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Effects of heat conditioning and dietary ascorbic acid supplementation on growth performance, carcass and meat quality characteristics in heat-stressed broilers

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Summary: This study was conducted to investigate the effects of heat conditioning and dietary ascorbic acid supplementation on growth performance, carcass and meat quality characteristics in heat-stressed broilers. A total of 320 male broilers were randomly assigned to 4 treatment groups as positive control (PC), heat stress (HS), heat conditioning (HC) and ascorbic acid supplementation (AA). Broilers in PC group were housed in thermoneutral conditions (24^{o}C) and fed with the basal diet throughout experimental period. Heat stress group was exposed to 35^{o}C for 6 h daily between 4 and 6 weeks and fed with basal diet throughout experimental period. Heat conditioned group was exposed to 36^{o}C at 5 d of age for 24 h, fed on the basal diet throughout experimental period and was exposed to 35^{o}C for 6 h daily between 4 and 6 weeks. Ascorbic acid supplemented group was fed a diet supplemented with 500 mg/kg L-ascorbic acid and was exposed to 35^{o}C for 6 h daily between 4 and 6 weeks. Heat stress significantly decreased final body weight, weight gain ($P<0.001$), feed consumption, carcass yields ($P<0.01$), but increased feed conversion ratio and mortality rate ($P<0.05$). Heat stress decreased redness ($P<0.001$) and ultimate pH value ($P<0.05$), whereas increased lightness and cooking loss ($P<0.001$) of broiler breast meat. Heat conditioning and AA supplementation increased final body weight, weight gain, carcass yield and also improved quality characteristics of breast meat of broilers under heat stress. These results suggest that HC and dietary AA supplementation may alleviate the negative effects of heat stress on broiler performance and meat quality.

Key words: Ascorbic acid, broiler, heat conditioning, heat stress, meat quality, performance.

Sıcak stresi altındaki broylerlerde erken dönem sıcağa alıştırma ve rasyona askorbik asit ilavesinin büyüme performansı karkas ve et kalite özellikleri üzerine etkileri

Özet: Bu araştırma, sıcak stresi altındaki broylerlerde erken dönem sıcağa alıştırma ve rasyona askorbik asit ilavesinin büyüme performansı, karkas ve et kalite özellikleri üzerine etkilerini araştırmak için yapılmıştır. Toplam 320 adet erkek broyler pozitif kontrol (PC), sıcak stresi (HS), erken dönem sıcağa alıştırma (HC) ve askorbik asit ilave edilen rasyonla besleme (AA) olmak üzere dört gruba ayrılmıştır. PC grubundaki broylerler deneme süresince termonötral koşullarda (24^{o}C) yetiştirilmiş ve bazal rasyonla beslenmiştir. HC grubu, 5 günlük yaşta 24 saat 36^{o}C'ye maruz bırakılmış, deneme süresince bazal rasyonla beslenmiş ve 4-6. haftalar arasında günde 6 saat 35^{o}C sıcaklığa maruz bırakılmıştır. AA grup, 500 mg/kg L-askorbik asit ilave edilen rasyonla beslenmiş ve 4-6. haftalar arasında günde 6 saat 35^{o}C sıcaklığa maruz bırakılmıştır. HS grubundaki broilerler, 4-6. haftalar arasında günde 6 saat 35^{o}C sıcaklığa maruz bırakılmış ve deneme süresince bazal rasyonla beslenmiştir. Sıcak stresinin final canlı ağırlık, ağırlık kazancı ($P<0.001$), yem tüketimi, karkas randımanını ($P<0.01$) azalttığı, buna karşın yemden yararlanma oranı ve ölüm oranını artırdığı ($P<0.05$) belirlenmiştir. Sıcak stresi, broiler göğüs etinin kırmızılık renk indeksi ($P<0.001$) ve kesimden 24 saat sonra ölçülen pH değerini ($P<0.05$) azaltırken, parlaklık renk indeksi ve pişirme kaybını arttırmıştır ($P<0.001$). Erken dönem sıcağa alıştırma ve rasyona askorbik asit ilavesinin, sıcak stresi altındaki broylerlerde final canlı ağırlık, ağırlık kazancı, karkas randımanında artışa ve et kalitesinde iyileşmeye neden olduğu belirlenmiştir. Bu bulgular, erken dönem sıcağa alıştırma ve rasyona askorbik asit ilavesinin, sıcak stresinin broyler performansı ve et kalitesi üzerindeki negatif etkilerini önleyebileceğini göstermektedir.

Anahtar sözcükler: Askorbik asit, broyler, et kalitesi, sıcağa alıştırma, sıcak stresi, performans.

Introduction

High ambient temperature is known as one of the major problems in broiler production especially in tropical and subtropical areas (10). Heat stress adversely affects feed intake, body weight, carcass characteristics and other traits associated with successful production and is the major cause of mortality in broilers reared in tropical environments (21). High environmental temperature affects meat quality by altering the physiology and metabolism of muscle (20, 28). It has been determined that cyclic high temperature induces oxidation stress of pectoralis major, lower pH, denatured muscle protein and high drip loss, L^* value (lightness) and shear force in broilers (15).

Early age heat conditioning has been proposed as a technique to reinforce resistance of broiler chickens to heat stress during the finishing period (37). Ascorbic acid can be synthesized by poultry and it is not required to be supplemented to the diet under normal conditions. However, ascorbic acid supplementation might be beneficial for the performance of broilers, when they are challenged with stressors (26). High environmental temperature, may increase the requirement of ascorbic acid, decrease the biosynthesis of this vitamin and affect the endocrine system responsible for the retention and proper metabolic functioning of this vitamin (21). Ascorbic acid is one of the most important antioxidants in biological system and the supplementation of ascorbic acid is relevant to the maintenance of redox balance in heat stressed broilers (23). Dietary ascorbic acid supplementation has been reported to have positive effects on growth performance, feed intake and feed efficiency in broilers under heat stress (7, 33). However, there is limited information about the effects of heat conditioning and dietary ascorbic acid supplementation on meat quality characteristics in broilers under heat stress conditions.

The objective of this study was to evaluate the effects of heat conditioning and dietary ascorbic acid supplementation on growth performance, carcass and meat quality characteristics in heat-stressed broilers.

Materials and Methods

Animals and experimental design: This study was approved by local ethic committee of Adnan Menderes University (Approval No:64583101/2013/045). A total of 320 male broilers (Ross 308) obtained from a commercial hatchery were used in this study. One-day-old broilers were wing-banded, weighed and then they were randomly assigned to 4 treatment groups as positive control (PC), heat stress (HS), heat conditioning (HC) and ascorbic acid supplementation (AA). Each group consisted of 4 replicates of 20 broilers per pen. The broilers of each group were placed in a separate room and they were housed in floor pens covered with wood shavings in windowed poultry house. The size of pen was 110x150 cm. Until the 3 weeks, all broilers were raised at comfort temperature. The brooding temperature was maintained at approximately 32^{o}C for the first 3 days and then decreased 3^{o}C weekly until 21 days. From 4th weeks until the end of the experiment (6 weeks of age), the broilers in PC group were raised in thermo neutral conditions and fed with the basal diet. The other 3 groups were exposed to heat stress in this period. Heat stress was applied exposing the broilers to a temperature of 35^{o}C for 6 hours/day from 10:00 to 16:00 h. The broilers in HS group were exposed to heat stress in the period of 4 to 6 weeks of age and fed with basal diet throughout experimental period. The broilers in HC group was exposed to a temperature of 36^{o}C for 24 h at the age of 5 days; fed with basal diet throughout experimental period and was exposed to heat stress in the period from 4 to 6 weeks of age. The broilers in AA group were fed a diet supplemented with 500 mg of L-ascorbic acid /kg ration and were exposed to heat stress in the period from 4 to 6 weeks of age. Average temperature was 24^{o}C and relative humidity was 56% for PC group. Average temperature was 35^{o}C from 10:00 to 16:00 h and was 24^{o}C from 16:00 to 10:00 h, relative humidity was 64% for HC, AA and HS groups. Heating of poultry house was supplied with electrical heaters. Water was provided *ad libitum* to all groups throughout the experimental period. Continuous lighting schedule of 24 hours was provided throughout the experimental period. Broilers were fed with a starter diet from 0 to 21 days of age (3060 kcal ME/kg, 23% crude protein) and grower diet from 22 to 42 days of age (3200 kcal ME/kg, 21.5% crude protein). The compositions of basal diets used in starter and grower periods of the experiment are presented in Table 1.

Table 1. Composition of basal diets and calculated nutrient content.
Tablo 1. Bazal rasyonların kompozisyonu ve hesaplanan besin madde içeriği.

Ingredients (%)	Starter diet (0-21 d)	Grower diet (22-42 d)
Vegetable oil	1.42	3.04
Corn	53.58	55.46
Soybean meal	27.00	23.00
Full-fat soybean	14.00	15.00
Di calcium phosphate (DCP)	1.80	1.30
DL-methionine	0.20	0.10
Ground limestone	1.30	1.50
L-lysine hydrochloride	0.10	0
Salt	0.35	0.35
Vitamin-mineral premix[1]	0.25	0.25
Calculated chemical analyses		
Crude protein, %	23.00	21.50
ME, kkal/kg	3060	3200
Calcium, %	0.97	0.90
Total phosphor, %	0.44	0.35
Lysine, %	1.33	1.16
Methionine + cystine, %	0.92	0.78

[1]: Vitamin-mineral premix contains followings for per 2.5 kg diet: 12000000 IU vitamin A, 3000000 IU Vitamin D_3, 30 g Vitamin E, 3.75 g vitamin K_3, 3 g vitamin B_1, 6 g vitamin B_2, 5 g vitamin B_6, 20 mg vitamin B_{12}, 40 g niacin, 10 g Ca-D-panthotenate, 1 g folic acid, 50 mg D-biotin, 500 g choline chloride, 80 g Mn, 60 g Fe, 60 g Zn, 5 g Cu, 0.5 g Co, 1 g I, 0.15 g Se

Performance parameters: Mortality was recorded daily and mortality rate was calculated for the periods from 0 to 3 weeks, from 4 to 6 weeks and from 0 to 6 weeks. All broilers were weighed individually at hatch and thereafter weekly until 6 weeks of age. Feed consumption was measured weekly. Feed conversion ratio was calculated as the ratio of feed consumption to body weight gain. Cumulative body weight gain, cumulative feed consumption and feed conversion rate per bird were calculated for the periods from 0 to 3 weeks, from 4 to 6 weeks and from 0 to 6 weeks.

Carcass and meat quality measurements: At 42 days of age, five broilers whose body weights were close to the group average were selected from each pen and they were slaughtered to determine carcass and meat quality characteristics after 12 h of feed withdrawal. Hot and cold carcass weights were determined. Cold carcass weights were recorded after the carcasses were stored at +4^{o}C for 24 h. Hot and cold dressing percentages were expressed as the percentages of body weight at slaughter. Each carcass was cut into five parts as breast, thigh, wing, neck and back according to the chicken cut technique of TSE (5) and then they were weighed. Carcass parts yield were expressed as the percentage of cold carcass weight.

Breast muscles and thigh muscles were used to determine meat quality characteristics. pH of meat was measured 15 min postmortem (pH_{15}) and 24 h after slaughter using a digital pH meter (Testo 205). Muscle color was measured on the surface on left breast and thigh muscles 24 h after slaughter. Color measurement was performed using a Minolta CR 400 chroma-meter (Konica Minolta Sensing, Inc., Osaka, Japan) in the CIELAB color space using a D65 illuminant, in which L^* indicates relative lightness, a^* indicates relative redness and b^* represents relative yellowness. Three pH and color measurements were taken for each sample. Cooking loss was determined in meat samples placed inside polyethylene bags in a water bath. Samples were heated until an internal temperature of 75^{o}C and cooled for 15 min under running tap water. They were taken from the bags, dried with filter paper and weighed. Cooking loss was expressed as the percentage of loss related to the initial weight (17).

Statistical analysis: Chi square test was performed for the statistical analysis of mortality rate (35). The growth performance, carcass and meat quality characteristics were analyzed by one-way analysis of variance using SPSS 13.0 packed program (34). Significant differences among treatment means were determined using Duncan's multiple range test (12).

Results

In the present study, no mortality was recorded in HC group at the age of 5 days and there were no significant differences among groups in terms of mortality rate in the period from 0 to 3 weeks of age (X^2 = 1.009). However, there were significant differences among treatment groups in terms of mortality rate in the periods from 4 to 6 weeks of age (X^2 = 11.21, P<0.05) and from 0 to 6 weeks of age (X^2 = 10.00, P<0.05). The highest mortality rate was recorded for HS group with 10.13%, followed by HC group (3.80%) and AA group (2.50%) from 4 to 6 weeks of age. However, no mortality was observed in PC group in this period. The mortality rates in the period from 0 to 6 weeks of age were 11.25%, 5%, 2.5% and 1.25% for HS, HC, AA and PC groups, respectively.

Weekly body weight gains of broilers in PC, HS, HC and AA groups are presented in Figure 1. There were no significant differences among groups in terms of weekly body weight gain in the period from 0 to 3 weeks of age. However, significant variations among groups were observed after 4th week. In weeks 5 and 6, the highest weight gain was recorded for broilers in PC group and the difference between PC and HS groups in terms of this trait was statistically significant (P<0.05). Body weight gain of broilers in HC and AA groups in these weeks was higher than those in HS group, but the differences were not statistically significant. Weekly feed consumption and feed conversion ratio of broilers in PC, HS, HC and AA groups are shown in Figure 2 and Figure 3. No significant differences were observed among groups in terms of weekly feed conversion ratio throughout experimental period. Weekly feed consumption was not statistically significant among groups in the period from 0 to 3 weeks of age. In weeks 4, 5 and 6, feed consumption was significantly higher for broilers in PC group, compared with HS group (P<0.05). HC group had significantly higher feed consumption than HS group in weeks 4th and 5th. However, the difference among AA and HS groups was not statistically significant.

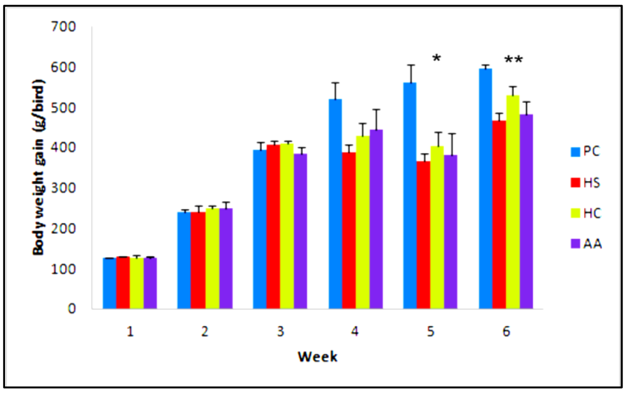

Figure 1. Weekly body weight gain of broilers in positive control, heat stress, heat conditioned and ascorbic acid supplemented groups (g/bird).
Şekil 1. Pozitif kontrol, sıcak stres, erken dönem sıcağa alıştırılan ve askorbic asit ilave edilen yemle beslenen gruplardaki broylerlerin haftalık canlı ağırlık artışları (g/broyler).
PC: Positive control, HS: Heat stress, HC: Heat conditioning
AA: Ascorbic acid supplementation.
*: P<0.05, **: P<0.01

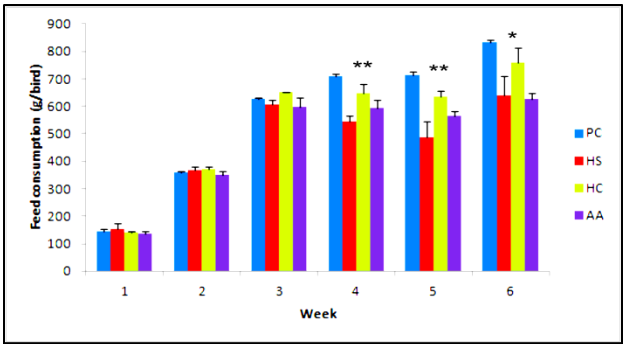

Figure 2. Weekly feed consumption of broilers in positive control, heat stress, heat conditioned and ascorbic acid supplemented groups (g/bird).
Şekil 2. Pozitif kontrol, sıcak stres, erken dönem sıcağa alıştırılan ve askorbic asit ilave edilen yemle beslenen gruplardaki broylerlerin haftalık yem tüketimi (g/broyler).
PC: Positive control, HS: Heat stress, HC: Heat conditioning
AA: Ascorbic acid supplementation.
*: P<0.05, **: P<0.01

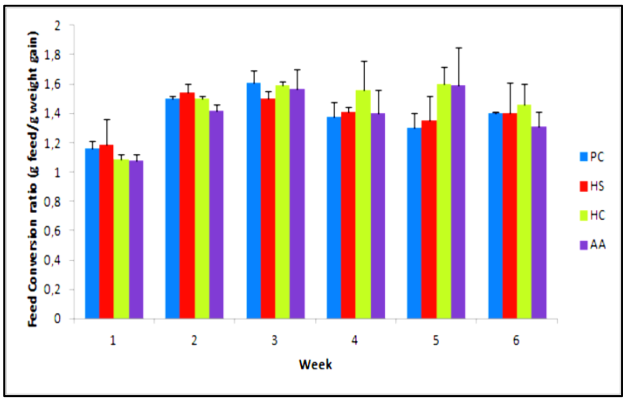

Figure 3. Weekly feed conversion ratio of broilers in positive control, heat stress, heat conditioned and ascorbic acid supplemented groups (g feed/g weight gain).
Şekil 3. Pozitif kontrol, sıcak stres, erken dönem sıcağa alıştırılan ve askorbic asit ilave edilen yemle beslenen gruplardaki broylerlerin haftalık yemden yararlanma oranı (g yem/g ağırlık kazancı).
PC: Positive control, HS: Heat stress, HC: Heat conditioning,
AA: Ascorbic acid supplementation.

Table 2. Initial and final body weight, cumulative body weight gain, feed consumption and feed conversion ratio of broilers.
Tablo 2. Broylerlerin başlangıç ve besi sonu canlı ağırlık, kümülatif ağırlık kazancı, yem tüketimi, yemden yararlanma oranı değerleri.

Traits[1]	Treatments[2]								Significance
	PC		HS		HC		AA		
	n		*n*		*n*		*n*		
Initial body weight (g)	80	47.33 ± 0.38	80	47.12 ± 0.44	80	47.36 ± 0.37	80	46.10 ± 0.40	ns
Final body weight (g)	79	2487.8 ± 23.21^{a}	71	2049.4 ± 15.90^{d}	76	2196.3 ± 18.27^{b}	78	2111.8 ± 21.15^{c}	***
Body weight gain (g/chick)									
0 to 3 weeks	4	764.9 ± 20.65	4	782.3 ± 15.17	4	786.7 ± 13.89	4	760.3 ± 4.85	ns
4 to 6 weeks	4	1676.1±17.18^{a}	4	1220.0 ± 26.32^{c}	4	1363.5 ± 16.68^{b}	4	1308.7 ± 30.77^{b}	***
0 to 6 weeks	4	2441.0 ± 35.53^{a}	4	2001.8 ± 24.03^{c}	4	2149.4 ± 22.48^{b}	4	2067.1 ± 33.46^{bc}	***
Feed consumption (g/chick)									
0 to 3 weeks	4	1133.2 ± 14.18	4	1127.0 ± 26.06	4	1163.7 ± 13.72	4	1086.2 ± 37.59	ns
4 to 6 weeks	4	3056.8 ± 22.94^{a}	4	2693.3 ± 90.36^{b}	4	2802.2 ± 96.43^{b}	4	2587.6 ± 32.80^{b}	**
0 to 6 weeks	4	4190.0 ± 25.03^{a}	4	3820.4 ± 70.91^{bc}	4	3965.9 ± 96.04^{b}	4	3673.8 ± 22.45^{c}	***
Feed conversion ratio (g feed/g gain)									
0 to 3 weeks	4	1.49 ± 0.04	4	1.45 ± 0.05	4	1.48 ± 0.02	4	1.43 ± 0.05	ns
4 to 6 weeks	4	1.82 ± 0.01^{b}	4	2.21 ± 0.12^{a}	4	2.06 ± 0.07^{ab}	4	1.98 ± 0.04^{ab}	*
0 to 6 weeks	4	1.72 ± 0.02^{c}	4	1.91 ± 0.05^{a}	4	1.85 ± 0.04^{ab}	4	1.78 ± 0.03^{bc}	*

[1]: Initial and final body weights measured as individually, Body weight gain, feed consumption and feed conversion ratio was calculated on a pen basis.
n represents the number of broiler in each group for initial and final body weights, whereas the number of pen in each group for body weight gain, feed consumption and feed conversion ratio.
[a, b, c:] Mean values within a row with no common superscript differ significantly (P<0.05).
ns: non significant *: P<0.05 **: P<0.01 ***: P<0.001
[2]PC: Positive control (This group was housed in thermoneutral conditions (24^{o}C) and fed with the basal diet). HS: Heat stress (This group was exposed to 35^{o}C for 6 h daily from 4 to 6 wk and fed with basal diet) HC: Heat conditioning (This group was exposed to 36^{o}C at 5 d of age for 24 h, fed with basal diet and was exposed to 35^{o}C for 6 h daily from 4 to 6 wk). AA: Ascorbic acid supplementation (This group was fed a diet supplemented with 500 mg/kg L-ascorbic acid and was exposed to 35^{o}C for 6 h daily from 4 to 6 wk).

Initial and final body weight, cumulative body weight gain, feed consumption and feed conversion ratio of broilers in the periods are summarized in Table 2. There were no significant differences among groups in terms of initial body weight, cumulative body weight gain, feed consumption and feed conversion ratio in the periods from 0 to 3 weeks of age. Heat stress significantly decreased final body weight, body weight gain (P<0.001), cumulative feed consumption (P<0.01), but significantly increased feed conversion ratio (P<0.05) in the periods from 4 to 6 weeks of age and from 0 to 6 weeks of age. The broilers in HS group had significantly lower final body weight and body weight gain from 4 to 6 weeks of age than those in HC and AA groups and had significantly lower body weight gain from 0 to 6 weeks of age than HC group (P<0.001). There were no significant differences between HS and HC groups and between HS and AA groups in terms of cumulative feed consumption in the periods from 3 to 6 weeks of age and from 0 to 6 weeks of age.

Hot and cold carcass yields, the percentages of carcass parts and internal organs are shown in Table 3. Heat stress significantly influenced the carcass characteristics and the percentages of internal organs of broilers. Hot (P<0.001) and cold carcass (P<0.01) yields, the percentages of breast (P<0.001) and abdominal fat (P<0.05) were significantly lower, whereas the percentages of neck (P<0.01), wings, back, liver (P<0.05) and gizzard (P<0.001) were significantly higher in HS group than those in PC group. HC and AA supplementation improved hot and cold carcass yields and abdominal fat yield of broilers exposed to heat stress.

Some meat quality characteristics measured on breast and thigh meat of broilers are summarized in Table 4. There were significant differences among treatment groups in terms of quality characteristics of breast and thigh meat. Initial (P<0.001) and ultimate pH values (P<0.05) of breast and thigh meat of broilers in HS group were lower compared with those in PC group. The L^*value of breast (P<0.001) and thigh meat (P<0.05) of broilers in HS group were significantly higher, whereas a^* value of breast (P<0.001) and thigh meat (P<0.05) were lower, compared with PC group. Cooking loss of breast (P<0.001) and thigh meat (P<0.01) of broilers in heat stress group were higher than those in PC group.

Discussion and Conclusion

Heat stress significantly increased the mortality rate of broilers in the period from 4 to 6 weeks of age. Heat conditioning and AA supplementation relieved the negative effects of heat stress on viability of broilers. It has been reported that the lower mortality of heat conditioned broilers may be due to better ability to maintain body temperatures (37). Yalcin et al. (38) also recorded the lower mortality rate for broilers exposed to 36°C at 5 days of age than those in control group under heat stress conditions. Decreased mortality with dietary AA supplementation may be due to the fact that AA

Table 3. Hot and cold carcass yields, the percentages of carcass parts and internal organs of broilers (%).
Tablo 3. Broylerlerin sıcak ve soğuk karkas randımanı, karkas parça ve iç organ oranları (%).

Traits	Treatments[1]				Significance
	PC	HS	HC	AA	
Hot carcass yield	76.93±0.37 [a]	74.28±0.35 [c]	76.44±0.40[ab]	75.59±0.26 [b]	***
Cold carcass yield	74.22±0.35[a]	71.82±0.59[b]	73.64±0.42[a]	73.03±0.31[ab]	**
[2]The percentage of carcass parts					
Breast	35.28±0.41[a]	32.05±0.61[b]	33.51±0.54[b]	32.35±0.59[b]	***
Thigh	28.94±0.43	29.62±0.49	29.18±0.51	30.02±0.40	**ns**
Wings	11.03±0.19[b]	11.76±0.26[a]	11.59±0.21[ab]	11.92±0.20[a]	*
Back	16.97±0.39[b]	18.54±0.31[a]	17.61±0.32[ab]	17.42±0.49[ab]	*
Neck	5.85±0.13[b]	6.51±0.18[a]	6.40±0.15[a]	6.59±0.19[a]	**
Abdominal fat	1.91±0.13[a]	1.40±0.09[b]	1.71±0.14[ab]	1.58±0.13[ab]	*
[3]The percentage of internal organs					
Heart	0.47±0.01	0.43±0.02	0.43±0.02	0.44±0.01	**ns**
Liver	1.78±0.05[b]	1.95±0.07[a]	1.72±0.07[b]	1.70±0.04[b]	*
Gizzard	1.26±0.05[c]	1.81±0.09[a]	1.40±0.07[bc]	1.55±0.06[b]	***

[1]PC: Positive control (This group was housed in thermoneutral conditions (24°C) and fed with the basal diet). HS: Heat stress (This group was exposed to 35°C for 6 h daily from 4 to 6 wk and fed with basal diet) HC: Heat conditioning (This group was exposed to 36°C at 5 d of age for 24 h, fed with the basal diet and was exposed to 35°C for 6 h daily from 4 to 6 wk). AA: Ascorbic acid supplementation (This group was fed a diet supplemented with 500 mg/kg L-ascorbic acid and was exposed to 35°C for 6 h daily from 4 to 6 wk).

[2]: The percentage of carcass parts weights to cold carcass weight

[3]: The percentage of internal organ weights to pre slaughter live weight

[a, b, c:] Mean values within a row with no common superscript differ significantly (P<0.05). n = 20

ns: non significant *: P<0.05 **: P<0.01 ***: P<0.001

Table 4. Some meat quality characteristics measured on breast and thigh meat of broilers.
Tablo 4. Broylerlerin göğüs ve but etinden ölçülen bazı et kalite özellikleri.

Traits	Treatments[1]				Significance
	PC	HS	HC	AA	
Breast					
pH_{15}	6.33±0.04^{a}	6.05±0.03^{c}	6.22±0.05^{ab}	6.16 ±0.04^{bc}	***
pH_{24}	5.94±0.06^{a}	5.68±0.06^{b}	5.91±0.07^{a}	5.73±0.09^{ab}	*
L^*	50.64±0.45^{c}	56.79±0.71^{a}	52.80±0.50^{b}	53.58±0.42^{b}	***
a^*	5.12±0.14^{a}	3.93±0.15^{b}	4.85±0.24^{a}	4.20±0.26^{b}	***
b^*	3.81±0.11	4.19±0.13	3.77±0.10	4.04±0.16	**ns**
Cooking loss (%)	21.59±0.59^{c}	30.04±0.99^{a}	23.92±0.83^{b}	24.31±0.57^{b}	***
Thigh					
pH_{15}	6.54±0.03^{a}	6.21±0.05^{c}	6.45±0.05^{ab}	6.39±0.04^{b}	***
pH_{24}	6.29±0.04^{a}	5.97±0.06^{c}	6.19±0.06^{ab}	6.12±0.05^{b}	***
L^*	48.41±1.56^{b}	55.33±1.22^{a}	50.66±1.23^{b}	52.04±1.67^{ab}	*
a^*	12.96±0.76^{a}	10.13±0.64^{b}	11.01±0.61^{ab}	12.56±0.67^{a}	*
b^*	5.41±0.61	5.33±0.60	6.00±0.38	7.05±0.52	**ns**
Cooking loss (%)	28.56±0.89^{c}	34.83±1.45^{a}	32.02±0.92^{ab}	31.60±0.61^{b}	**

[1]PC: Positive control (This group was housed in thermoneutral conditions (24°C) and fed with the basal diet). HS: Heat stress (This group was exposed to 35°C for 6 h daily from 4 to 6 wk and fed with basal diet) HC: Heat conditioning (This group was exposed to 36°C at 5 d of age for 24 h, fed with the basal diet and was exposed to 35°C for 6 h daily from 4 to 6 wk). AA: Ascorbic acid supplementation (This group was fed a diet supplemented with 500 mg/kg L-ascorbic acid and was exposed to 35°C for 6 h daily from 4 to 6 wk).
pH_{15}: Initial pH value measured at 15 min post mortem, pH_{24}: pH value measured at 24 h post mortem
[a, b, c:] Mean values within a row with no common superscript differ significantly ($P<0.05$). n = 20
ns: non significant *: $P<0.05$ **: $P<0.01$ ***: $P<0.001$

ameliorates stress inducing suppression of hormonal and cell mediated immunity and improves the response of chickens to cell-mediated immunity (16).

It has been well documented that heat stress causes to decrease in growth performance and feed consumption and to increase in feed conversion ratio of broilers (1, 3, 24, 31). In the current study, it was also determined that heat stress resulted in a decrease in final body weight and body weight gain of broilers in the periods from 4 to 6 weeks and from 0 to 6 weeks of age. This result may be explained by decreasing in feed consumption of broilers exposed to high ambient temperature for reducing metabolic heat production and maintaining homeothermy (2, 32). Indeed, the broilers in HS group consumed 11.89 % less feed than those in PC group in the period from 4 to 6 weeks of age. However, feed conversion ratio was higher in HS group than PC group in this period (P<0.05). Both HC and AA supplementation positively affected the growth performance of broilers exposed to heat stress. Heat conditioned group had significantly higher body weight gain during the periods from 4 to 6 weeks and from 0 to 6 weeks and higher final body weight at 42 days of age, compared with HS group (P<0.001). This finding supports the knowledge that early heat conditioning induces the heat tolerance of broiler chickens at later growth stage prior to marketing (23, 37). Similar results were obtained by El-Moniary et al. (13) and Yalçin et al. (39). Unlike our study, Liew et al. (22) reported that heat conditioning had no significant effect on growth performance of broilers subjected to heat stress. This difference between the studies could be attributed to the difference in heat conditioning protocol applied in the studies. In comparison with HS group, 500 mg/kg AA supplemented diet fed group had significantly higher final body weight and body weight gain in the period from 4 to 6 weeks of age (P<0.001). These findings indicate that AA supplementation alleviated the negative effect of heat stress on growth performance of broilers. This situation could be related to suppressive effects of AA on plasma corticosterone and adrenocorticotropic hormone (25, 33). With regard to the effects of dietary AA supplementation on body weight gain and final body weight of broilers under heat stress, the results obtained in this study are in agreement with previous literature reports (6, 7, 19, 23). There were no significant differences among HS, HC and AA groups in terms of cumulative feed consumption in the period from 4 to 6 weeks of age. Onu (29) also reported that 450 mg AA supplementation/kg ration did not affect feed consumption of broilers during the dry season. However, Sahin et al. (33) reported that 250 mg AA supplementation/ kg ration increased feed consumption of broilers reared under high temperature (32°C). Attia et al. (7) also determined that 250 mg AA supplementation/kg ration increased feed consumption of broilers exposed to 38°C for 4 h three days weekly. The differences between the studies in terms of feed consumption could be due to the differences in the conditions of the experiments and AA levels used in the studies. Ascorbic acid supplemented group had better feed conversion ratio, compared with HS group. This result is consistent with previous findings (7, 29, 33).

Broilers in HS group had significantly lower hot ($P<0.001$) and cold carcass ($P<0.01$) yields than those in PC group. This is not surprising, since the broilers in HS group had significantly lower final body weight than those in PC group. Heat stress significantly decreased breast yield ($P<0.001$) and abdominal fat yield ($P<0.05$) and indirectly caused to increase in wings, back ($P<0.05$) and neck yields ($P<0.01$). Similar to the current study, Akşit et al. (3) reported that heat stress caused to decrease in carcass and breast yields. In the present study, the percentage of heart was not influenced by heat stress; however, the higher percentages of liver and gizzard were obtained in HS group, compared with PC group. This result may be explained as an indirect effect of decreased carcass yield in broilers exposed to heat stress. Heat conditioning and AA supplementation improved hot and cold carcass yields and abdominal fat yield of broilers exposed to heat stress. Similarly, Sahin et al. (33) and Attia et al. (7) found that 250 mg AA supplementation/kg ration significantly increased carcass yield of broilers exposed to heat stress.

The pH value is one of the most important physical quality criteria of meat and it is widely used as a predictor of meat technological and sensory qualities. The pH value is a direct reflection of muscle acid content, and affects shear force, water holding capacity and color of meat (9, 14, 36). It has been reported that seasonal heat stress accelerates post mortem metabolism and biochemical changes in the muscle, which produces a faster pH decline, lower ultimate pH and higher lightness in turkey meat (27). In this study, it was also observed that heat stress significantly decreased initial and ultimate pH values measured on breast and thigh meat ($P<0.05$). This result is in agreement with previous literature reports (3, 9, 36, 40).

Color is another important parameter that determines quality of meat, which is related to pH, water holding capacity, shear force and chemical composition (4, 30). Breast and thigh muscles of the broilers in HS group had significantly higher lightness and lower redness, compared with those in PC group ($P<0.05$). Similar to the current study, Lu et al. (24) also reported the higher L^* value for the broilers reared at 34°C than those reared at 21°C.

Heat stress significantly influenced cooking loss of breast ($P<0.001$) and thigh meat ($P<0.01$). Cooking loss of breast and thigh meats of broilers in HS group was higher than that control group. This result may be due to the lower ultimate pH value of breast and thigh meat of broilers in HS group than PC group. It has been reported that low ultimate pH induces structural changes in the muscle with an impairment of the technological processing ability. Artificially acidified turkey meat induces restructuration of the myofibrillar network, which also cause to a marked decrease in water holding capacity (8, 11).

The results from the present study revealed that both HC and dietary AA supplementation resulted in significant improvement of meat quality parameters measured on breast and thigh meat in broilers subjected to heat stress. HC increased ultimate pH and redness, whereas decreased lightness and cooking loss of broiler breast and thigh muscles. Ascorbic acid supplementation also increased ultimate pH and decreased lightness and cooking loss of broiler breast and thigh meat and increased redness of thigh meat. Imik et al. (18) also reported that 250 mg AA supplementation/kg ration caused to decrease in L^* value and increase in a^* and b^* of the breast meat in quails exposed to 34°C for 8 hours/day from 08:00 to 16:00 h.

As a result of this study, heat stress had negative effect on growth performance, carcass and meat quality characteristics of broilers. Heat conditioning and dietary AA supplementation partly alleviated the negative effect of heat stress on these traits. The results from this study suggested that early HC and dietary AA supplementation should be taken into consideration as management technique to improve performance and meat quality in broilers under heat stress conditions.

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