# ENVIRONMENT, WELL-BEING, AND BEHAVIOR

## Effects of Temperature During Rearing and Crating on Stress Parameters and Meat Quality of Broilers

M. Akşit,* S. Yalçın,†[1] S. Özkan,† K. Metin,‡ and D. Özdemir*

*Faculty of Agriculture, Department of Animal Science, and ‡Faculty of Art and Science, Department of Biology, Adnan Menderes University, TR-09100 Aydın, Turkey; and †Faculty of Agriculture, Department of Animal Science, Ege University, TR-35100 İzmir, Turkey

**ABSTRACT** Two trials were conducted to study the effects of heat stress during rearing (trial 1) and crating (trial 2) on broiler stress parameters and fear, breast meat quality, and nutrient composition. The relationships between stress parameters and meat quality traits were also determined. Trial 1 consisted of 3 temperature treatments from 3 to 7 wk: control (temperature was 22°C); diurnal cyclic temperature (temperature was 28°C from 1000 to 1700 h and 22°C from 1700 to 1000 h); and constant high temperature (34°C; temperature was 34°C). In trial 2, broilers from the control and 34°C groups in trial 1 were used. Broilers in each group were placed in transport cages. The 9 cages from the control group were divided into 3 groups and placed into 3 rooms at 15, 22, or 34°C for 2 h. The 3 cages from the 34°C group were also held in the room at 34°C (34–34°C). Diurnal cyclic temperature had no effect on BW up to 5 wk of age. The effect of 34°C constant temperature on BW of broilers increased with age. Plasma levels of glucose and albumin increased by 34°C, but no dramatic change in levels occurred when those broilers were crated at 34°C. The heterophil:lymphocyte (H:L) was higher for the 34–34°C broilers and the control broilers in the 34°C room than those from the 22 and 15°C room. Breast muscle glycogen level decreased in broilers reared under diurnal cyclic or high temperatures. A lower pH and higher lightness (L*) and redness values and redness:yellowness were found in meat for broilers from both 34°C and 34–34°C groups. Higher H:L was associated with breast muscle pH according to first-order polynomial regression. The H:L had a significant effect on L* values, which were described by a second-order polynomial regression. Blood glucose level was positively correlated with L* and redness values. Duration of tonic immobility was neither influenced by rearing and crating temperatures nor associated with meat quality parameters.

**Key words**: stress, meat quality, broiler

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## INTRODUCTION

The effects of heat stress on broiler performance and meat quality have been investigated extensively. High ambient temperatures from 21 d to slaughter age result in a decrease in growth rate, meat yield (Yalçın et al., 1997; 2001; Yunis and Cahaner, 1999), and breast protein content (Yalçın et al., 1999) in broilers. Heat stress during rearing is also one of the prominent antemortem stressors that results in a faster pH decline and pale color in the breast meat of turkeys (McKee and Sams, 1997). McCurdy et al. (1996) reported that the mean lightness (**L***) value in the breast muscle of turkeys was the highest during the summer. Petracci et al. (2004) observed higher L* and lower redness (**a***) and yellowness (**b***) for the breast muscle fillets of broilers reared in the summer than those reared in winter. Yalçın et al. (2005) found that breeder age influenced meat quality and that broilers from young breeders had lower pH values when reared at high ambient temperatures.

It was reported that acute heat stress during crating leads to alterations in blood acid-base status and influences postmortem muscle glycogen levels and breast meat pH (Sandercock et al., 2001). However, conflicting results have been reached in studies. Holm and Fletcher (1997) observed that broilers held at 29°C during crating had lower ultimate pH than those from broilers held at 7 and 18°C. Petracci et al. (2001) reported that the crating temperature effect on meat quality traits was not always consistent.

High ambient temperatures during rearing are also associated with an increase in the stress status of broilers, which is measured by heterophil:lymphocyte (**H:L**) and longer fearful behavior, as indicated by the duration of tonic immobility (**TI**; Yalçın et al., 2003). Preslaughter treatments (catching, crating, and transportation) during the summer increase blood uric acid, albumin, and glu-


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[1]Corresponding author: servet.yalcin@ege.edu.tr

cose levels, which are reliable indicators of stress in broilers (Yalçın et al., 2004). Kannan et al. (1997) suggested that higher preslaughter stress levels may affect the color of thigh meat in broilers. Remignon et al. (1998) studied the influence of acute stress before slaughter on muscle and meat quality of quails from lines divergently selected for long or short TI duration. They found no difference among lines for breast meat color under acute stress conditions, but quails from the long TI line had a higher pH at 24 h postmortem and higher glycolytic activity in the breast muscle. Debut et al. (2003) found no relationship between TI duration and meat quality parameters or stress sensitivity, measured by the activity of the birds on the shackle line. However, the relationships between stress parameters and meat quality traits have not been clearly demonstrated. Consequently, this experiment was performed to study the effects of heat stress during rearing and crating on broiler stress parameters and fear, meat quality, and breast nutrient composition and to determine the relationships between stress parameters and meat quality traits. The effect of heat stress on broiler performance was also investigated.

## MATERIALS AND METHODS

Two trials were conducted.

### *Trial 1*

In this experiment, the effect of high ambient temperatures during rearing on broiler performance and meat quality was evaluated.

A total of 480 chicks (Ross 308) were obtained from a local hatchery. Chicks were wing-banded and randomly assigned to 3 rooms with 4 replicate pens (40 chicks/pen) in each room. The temperature was 32°C in each room on d 1 and was decreased weekly by 2.5°C until wk 3.

The broilers were reared at 3 temperature schedules from 3 to 7 wk of age: control (temperature was maintained at 22°C); diurnal cyclic temperature [temperature was 28°C from 1000 to 1700 h and 22°C from 1700 to 1000 h (**28–22°C**)]; constant high temperature [temperature was kept at 34°C (**34°C**)]. Relative humidity was 60% during the experiment.

The chicks received ad libitum diets containing 22.3% CP and 3,191 kcal/kg of ME from day of hatch to 3 wk and 20.0% CP and 3,204 kcal/kg of ME from wk 3 to 7. Lighting was 23L:1D.

Body weights were determined at hatch, before heat treatment (3 wk), and at 4, 5, 6, and 7 wk of age. Feed consumption was measured from 0 to 3 wk and from 3 to 7 wk on a pen basis. Feed conversion was calculated for each group.

Broilers were slaughtered at 7 wk of age after 8 h of feed withdrawal. Broilers were crated and transported to the university slaughterhouse facilities immediately. Carcass weights of 12 broilers (6 broilers from each sex) from each group were obtained after chilling. Breast was dissected, skin was removed, and the breast muscles (pectoralis major and pectoralis minor) were weighed. Carcass and breast yield was expressed as percentages of BW at slaughter.

### *Trial 2*

This trial was conducted to evaluate the effect of crating temperatures on the meat quality of broilers and to determine the correlations between stress parameters and meat quality traits.

Birds from trial 1 were utilized. A total of 72 broilers from the control group and 24 broilers from the 34°C group were randomly caught and placed in transport cages (97 × 57 × 27 cm), 8 broilers to a cage. The 9 cages from the control group were divided into 3 groups and placed into 3 rooms at different holding temperatures: 15°C (**control–15°C**), 22°C (**control–22°C**), and 34°C (**control–34°C**) for 2 h. The 3 cages from the 34°C group were

**Table 1.** Effect of rearing temperature on live performance of broilers

| | BW (g) | | | | Food consumption (g) | Food conversion |
|---|---|---|---|---|---|---|
| Treatments[1] | 4 wk | 5 wk | 6 wk | 7 wk | 3 to 7 wk | 3 to 7 wk |
| Control | 1,052 | 1,570[a] | 2,209[a] | 3,000[a] | 4,745[a] | 1.95[a] |
| 28–22°C | 1,044 | 1,572[a] | 2,098[b] | 2,700[b] | 4,517[ab] | 2.14[b] |
| 34°C | 1,025 | 1,483[b] | 1,934[c] | 2,400[c] | 4,205[b] | 2.28[c] |
| SEM | 7 | 13 | 16 | 28 | 117 | 0.04 |
| Sex | | | | | | |
| Male | 1,059 | 1,590 | 2,172 | 2,859 | — | — |
| Female | 1,021 | 1,494 | 1,989 | 2,542 | — | — |
| SEM | 6 | 11 | 12 | 22 | — | — |
| Statistical analyses | *P*-values | | | | | |
| Temperature | 0.045 | <0.001 | <0.001 | <0.001 | 0.029 | <0.001 |
| Sex | <0.001 | <0.001 | <0.001 | <0.001 | — | — |
| Temperature × sex | 0.775 | 0.365 | 0.255 | 0.084 | — | — |
| BW at 3 wk | <0.001 | <0.001 | <0.001 | <0.001 | — | — |

[a–c]Means in the same column with no common superscript differ significantly.

[1]Control = temperature was maintained at 22°C; 28–22°C = temperature was 28°C from 1000 to 1700 h and 22°C from 1700 to 1000 h; 34°C = temperature was kept at 34°C from 3 to 7 wk.

also held in the room at 34°C (**34–34°C**). Birds were transported to the university poultry slaughterhouse. Deboned breast meat samples were collected after chilling.

### Stress and Fear Measurements

Three milliliters of blood was pulled from each of the 36 broilers (18 broilers/sex) from the control group and 12 broilers (6 broilers/sex) from the 34°C group in a tube containing EDTA before caging. Two hours after caging, blood from the same broilers in the different rooms was collected again. Blood was centrifuged, and plasma was stored at –80°C for glucose, uric acid, and albumin analysis. Analysis was performed using commercial kits.

To obtain the H:L, 1 drop of blood was collected from the same broilers on a glass slide. The smear was stained using Gimsa 2 h after fixation with methyl alcohol. One hundred leukocytes were counted, and the H:L was calculated (Gross and Siegel, 1983).

Duration of TI of the same broilers before and after crating was recorded. Placing a bird on its back induced TI. The bird was restrained for 10 s by maintaining a light pressure on its sternum. A stopwatch was started to record latencies until the bird righted itself. If the bird righted itself in <10 s, the restraining procedure was repeated. If the bird did not show a righting response over the 10-min test period, a maximum score of 600 s was given (Campo and Rodendo, 1997).

### Meat Quality Measurements

Breast samples from trials 1 and 2 were individually placed in plastic bags and stored for 24 h in a 4°C cooler. The pH at 24 h postmortem was recorded from the left breast muscle.

Trichromatic coordinates (L*, a*, and b*) were measured on the left breast muscle at 24 h using a Minolta chromameter (Minolta Corp., Ramsey, NJ). The chroma value, which is the intensity of color, was calculated as

$$C = \sqrt{(a^{*2} + b^{*2})}$$

where C = chroma value.

### Chemical and Biochemical Analysis

Right breast muscle samples were analyzed for moisture, protein, and ash content according to the official methods of analysis (Association of Official Analytical Chemists, 1980).

To measure muscle glycogen content, 1 g of sample from each breast muscle was collected and frozen. After homogenization, glycogen was determined according to Roe et al. (1961) and Carroll et al. (1956). The hydroxyproline concentration was determined according to Reddy and Enwemeka (1996). The collagen content of tissue was calculated assuming that 12.5% of collagen is hydroxyproline (Edward and O'Brien, 1980). Collagen content was expressed as grams/100 g of tissue weight.

### Statistical Analysis

Analyses of variance were performed using the GLM procedure of SAS (SAS Institute, 1999) to test the effects of temperature, sex, and temperature by sex interaction on performance. Because BW at 3 wk was different among groups, it was included in the model as a covariate to analyze BW data. Sex effect was not significant for the blood parameters and meat quality traits; therefore, sex was excluded as a factor. When a significant effect was noted ($P < 0.05$), means were compared using the Tukey test. Relationships between stress parameters and meat quality traits were generated using the correlation coefficient and regression polynomials options of SAS (SAS Institute, 1999).

## RESULTS

### Trial 1

As expected, the 34°C treatment significantly decreased BW of broilers at 4, 5, 6, and 7 wk, but there was no difference between control and the 28–22°C group at 4 and 5 wk of age (Table 1). At 7 wk, the BW of broilers from the 28–22° C and 34°C groups was 300 and 600 g lower than those obtained in the control group, respectively. Feed consumption and feed conversion from 3 to 7 wk were significantly affected by treatments, being the highest for the 34 °C group. Although broilers from the 28–22°C group consumed 228 g less feed/broiler than that consumed by control broilers, the difference was not significant.

The highest carcass yield was obtained for broilers from the control group (Table 2). Breast yield of broilers from the 28–22°C group was similar to control. High temperature decreased breast yield by 1.5%.

Breast meat glycogen content was similar in the 22–28°C and 34°C groups, which was lower than the control group. There was no effect of temperature on collagen content of breast meat (Table 2).

Breast meat moisture was lower in meats from the 34°C group than moisture in meats from the 22–28°C and control groups. Protein content was decreased by heat stress at 34°C, whereas the protein content of the 22–28 °C group was between the 34°C and control groups. There was no effect of diurnal cyclic temperature on breast meat ash content, but it was decreased by 34°C.

Lower pH values were obtained for the breast meat from broilers reared at 34°C, whereas the 22–28°C group had intermediate pH levels. Trichromatic coordinates were affected by rearing temperature (Table 2). High rearing temperatures influenced the L* values of meat, being highest in the meat from broilers heat-stressed at 34°C, which was followed by the 22–28°C group. The a* values were increased by both the 22–28°C and 34°C rearing temperatures, whereas the b* values of meat from the 34°C group were similar to the control group. There were higher color intensities in the meat from the 22–28°C and 34°C groups than those obtained from the control group (Table 2).

**Table 2.** Effect of rearing temperature on carcass and breast yield, meat nutrient composition, and meat quality traits

| | Yield | | Meat nutrient composition | | | | | Meat quality[1] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatments[2] | Carcass (%) | Breast (%) | Glycogen (mg/g) | Collagen (g/100 g) | Moisture (%) | Protein (%) | Ash (%) | pH | L* | a* | b* | a*:b* | C |
| Control | 73.8[a] | 29.9[a] | 0.188[a] | 0.096 | 74.7[a] | 23.5[a] | 1.13 | 6.00[a] | 48.94[c] | 2.99[b] | 4.19[b] | 0.76[b] | 5.23[b] |
| 28–22°C | 72.9[b] | 29.5[a] | 0.106[b] | 0.100 | 74.4[a] | 22.1[ab] | 1.17 | 5.95[ab] | 53.04[b] | 4.49[a] | 5.71[a] | 0.82[b] | 7.33[a] |
| 34°C | 71.5[c] | 28.4[b] | 0.104[b] | 0.105 | 72.4[a] | 21.6[b] | 1.38 | 5.89[b] | 53.94[a] | 5.21[a] | 4.44[b] | 1.39[a] | 6.85[a] |
| SEM | 0.2 | 0.2 | 0.022 | 0.009 | 0.2 | 0.3 | 0.04 | 0.02 | 0.30 | 0.28 | 0.31 | 0.14 | 0.33 |
| *P*-values | <0.001 | <0.001 | 0.015 | 0.468 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.003 | 0.005 | <0.001 |

[a–c]Means in the same column with no common superscript differ significantly.

[1]L* = lightness; a* = redness; b* = yellowness; C = chroma value.

[2]Control = temperature was maintained at 22°C; 28–22°C = temperature was 28°C from 1000 to 1700 h and 22°C from 1700 to 1000 h; 34°C = temperature was kept at 34°C from 3 to 7wk.

## *Trial 2*

Blood glucose, albumin, uric acid levels, H:L, and TI durations of broilers before and after crating are given in Table 3.

Rearing broilers at 34°C resulted in an increase in blood glucose, uric acid levels, and H:L at 7 wk of age (before crating). Heat stress had no effect on TI duration.

After 2 h of crating at 34°C, blood glucose and H:L levels increased for the broilers from the control–34° C group, and these levels were similar to the broilers from the 34–34°C group. Intermediate blood glucose levels were obtained for the broilers from the control–15°C group, whereas the control–22°C broilers had the lowest blood glucose levels. No significant differences were obtained between control–22°C and control–15°C broilers for H:L (Table 3). Blood albumin levels and duration of TI were not different among treatment groups before and after crating. Although blood uric acid level was higher for the broilers from the control–34°C group than the others, it was not statistically significant.

Although muscle glycogen levels were higher in chickens from the control–22°C group compared with chickens from the other treatment groups, they were not statistically significant. Crating temperature had no effect on muscle collagen levels (Table 4).

The lowest moisture content was obtained for the breast meat of broilers from the 34–34°C group. It was followed by the broilers from the control–34°C group. The difference between broilers reared at control temperature and crated either at control–22°C or control–15°C was not significant for breast muscle moisture. The protein level of breast meat of broilers from the 34–34°C group was lower than breast meat from the control–22°C broilers but similar to the broilers reared at control temperature and caged either at control–15°C or control–34°C.

Preslaughter temperatures exhibited significant effects on meat quality parameters. The lowest muscle pH 24 h postslaughter was obtained in the breast of 34–34°C broilers, whereas no difference was observed in the breast muscle pH between control–34°C and control–15°C broilers. The control–15°C broilers had similar pH values to the control–22°C broilers (Table 4).

Significant differences were observed due to crating temperature for muscle color, with a lighter and redder color for the 34–34°C broilers, whereas control–15°C and control–34°C broilers had similar L* values to control. The control–34°C broilers had redder breast meat than

**Table 3.** Blood glucose, albumin, uric acid levels, heterophil:lymphocyte (H:L), and tonic immobility (TI) durations of broilers before and after crating

| Treatment[1] | Glucose (mg/dL) | Albumin (g/dL) | Uric acid (mg/dL) | H:L | TI duration |
|---|---|---|---|---|---|
| Before crating | | | | | |
| Control | 166 | 1.30 | 3.27 | 0.38 | 243 |
| 34°C | 187 | 1.37 | 5.18 | 0.58 | 166 |
| SEM | 5 | 0.02 | 0.40 | 0.30 | 40 |
| *P*-values | 0.016 | 0.120 | 0.002 | <0.001 | 0.231 |
| After crating | | | | | |
| Control–22°C | 149[b] | 1.20 | 3.52 | 0.30[b] | 266 |
| Control–34°C | 182[a] | 1.22 | 6.04 | 0.81[a] | 299 |
| Control–15°C | 161[ab] | 1.31 | 3.28 | 0.40[b] | 241 |
| 34–34°C | 192[a] | 1.26 | 4.76 | 0.81[a] | 379 |
| SEM | 10 | 0.05 | 0.93 | 0.07 | 60 |
| *P*-values | 0.035 | 0.481 | 0.173 | <0.001 | 0.420 |

[a,b]Means in the same column with no common superscript differ significantly.

[1]Control = temperature was maintained at 22°C; 34°C = temperature was kept at 34°C from 3 to 7 wk. Crated broilers from the control group were placed into 3 rooms at different holding temperatures: 15°C (Control–15°C), 22°C (Control–22°C), and 34°C (Control–34°C) for 2 h. The broilers from the constant high temperature group were also held in the room at 34°C (34–34°C).

**Table 4.** Effects of crating temperatures on breast meat nutrient composition and meat quality traits in broilers reared at control temperatures or 34°C from 21 to 49 d of age

| | Meat nutrient composition | | | | | Meat quality[1] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Crating temperatures[2] | Glycogen (mg/g) | Collagen (g/100 g) | Moisture (%) | Protein (%) | Ash (%) | pH | L* | a* | b* | a*:b* | C |
| Control–22°C | 0.172 | 0.110 | 74.6$^{a}$ | 23.5$^{a}$ | 1.13 | 5.99$^{a}$ | 48.93$^{b}$ | 3.04$^{c}$ | 4.00 | 0.80$^{c}$ | 5.11 |
| Control–34°C | 0.081 | 0.100 | 73.0$^{b}$ | 22.7$^{ab}$ | 1.11 | 5.91$^{b}$ | 50.50$^{b}$ | 4.65$^{ab}$ | 3.74 | 1.51$^{ab}$ | 6.11 |
| Control–15°C | 0.065 | 0.104 | 74.4$^{a}$ | 22.3$^{b}$ | 1.13 | 5.94$^{ab}$ | 49.73$^{b}$ | 3.79$^{bc}$ | 4.65 | 0.98$^{b}$ | 6.19 |
| 34–34°C | 0.076 | 0.100 | 72.2$^{c}$ | 22.1$^{b}$ | 1.25 | 5.87$^{c}$ | 54.22$^{a}$ | 5.22$^{a}$ | 3.30 | 1.95$^{a}$ | 6.26 |
| SEM | 0.033 | 0.006 | 0.2 | 0.3 | 0.06 | 0.01 | 0.44 | 0.36 | 0.44 | 0.23 | 0.44 |
| *P*-values | 0.100 | 0.587 | <0.001 | 0.026 | 0.266 | <0.001 | <0.001 | 0.001 | 0.204 | 0.006 | 0.240 |

[1]L* = lightness; a* = redness; b* = yellowness; C = chroma value.

[2]Crated broilers from control group were placed into 3 rooms at different holding temperatures: 15°C (Control–15°C), 22°C (Control–22°C), and 34°C (Control–34°C) for 2 h. The broilers from the constant high temperature group were also held in the room at 34°C (34–34°C).

control–22°C and control–15°C broilers, but it was similar to control–34°C broilers. The b* values were not different among treatments. The highest a*:b* value was obtained for the broilers from the 34–34°C group, which was similar to the a*:b* values obtained from the control–34°C group. There was no crating temperature effect on chroma value.

### *Relationships Among Traits*

The H:L was negatively correlated with breast pH (Table 5). The correlation between H:L and L* was positive, whereas there was no association between H:L and a* and b* values. The correlation between H:L and breast muscle weight was negative. Blood uric acid and albumin levels did not correlate with muscle pH. Blood glucose level was negatively correlated with muscle pH but positively correlated with color. Blood albumin was found positively correlated with b*. The Spearman's ranks correlations between duration of TI and meat quality traits were very low (from 0.078 to –0.192).

There was a negative correlation between blood albumin and TI duration and although H:L, blood glucose, and uric acid levels were not associated with duration of TI, blood glucose level was positively correlated with blood uric acid level.

The ultimate pH was not correlated with breast muscle weight. Correlations between breast weight and L* value were estimated to be –0.399. The pH was highly negatively correlated with L* and a* values. Correlation between a* and b* values was not significant. Positive correlation of 0.436 was obtained between L* and a* values. Muscle collagen level was negatively correlated with breast muscle weight and pH. Correlation between collagen and glycogen content was positive and significant.

Figure 1 shows the decline in muscle pH with increments in H:L. The linear regression equation for this correlation was

$$pH = 6.03 - 0.21\ H{:}L.$$

Second-order polynomial coefficients were found to be significant for H:L effect on breast muscle L* values. The regression equation was

$$L^* = 48.74 - 0.55\ H{:}L + 10.15\ H{:}L^2.$$

Blood glucose effect on breast muscle pH could be explained by a second-order polynomial equation (Figure 2). The equation was

$$pH = 5.81 + 0.0026\ \text{blood glucose} - 0.00001\ \text{blood glucose}^2.$$

Linear regression was found to be significant for the effect of blood glucose on b* value. The equation was

$$b^* = 1.37 + 0.015\ \text{blood glucose}.$$

The b* value of breast meat was also affected by blood albumin level in a second-order polynomial regression manner (Figure 3). The equation was

$$b^* = 13.77 - 18.97\ \text{blood albumin} + 8.74\ \text{blood albumin}^2$$

## DISCUSSION

Diurnal cyclic temperature of 28–22°C had no effect on BW up to 5 wk of age. The BW of broilers from the 28–22°C group decreased by 5 and 9.9% at 6 and 7 wk of age compared with the control group. The effect of heat stress (34°C constant temperature) on the BW of broilers increased with age. Heat-stressed broilers at 34°C had 2.6, 5.5, 12.4, and 19.9% lighter BW at 4, 5, 6, and 7 wk of age than the broilers from the control group. This reduction in the BW of broilers from the 34°C group is similar to the results obtained by Yunis and Cahaner (1999) and Yalçın et al. (1997). This result may be explained by the difficulty in dissipating high internal heat under high ambient temperatures, which leads to decreased food intake (Yunis and Cahaner, 1999). Indeed, from 3 to 7 wk, feed intake of the 34°C group was lower than the control group. Furthermore, there were no significant differences in the feed intake of broilers from different groups at 4 and 5 wk of age; however, at 6 and 7 wk of age, birds from the 28–22°C and 34°C groups consumed an average of 18 and 41 g/bird per day less feed (data not shown). Broilers reared at 34°C exhibited a significant decrease in carcass and breast yield. These

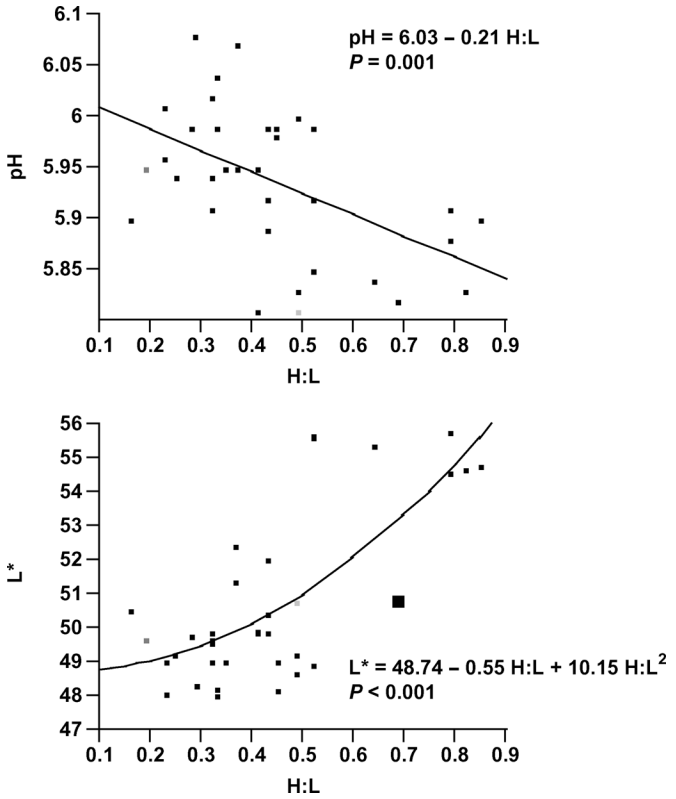


**Figure 1.** Linear and polynomial regressions between the heterophil:lymphocyte (H:L) and breast muscle pH (top) and lightness (L*) value (bottom), respectively

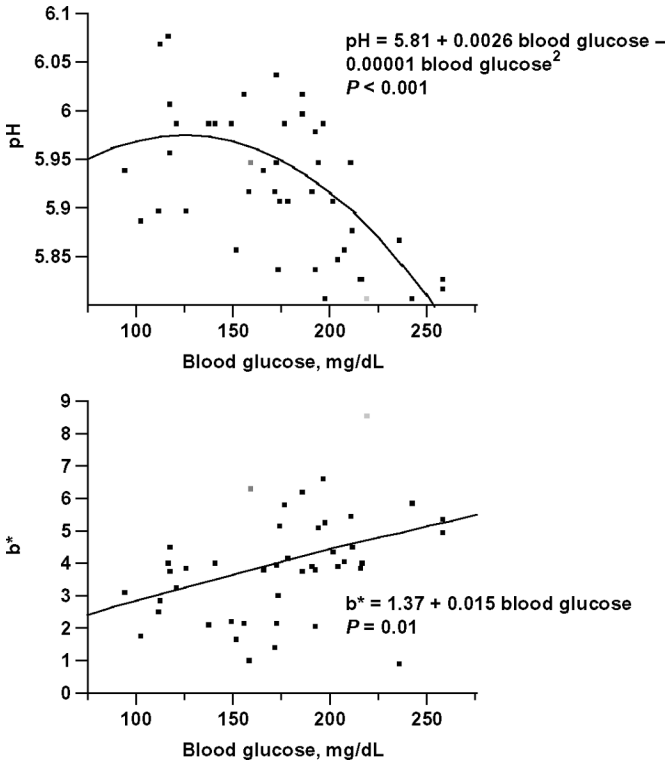


**Figure 2.** Polynomial and linear regression between blood glucose and breast muscle pH (top) and yellowness (b*) value (bottom), respectively

results agree with those reported by Mendes et al. (1997) and Yunis and Cahaner (1999).

Plasma levels of glucose and albumin increased by high ambient temperature during rearing and, no dramatic change in levels occurred when heat-stressed broilers were crated at 34°C. However, the increase in H:L for the broilers crated at 34°C, either from control or heat-stress rearing, were remarkable. The H:L is a sensitive indicator of stress, and 0.2, 0.5, and 0.8 characterize low, optimum, and high levels of stress, respectively (Gross and Siegel, 1983). In the present study, the H:L ratio was 0.58 for the broilers reared at 34°C, being higher than those broilers reared at control temperature. This indicates a moderate effect of heat stress. However, 2 h after crating at 34°C, H:L was increased to 0.81 for the 34–34°C and control–34°C broilers. This result indicated that crating at high temperatures increased stress level, regardless of broiler rearing temperature. Crating broilers at 22 or 15°C did not result in changes in H:L, indicating that crating temperature has a significant effect on the stress status of broilers. Rearing and crating temperatures did not influence the duration of TI. Yalçın et al. (2003) obtained longer TI duration in broilers heat-stressed from 21 to 42 d. This difference may probably be due to the age of the fear measurements.

Breast muscle glycogen level decreased when broilers were reared under diurnal cyclic or high temperatures. Although, the differences in values before and after crating were not statistically analyzed in the present study, crating also decreased muscle glycogen level (0.132 mg/g vs. 0.0985 mg/g before and after crating, respectively). The results may suggest that the decrease in muscle glycogen by crating was not more pronounced when broilers were crated at 22°C.

Tankson et al. (2001) reported that adrenocorticotropin and heat treatment caused reductions in carcass protein

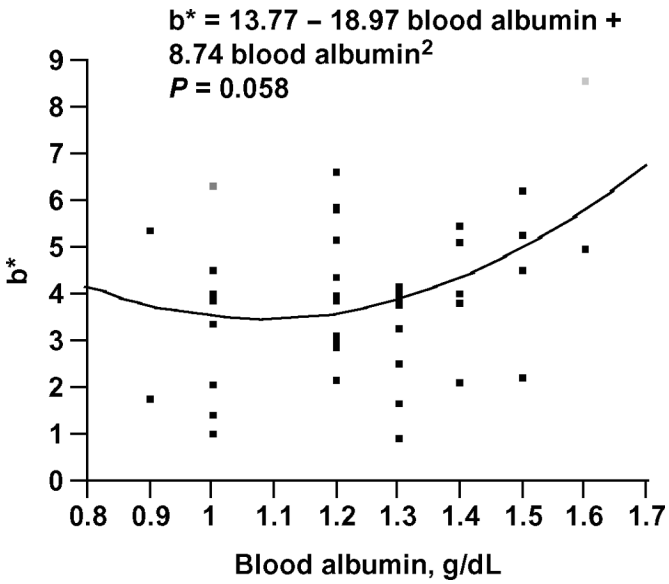


**Figure 3.** Polynomial regressions between blood albumin and breast muscle yellowness (b*) value

**Table 5.** Correlation coefficients among traits[1]

| | Blood stress parameters | | | | | Muscle traits | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | H:L | Glucose | Albumin | Uric acid | TI | pH | L* | a* | b* | Glycogen | Collagen |
| Blood glucose | 0.359* | — | — | — | — | — | — | — | — | — | — |
| Blood albumin | 0.137 | 0.215 | — | — | — | — | — | — | — | — | — |
| Blood uric acid | 0.232 | 0.294* | –0.077 | — | — | — | — | — | — | — | — |
| TI | 0.008 | –0.243 | –0.379* | –0.133 | — | — | — | — | — | — | — |
| pH | –0.557*** | –0.580*** | 0.142 | –0.169 | –0.034 | — | — | — | — | — | — |
| L* | 0.665*** | 0.326* | 0.243 | 0.027 | –0.192 | –0.562*** | — | — | — | — | — |
| a* | 0.213 | 0.344* | 0.059 | –0.039 | 0.078 | –0.374** | 0.436** | — | — | — | — |
| b* | –0.144 | 0.399** | 0.293* | 0.028 | –0.158 | –0.103 | 0.041 | 0.042 | — | — | — |
| Glycogen | 0.262 | –0.106 | –0.255 | 0.033 | –0.183 | 0.159 | 0.136 | 0.069 | 0.079 | — | — |
| Collagen | 0.227 | –0.391 | –0.060 | –0.140 | –0.104 | 0.280* | 0.143 | 0.121 | –0.203 | 0.391** | — |
| Breast weight | –0.311* | 0.128 | –0.234 | –0.027 | 0.151 | 0.132 | –0.399** | 0.002 | 0.047 | 0.087 | –0.289* |

[1]TI = tonic immobility; L* = lightness; a* = redness; b* = yellowness; H:L = heterophil:lymphocyte.

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

content, whereas adrenocorticotropin, but not heat, reduced carcass moisture. In the present experiment, chronic (during rearing) and acute (during crating) heat stress decreased moisture levels in breast meat of broilers. Broilers reared and crated at 34°C had the lower muscle protein levels than those reared and crated at control temperatures. However, this effect seems more due to the rearing temperatures, not due to the high crating temperatures. The control–34°C broilers had similar protein levels to the control–22°C and to 34–34°C broilers. Lower protein levels obtained for breast meat of broilers from control–15°C indicated that cold crating temperature had significant effect on muscle protein levels. No significant differences were found for muscle collagen content. Because collagen stability may explain tenderness of meat, we may conclude that heat stress had no effect on breast tenderness.

A lower pH and higher L* and a* values and a*:b* were found in meat for broilers from both 34°C and 34–34°C groups. This result agreed with the results obtained in heat-stressed turkeys by McKee and Sams (1997) and showed that accelerated rate of growth postmortem glycolysis changed muscle color (McKee and Sams, 1997; Pietrzak et al., 1997). The results suggested that crating at 22°C or 15°C did not result in a change in pH, L*, and a* values, and rearing at high temperatures had a more dramatic effect on meat quality parameters than crating at high temperatures.

There was no correlation between breast muscle weight and pH, which confirms LeBihan-Duval et al. (1999). Higher breast weight was associated with lower L* values, collagen content, and H:L. Lower ultimate pH values were associated with higher L* values. Similar results have been reported previously (Barbut, 1997; LeBihan-Duval et al., 1999; Yalçın et al., 2005).

The results showed that muscle pH changed linearly by increments in H:L values, whereas increments in blood glucose resulted in a change in a quadratic manner in pH. The L* and b* values of breast muscle were increased according to a second polynomial regression by increments in H:L, and blood albumin level, respectively. Duration of TI did not associate with meat quality parameters, which was consistent with the results obtained by Debut et al. (2003).

In conclusion, results of these experiments showed that high ambient temperature during rearing and crating had adverse effects on meat quality. However, crating temperature effect was not as dramatic as that observed for rearing temperature effect. Stress parameters associated with meat quality traits, whereas duration of TI did not correlate with meat quality.

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