0.05).

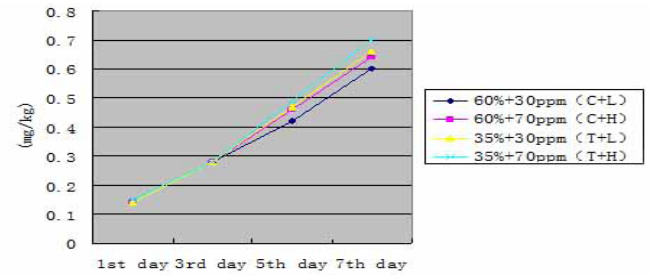

Figure 1. TBARS contents of pectoral muscle stored for the different periods of time in broilers exposed to different humidity and ammonia concentrations. For other abbreviations, see Table 1.

Table 7. Effect of humidity and ammonia on meat quality of broilers.

Treatments		$pH_{45\ min}$ after slaughtering	$pH_{24\ h}$ after slaughtering	Drip loss (%)	Shear force (N)
60%+30 ppm (C+L)		5.68[a,b]	5.61	1.95[a]	48.64[a]
60%+70 ppm (C+H)		5.64[a,b]	5.56	2.25[a]	59.13[a,b]
35%+30 ppm (T+L)		5.48[a]	5.49	1.61[a]	59.78[a,b]
35%+70 ppm (T+H)		5.71[b]	5.49	3.33[b]	67.28[b]
SE		0.037	0.029	0.169	2.390
P value	Ammonia (A)	0.205	0.651	0.009	0.075
	Humidity (H)	0.374	0.128	0.290	0.057
	A x H	0.068	0.747	0.052	0.757

[a,b]Values with different letters in the same column indicate significant difference (P < 0.05). For other abbreviations, see Table 1.

The pectoral muscle color indexes of broilers exposed to different humidity and ammonia concentration are shown in Table 8. Meat colors of the broilers were influenced by the ammonia concentration. Under the high ammonia concentration, pectoral muscle L* and b* increased 45 min after slaughtering (P = 0.054 and P < 0.05, respectively), but the pectoral muscle a* decreased (P < 0.01). Under the low humidity condition, pectoral muscle L* of the broilers decreased (P = 0.053). Pectoral muscle a* of the broilers was significantly higher in the high ammonia and low humidity treatment (T+H) than in the low ammonia control (C+L) (P < 0.05). Among the treatments, the meat color indicators of broilers did not vary significantly 24 h after slaughtering (P > 0.05).

Table 8. Effect of humidity and ammonia on meat color indexes of broilers.

Treatments		45 min after slaughtering			24 h after slaughtering		
		L*	a*	b*	L*	a*	b*
60%+30 ppm (C+L)		38.41	10.32[b]	8.1	47.88	9.3	16.15
60%+70 ppm (C+H)		39.47	7.32[a]	9.33	49.12	8.44	17.22
35%+30 ppm (T+L)		37.02	8.16[a]	8.37	48.26	7.93	16.13
35%+70 ppm (T+H)		38.41	8.08[a]	8.7	49.31	7.87	18.73
SE		0.298	0.202	0.17	0.468	0.342	0.532
P value	Ammonia (A)	0.054	0.001	0.033	0.236	0.512	0.1
	Humidity (H)	0.053	0.098	0.599	0.761	0.172	0.491
	A x H	0.788	0.002	0.197	0.915	0.560	0.482

[a,b]Values with different letters in the same column indicate significant difference (P < 0.05). L* = lightness; a* = redness; b* = yellowness. For other abbreviations, see Table 1.

DISCUSSION

The results of this study showed that high ammonia concentration (70 ppm) significantly decreased the ADFI and DWG in the late growth period and the final weight of broilers, but it did not affect the feed to gain ratio. This was basically consistent with previous results (Quarles and Kling, 1974; Reece et al., 1981; Miles et al., 2004). Quarles and Kling (1974) raised broilers in artificial climate chambers that were set up to have ammonia concentrations of 25 and 50 ppm when the broilers were 4 weeks old to 8 weeks old; the BW of the broilers was significantly lower at 50 ppm ammonia than at 25 ppm ammonia, and the feed efficiencies of the broilers did not differ significantly. Reece et al. (1981) revealed that the BW of the broilers was significantly lower at 50 ppm ammonia than at 25 ppm ammonia when broilers were raised at 25 and 50 ppm ammonia for 28 days beginning when they were 1 day old, and the feed to gain ratio of the broilers at the two ammonia concentrations did not differ significantly. Miles et al. (2004) found that when broilers were exposed to ammonia at different concentrations for 28 days, their BW was significantly lower at 50 and 75 ppm ammonia than at 0 and 25 ppm ammonia, the BW of the broilers at the latter two ammonia concentrations did not significantly differ, and the feed efficiencies of the broilers at the four ammonia concentrations did not significantly differ. Lower feed intakes of broilers were probably associated with ammonia damaging their eyesight, thus rendering it difficult to find food (Ritz et al., 2004) or infiltrate in their blood, which would change their blood pH, inhibit respiration, and decrease their respiration rate and energy requirement (Charles and Payne, 1966). The unchanged feed to gain ratios probably indicated that the decreased final weights (or daily BW gains) of broilers result from lowered feed intake rather than metabolic changes (Charles and Payne, 1966). Moreover, research proved that blood uric acid and blood plasma uric acid nitrogen at 30 and 60 ppm ammonia did not differ significantly (Beker et al., 2004). Urea nitrogen contents of domestic animals and blood and uric acid contents of poultry blood reflect animal and poultry metabolism; the urea nitrogen contents or uric acid contents are increased in the blood plasma if metabolism is affected (Webel et al., 1997; Hartman et al., 2006).

The effects of humidity on broiler production capacity have not received proper attention, and the humidity that is suitable for broilers ranges from 55 to 60%. However, unfavorable humidity affects the growth of broilers. This study revealed that the ADFI, ADG, and the final BW of broilers were lower at 35% humidity than at 60% humidity, but the feed efficiencies did not remarkably differ. This result basically agreed with previous results that showed that low humidity could cause decreased thyroxin content, which was highly positively correlated with feed intake (Yahav et al., 1995; Yahav, 2000). Feed intake depends on the energy that is required for life and growth. At room temperature, the energy requirement for poultry to maintain their life is the lowest at 60% humidity, and it increases when the humidity is below 60%; therefore, the growth capacity of poultry is low at low humidity (Hurwitz et al., 1980). Furthermore, the effects of high-concentration ammonia and low humidity on broiler production capacity are additive.

In their normal life activities, poultry can generate reactive oxygen species inside their bodies, which attack biological membranes and cause lipid hydroperoxide formation and tissue damages. The method for assessing oxidative damage to living beings is to determine the TBARS or malondialdehyde (MDA) content in blood or tissues (Gutteridge, 1982; Stam et al., 1989; Armstrong and Browne, 1994). The TBARS content of meat products is better to indicate rancidity than the peroxide content (Barbut, 1997). Living beings have their own antioxidation

mechanisms: employing blood or muscle SOD and GSH-Px and total antioxidative capacity to enhance the antioxidative capacity, reduce reactive oxygen species-caused damages, and improve immune capacity. This study showed that high concentrations of ammonia reduced the total antioxidative capacities of broiler blood and muscles and tended to decrease the blood SOD. Low humidity reduced pectoral muscle SOD and GSH-Px activities and tended to lower the GSH-Px activity of broiler blood. Pectoral muscle TBARS contents tended to be higher at the high ammonia concentration than at the low ammonia concentration; in particular, it was significantly higher at the high ammonia concentration on the 5th day after slaughtering. Pectoral muscle TBARS contents tended to be higher at 35% humidity than at 60% humidity; particularly, they were significantly higher on the 5th and 7th days after slaughtering. Furthermore, the pectoral muscle TBARS content gradually increased with time after slaughtering. Currently, there are no reports on the effects of different ammonia concentrations or humidity on antioxidative capacities of broilers. Reports from fish showed that a high concentration of ambient ammonia reduced SOD contents in *Penaeus vannamei* and *Eriocheir sinensis* H. Milne-Edwards blood (Liu and Chen, 2004; Hong et al., 2007). Other research also showed that the stress of transportation could decrease the total antioxidative capacities of domestic animals, but it increased their MDA contents (Chirase et al., 2004; Nazifi et al., 2009).

Muscle pH, water-holding capacity (drip loss), shear force, and meat color are commonly adopted indicators of meat quality. Muscle pH does not only intuitively indicate muscle acidity but also directly affects meat tenderness, drip loss, and meat color. Muscle water-holding capacity, i.e., muscle water-retaining capacity, which is assessed in terms of drip loss or water loss, directly influences meat taste, succulence, color, nutrients, and flavor, and it more greatly affects processed meat yield, structure, and color. Muscle tenderness, a meat quality indicator that can be expressed in terms of meat shear force, can indicate the internal structure of meat, as well as muscle myofibril content, fat content, distribution, and chemical structure of connective tissue. Normally, there is a negative correlation between meat shear force and tenderness. Meat colors are other easily observable external indicators of physiological, biochemical, and microbiological changes in meats. Redness (a*) is a very important indicator for red muscles. Lightness (L*) is another important indicator, which is correlated with drip loss and pH (Barbut, 1997).

This study found that different concentrations of ammonia did not have a significant effect on the pectoral muscle pH, and a high concentration of ammonia increased pectoral muscle drip losses, which did not agree with previously reported results. Sackett et al. (1986) reported that 25 and 75 ppm ammonia did not affect drip losses of broiler pectoral muscles, but the pH of the pectoral muscles was lower at 25 ppm ammonia than at 75 ppm ammonia. The reason for this was probably that different types of stresses caused meat qualities of different kinds of poultry to vary (Debut et al., 2003). Stresses damage pectoral fascia completeness and thereby intensify glycolysis, which reduced the pectoral muscle pH and was negatively correlated with pectoral muscle drip loss (Qiao et al., 2001). At the low humidity, the pectoral muscle pH tended to decrease 24 h after slaughtering; as a result, the pectoral muscle drip loss tended to rise. Besides, previous reports also demonstrated that different stresses could increase drip losses of broiler muscles (Sandercock et al., 2001; Aksit et al., 2006; Yue et al., 2010). This study revealed that both a high concentration of ammonia and low humidity increased the shear forces of pectoral muscles, which basically agreed with the result that other stresses could increase the shear forces of broiler muscles (Lippens et al., 2000). This study also found that both the drip losses and shear forces of broiler muscles were significantly higher in the high concentration of ammonia and

low humidity treatment (T+H) than in the low concentration of ammonia (C+L), indicating that different concentrations of ammonia and humidity had additive effects on drip losses and shear forces of broiler pectoral muscles.

This study revealed that 45 min after slaughtering, a high concentration of ammonia increased pectoral muscle L* and b*, and it decreased pectoral muscle a*; at low humidity, the pectoral muscle L* decreased and the pectoral muscle a* increased, which indicated that the two stressors presented different effects. Previous reports described different results. Qiao et al. (2001) found that L* was negatively correlated with a* in pectoral muscles. Aksit et al. (2006) reported that the stress of high temperature increased the L*, a*, and a*/b* ratio of broiler pectoral muscles. Yue et al. (2010) reported that the stress of long-distance transportation increased the a* of broiler pectoral muscles. These results indicated that different stress types could cause different effects in different species of poultry (Debut et al., 2003).

Although this study did not find that poultry house humidity and ammonia had a statistically significant interaction that affected the main broiler parameters, its results indicated that humidity influenced ammonia toxicity. Low humidity could intensify the effects of high-concentration ammonia because liquid ammonia partially transforms into gaseous ammonia at low humidity in a poultry house. High concentrations of ammonia could reduce the proportion of liquid ammonia that transformed into the gaseous state or cause gaseous ammonia to transform into the liquid state, thereby alleviating the negative effects of ammonia. Alleviating the effects of humidity on ammonia toxicity still need further in-depth research.

The results of this study suggested that 70 ppm ammonia could cause broilers to reduce their production capacity and body and muscle antioxidative capacity and cause oxidative stress, thereby reducing the meat qualities. At 35% humidity, broilers had decreased production capacity, blood and muscle antioxidative capacities, and muscle qualities. Low humidity could intensify the effects of high concentrations of ammonia, and high humidity alleviated the negative effects of high ammonia concentrations to some extent.

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