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Effects of dietary curcumin and acetylsalicylic acid supplements on performance, muscle amino acid and fatty acid profiles, antioxidant biomarkers and blood chemistry of heat-stressed broiler chickens

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ABSTRACT

The objective was to investigate the effects of dietary curcumin and acetylsalicylic acid (ASA) on the performance and physiological responses of broiler chickens under chronic thermal stress. One hundred and sixty day-old male chicks (Ross 308) were divided equally into 4 groups (each contained 4 replicates). On the day 22 of age and thereafter, the first group (TN) was raised in a thermoneutral condition (23 ± 1 °C), while the second group (HS) was subjected to 8 h of thermal stress (34 °C) and both groups fed the basal diet with no supplements. The third (CR) and fourth (AS) groups were subjected to the same thermal stress conditions and fed curcumin-supplemented diet (100 mg curcumin kg^{-1} diet) and ASA-supplemented diet (1 g ASA kg^{-1} diet), respectively. Dietary treatment had a significant effect on ADFI ($P = 0.041$), average daily gain ($P = 0.013$) and final body weight ($P = 0.001$). The curcumin-supplemented had higher values for these measures compared with other experimental groups ($P < 0.05$). Also, the dietary curcumin supplement significantly increased the carcass yield as compared to the HS group ($P < 0.05$). Compared with the HS group, the dietary curcumin and ASA supplements decreased the concentration of malondialdehyde in the breast muscles ($P = 0.014$). Both dietary supplements exhibited a marked ability to restore the serum TAC, Na and K in heat-stressed broiler chickens. The current study reported a remarkable ability of curcumin supplement to restore the concentrations of poly-unsaturated fatty acids (PUFA) in the breast muscles of heat-stressed broilers, including α-linolinec acid and Docosahexaenoic acid ($P = 0.009$ and 0.001, respectively). It could be concluded that supplemental dietary curcumin or ASA enhanced growth performance and antioxidant biomarkers of heat-stressed broilers. Moreover, curcumin might be an effective dietary supplement to alleviate the adverse effect of chronic thermal stress on carcass yield and meat quality.

1. Introduction

Thermal stress is one of the major concerns in poultry production. Indeed, such stress does not only compromise health condition and welfare (Roushdy et al., 2018), but also adversely affects survival (Bogin et al., 1996), growth performance (Sahin and Kucuk, 2003), and product quality (El-Tarabany, 2016) in poultry. Oxidative stress occurs when this critical balance is missed because of excess reactive oxygen species (ROS), antioxidant depletion or both (Borisiuk and Zinchuk, 1995). The heat stress and the oxidative stress adversely affect the cellular structures, causing impairment of transcription, RNA processing, translation, oxidative metabolism, and membrane structure and function (Iwagami, 1996). Hormonal and metabolic changes, secretion of inflammatory markers (Etches et al., 2008), decrease in the level of antioxidants have also been reported in response to the thermal stress (Sahin et al., 2010).

The harmful impacts of high environmental temperatures on poultry production can be managed through housing design and cooling systems as well as a manipulation of feed formulations (Alagawany et al., 2017). Acetylsalicylic acid (ASA) is the active part of aspirin and well known as a classic antipyretic drug (Wu et al., 2016). Aspirin inhibits the biosynthesis of prostaglandins; consequently, may reset the hypothalamic thermostat (Truong et al., 2016). Supplementation of acetylsalicylic acid in poultry diets has been shown to improve

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production performance and physiological traits under heat stress conditions (Wu et al., 2015), though reports have been inconsistent (Mcdaniel and Parker, 2004). Although numerous studies have focused on the pharmacokinetics of ASA in birds (Poźniak et al., 2013) and their ability in treating inflammation in domestic fowl (Hocking et al., 2005), the data and information on the tolerance and side effects of salicylates in poultry are lacking.

Recently, the use of natural alternatives such as plant products to ameliorate the negative impacts of heat stress has been a constant objective in the modern poultry business. Curcumin [1,7-bis (4-hydroxy 3-methoxy phenyl)- 1,6-heptadiene-3,5-Dione; Diferulylmethane] is the active ingredient in the traditional herbal plant called Curcuma longa (Turmeric), which possesses an economic importance due to its peculiar rhizome (Goel et al., 2008). The curcumin is usually used as a dye and a food condiment because it exerts protective effects against oxidation, being capable of eliminating free radicals and, thus, protecting the cells against lipid peroxidation (Khan et al., 2012). Moreover, different clinical and experimental studies have proved that curcumin is a pharmacologically safe agent with many activities including antioxidant function (Khalil et al., 2012), anti-inflammatory (Griesser et al., 2011) and antimicrobial properties (Negi et al., 1999). However, the information related to the use of curcumin under heat stress conditions on performance and physiological responses of broiler chickens is limited and the earlier studies on the impact of AS supplementation in broiler diets resulted in inconsistent conclusions. Therefore, the present study was performed to elucidate the effects of dietary curcumin or ASA on the performance, carcass traits, muscle amino acids and fatty acid profiles as well as the blood chemistry and antioxidant activities in broiler chickens under chronic thermal stress conditions.

2. Materials and methods

This work was performed in accordance with the standards include animal ethical guidelines of the New Valley University, Egypt.

2.1. Birds, management and experimental design

One hundred and sixty day-old male chicks (Ross 308) were obtained from a local hatchery. The chicks were divided equally into 4 groups (each group contained 4 replicates) with 10 chicks in each pen replicate. The initial stocking density was 15 birds/m^2. The pens were provided with fresh wood shavings and feeding was *ad libitum* over the whole experimental period. The supplementary heat was provided by digital heating devices that maintaining a stable temperature. An automated Diesel Heater was used to provide the supplementary heat in each experimental group (Naganpuriya High Tech Farming Equipment; 220v50 Hz). Moreover, the temperature and relative humidity in each group were regularly checked by a sensitive thermohygrometer. All experimental groups were subjected to a stable brooding temperature (34 °C), which declined gradually to reach the comfort zone on the day 21 of age. On the day 22 of age and thereafter, the first group (TN) was raised in a thermoneutral condition (23 ± 1 °C) and fed the basal diet with no supplements. The second group (HS) was subjected to 8 h of thermal stress (34 °C and 58 ± 3% relative humidity; 08:00–16:00) and fed the basal diet with no supplements. The third group (CR) was subjected to the same thermal stress conditions and fed a curcumin-supplemented diet (100 mg curcumin kg^{-1} diet, which was purchased from Sigma–Aldrich, St. Louis, MO, USA). The fourth group (AS) was subjected to the same thermal stress conditions and fed an ASA-supplemented diet (1 g ASA kg^{-1} diet, which was purchased from Algomhoria CO., Egypt). When the heat-stressed groups were not subjected to heat stress, the thermoneutral environmental temperature (23 ± 1 °C) was provided. As a routine program, the regular vaccination against Newcastle disease (Nobilis ND Clone 30, Intervet: on the 7th and 18th day of age) and Gumboro disease (Nobilis Gumboro D78, Intervet: on the 14th day of age) were performed. Four times a day, housing facilities were checked for the constant feed and water supply, stability of the environmental temperature and ventilation, mortalities, and unexpected events. All birds were fed the same basal diets to meet the standard requirements of broiler chickens (NRC, 1994, Table 1).

Table 1
Ingredient composition and calculated chemical analysis of the basal diets.

	Starter period (1–21 d)	Grower-Finisher period (22-42d)
Ingredients		
Yellow maize	60.50	65.00
Soybean meal (48%)	30.80	25.00
Corn gluten (60%)	4.00	3.50
Maize oil	–	1.80
Di- calcium phosphate	2.30	2.30
Limestone	1.40	1.40
DL- methionine	0.10	0.10
Lysine	0.10	0.10
[a]Vitamin and trace mineral mix	0.35	0.35
Salt (NaCl)	0.35	0.35
Coccidostate	0.10	0.10
Calculated analysis		
[b]ME (KJ/kg)	12,342	12,949
Crude protein (%)	22.40	19.75
Calcium%	1.05	1.05
Available phosphorus%	0.45	0.45
Lysine %	1.18	1.14
Methionine	0.48	0.45

[a] Providing the following per kg of diet: of diet: 8000 IU vitamin A, 600 IU vitamin D3, 16 mg vitamin E, 1 mg thiamine, 3 mg riboflavin, 1 mg pyridoxine, 0.01 mg vitamin B12, 1 mg vitamin K3, 16 mg niacin, 7 mg pantotenic acid, 70 mg Mn, 50 mg Zn, 30 mg Fe, 4 mg Cu, 1 mg I, 0.2 mg Co, 0.1 mg Se, 240 mg choline, 300 units phytase, 110 mg ethoxyquin.
[b] ME: metabolizable energy.

2.2. Growth performance and carcass yield

Individually, birds were weighed, and feed conversion ratio (FCR) was estimated as actual feed intake (FI) divided by the body gain (22–42 days). For performance traits, each pen was considered as the experimental unit. At the end of the experiment (42 days), three chickens per replicate were selected (12 birds per each group), weighed, fasted for 6 h and slaughtered to determine carcass yields. The slaughter technique was practiced according to the prestunning method which was described by the Malaysian institutes (JAKIM, 2011). After evisceration, carcasses were also spray-washed, immersion chilled at 2 °C for 30 min, allowed to effectively drain for 5 min, and carcass yields were calculated as percentages of the live body weight.

2.3. Blood sampling, biochemical and hematological analyses

At day 42 of age, two blood samples (8 birds per each group) were collected in plain or EDTA-treated tubes by the brachial vein route. Using an automated analyzer (AL 820, Swiss), the EDTA blood samples were used to determine the erythrocyte count and hemoglobin concentration. The samples collected in the plain tubes were centrifuged (1200 × *g*) to collect sera and stored at −20 °C. Using the specific commercial kits (Roche diagnostics GmbH, Mannheim, Germany), serum concentrations of total protein, albumin, cholesterol, AST and ALT were determined using a Robert R. GmbH Photometer (5010 VST, Germany). Colorimetrically, the activity of total antoxidant capacity (TAC) was measured according to the instructions supplied by the commercial assay kits (Cell Biolabs, Inc., San Diego, USA). The concentrations of sodium (Na) and potassium (K) in serum samples were determined by an electrolyte analyzer (Shenzhen Kindle Medical Devices Co. Ltd., China).

2.4. Determination of malondialdehyde level and antioxidant activity in tissues

Samples of breast muscle were homogenized in buffer (100 mM KCl, 50 mM Tris–HCl, and 2 mM EGTA, pH 7.4), centrifuged at 700 × *g*, and the supernatants then collected. According to the method of karalas et al. (2002), the samples were analyzed on an Agilent HP 1100 series HPLC apparatus, USA. In order to determine the superoxide dismutase (SOD) and catalase (CAT) activities in heart tissues, the homogenate of each sample was prepared in a 10 mM phosphate buffer (pH 7.4), and the resulting suspension was centrifuged at 12,000 × *g* for 10 min at 4 °C. The supernatant was collected and used to determine the SOD and CAT activities by spectrophotometer. The SOD activity was monitored for 2 min interval. The activity was expressed as the amount of enzyme that inhibits the auto oxidation of pyrogallol (Ahmed-Farid et al., 2017). Based on the decomposition of H_2O_2, the CAT activity was measured (Aebi, 1984).

2.5. Muscle fatty acid and amino acid profiles

From the slaughtered birds, two birds from each replicate (8/group) were chosen to estimate the muscle FA and amino acid profiles. From the chilled carcasses, the breast muscle was dissected with careful removal of any fat or connective tissues. The obtained samples were directed to the chemical analyses of muscle FA and amino acids (AA) profiles. Lipids were extracted with a chloroform:methanol mixture (2:1, then vortex for 2 min and centrifuged for 10 min at 4000 rpm). The free FA were purchased from Sigma-Aldrich (Sigma, St. Louis, MO), and FA concentrations were determined using an Agilent Technologies of gas chromatography (7890A GC). The conditions of flow rate through the GC column and the splitless injection mode were practiced according to the protocol described by Radwan and Ahmed (2016). The contents of free AA in the breast muscle were estimated by the modified protocol of Hughes et al. (2002). Using a Nova-Pak™ C_{18} column (4 μm, 3.9 × 4.6 mm), the derivatized samples and AA standards were injected into the column for separation by HPLC.

2.6. Statistical analyses

The data were analyzed by ANOVA using the GLM procedures of the IBM SPSS software program (Version 16.0; IBM Corp., NY, USA). For performance traits, each pen was considered as the experimental unit. The model comprised the fixed effects of the dietary supplements (four levels: TN, HS, CR and AS) and the random effect of experimental error. Using the Duncan Multiple Range Test (DMRT), multiple mean comparisons were performed. The outputs are expressed as means and the standard error of means (SEM).

3. Results

3.1. Growth performance and carcass yield

The effects of dietary curcumin and ASA supplements on growth performance and carcass yield of heat-stressed broilers are illustrated in Table 2. Dietary treatment had a significant effect on ADFI (P = 0.041), average daily gain (P = 0.013) and final body weight (P = 0.001). The curcumin-supplemented group had higher values for these measures compared to other experimental groups (all, P < 0.05). Moreover, the TN and AS groups exhibited significantly higher average daily gain and final body weight as compared to the HS group. Also, dietary treatment had a significant effect on the FCR and carcass yield (P = 0.008 and 0.047, respectively). The dietary curcumin or ASA supplements significantly improved the FCR as compared to the HS group (P < 0.05). The dietary curcumin supplement significantly increased the carcass yield as compared to the HS group (P < 0.05). However, no significant difference was reported in carcass yield between the ASA-supplemented group and the HS group.

Table 2
Effect of dietary supplementation with curcumin and acetylsalicylic acids on growth performance of heat-stressed broiler chickens.

Parameter	Experimental groups					
	TN[a]	HS[b]	CR[c]	SA[d]	SEM[e]	*P*-value
Initial body weight (g)	779.5	776.0	773.5	770.0	11.3	0.734
Final body weight (g)	2031[b]	1815[c]	2236[a]	2032[b]	71.0	0.001
[f]ADFI (g)	108.3[b]	105.6[b]	118.6[a]	106.3[b]	3.6	0.041
Average daily gain (g)	69.5[b]	57.7[c]	81.2[a]	70.1[b]	3.2	0.013
Feed conversion ratio	1.63[b]	2.26[a]	1.55[b]	1.64[b]	0.11	0.008
Carcass yield (%)	75.31[a]	70.53[b]	75.47[a]	72.34[ab]	1.23	0.047

[a,b,c] Values within a row with different superscripts differ significantly.
[a] Thermonuteral group.
[b] Heat-stressed group.
[c] Group supplemented with curcumin.
[d] Group supplemented with acetylsalicylic acid.
[e] standard error of means.
[f] Average daily feed intake.

3.2. Blood biochemical, hematological and antioxidant indices

The effects of dietary curcumin and ASA supplements on blood biochemical and antioxidant indices of heat-stressed broilers are illustrated in Table 3. Dietary treatment had a significant effect on RBC count (P = 0.021) and hemoglobin contents (P = 0.049) as well as the serum total proteins (P = 0.001), albumin (P = 0.005), cholesterol (P = 0.002), AST (P = 0.001) and ALT (P = 0.017). The HS group showed significantly higher RBC and hemoglobin contents compared to other experimental groups (P < 0.05). The dietary curcumin supplement significantly increased the serum total proteins and albumin as compared to the HS group (all, P < 0.05). Also, the dietary curcumin and ASA supplements significantly decreased the serum cholesterol, AST and ALT as compared to the HS group (all, P < 0.05). Additionally, both dietary supplements exhibited a marked ability to restore the serum TAC, Na and K in heat-stressed broiler chickens

Table 3
Effect of dietary supplementation with curcumin and acetylsalicylic acids on blood hematological, biochemical and antioxidant parameters of heat-stressed broiler chickens.

Parameter	Experimental groups					
	TN[a]	HS[b]	CR[c]	SA[d]	SEM[e]	*P*-value
[f]RBC (x10^6/μl)	5.53[b]	6.13[a]	5.67[b]	5.43[b]	0.08	0.021
Hemoglobin (g/dl)	13.77[ab]	14.17[a]	13.0[b]	13.47[ab]	0.28	0.049
Total protein (g/ dl)	6.75[a]	5.80[b]	6.51[a]	6.45[a]	0.13	0.001
Albumin (g/ dl)	4.46[a]	4.05[c]	4.31[ab]	4.10[bc]	0.07	0.005
Globulin (g/ dl)	2.30	1.75	2.20	2.36	0.14	0.102
Cholesterol (mg/ dl)	79.47[b]	86.17[a]	79.20[b]	79.20[b]	1.22	0.002
[g]ALT (U/l)	57.47[b]	63.07[a]	52.47[c]	58.13[b]	0.97	0.001
[h]AST (U/l)	42.83[b]	56.63[a]	45.97[b]	44.93[b]	1.24	0.017
K^+ (mmol/l)	4.09[a]	3.72[b]	3.99[ab]	4.16[a]	0.10	0.040
Na^+ (mmol/l)	133.3[a]	113.7[b]	133.6[a]	131.6[a]	5.6	0.015
[i]TAC (U/l)	1.49[a]	1.36[b]	1.55[a]	1.47[a]	0.04	0.008

a,b,c Values within a row with different superscripts differ significantly.
[a] Thermonuteral group.
[b] Heat-stressed group.
[c] Group supplemented with curcumin.
[d] Group supplemented with acetylsalicylic acid.
[e] Standard error of means.
[f] Red blood cells.
[g] Alanine aminotransferase.
[h] Aspartate aminotransferase.
[i] Total antioxidant capacity.

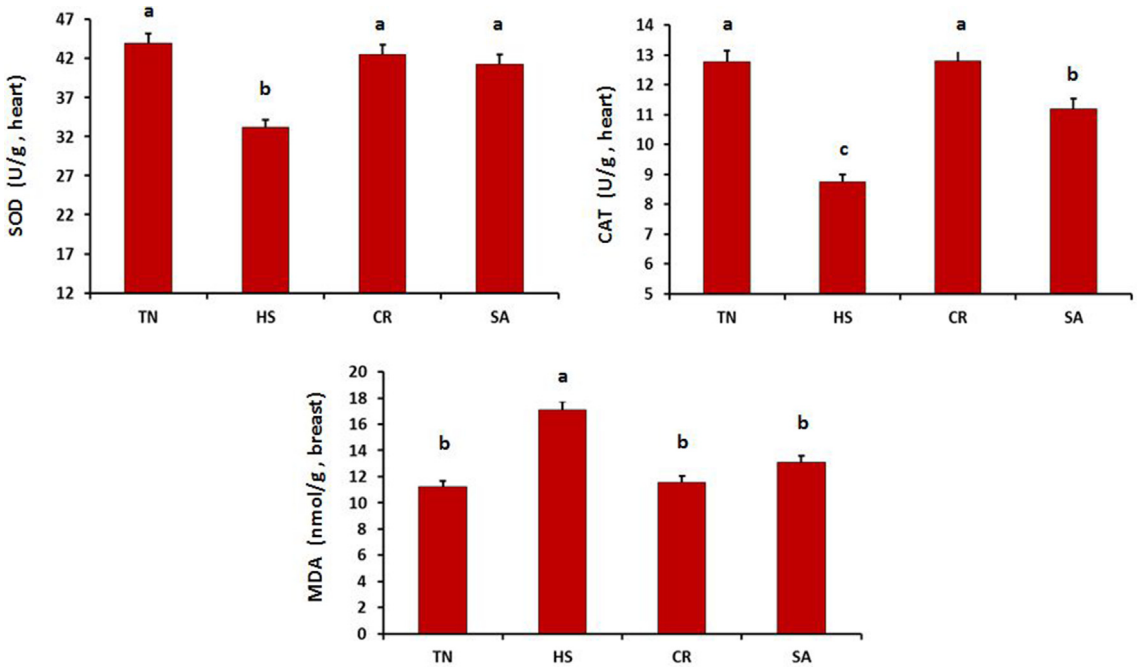

Fig. 1. Effects of dietary supplementation of curcumin and acetylsalicylic acids on the heart superoxide dismutase (SOD) and catalase (CAT) as well as the breast muscle malonaldhyde (MDA) concentration in heat-stressed broiler chickens (P = 0.001, 0.004 and 0.014, respectively).

(P = 0.008, 0.015 and 0.040, respectively).

3.3. Malondialdehyde level and antioxidant activity in tissues

As shown in Fig. 1, dietary treatment had a significant effect on the MDA concentration in the breast muscles (P = 0.014). The dietary curcumin and ASA supplements significantly decreased the MDA concentration in the breast muscles as compared to the HS group (all, P < 0.05). Moreover, both dietary supplements exhibited a marked ability to restore the antioxidant activity (SOD and CAT) in the heart muscles of heat-stressed broilers (P = 0.001 and 0.004).

3.4. Muscle fatty acid and amino acid profiles

As described in Table 4, dietary treatment had a significant effect on the saturated FA (Myristic) contents of the breast muscles (P = 0.001). The CR and SA groups showed significantly lower saturated FA (Myristic) contents of the breast muscles as compared to the HS group (P < 0.05). Moreover, both dietary supplements exhibited a marked ability to restore the muscular Oleic and Linoleic FA contents in heat-stressed broilers (P = 0.001 and 0.013, respectively). Meanwhile, the current study reported a remarkable ability of curcumin supplement to restore the polyunsaturated FA (PUFA) contents in the breast muscles of heat-stressed broilers, including α-lenolinec acid, Docosahexaenoic acid and Eicosapentaenoic acid (P = 0.009, 0.001 and 0.025, respectively).

As shown in Table 5, dietary treatment had a significant effect on the lysine and Isoleucine muscular contents (P = 0.003 and 0.001, respectively). The CR group showed a marked increase in lysine and Isoleucine muscular contents when compared with the HS group (all, P < 0.05). Moreover, both dietary supplements exhibited a marked ability to restore the muscular essential AA contents in heat-stressed broilers, such as leucine, valine, methionine, therionine and phenylalanine (P = 0.012, 0.008, 0.001, 0.018 and 0.007, respectively). Meanwhile, curcumin supplement had the ability to restore the non-essential AA contents in the breast muscles of heat-stressed broilers, such as alanine glycine, proline and aspartic acid (P = 0.034, 0.002, 0.026 and 0.009, respectively).

Table 4
Effect of dietary supplementation with curcumin and acetylsalicylic acids on the fatty acid profile (g/100 g) of breast muscle in heat-stressed broiler chickens.

Item	Experimental groups					
	TN[a]	HS[b]	CR[c]	S[d]	SM[e]	*P*-value
Myristic ($C_{14:0}$)	0.81[b]	0.97[a]	0.79[b]	0.82[b]	0.04	0.013
Palmitic ($C_{16:0}$)	31.06[b]	36.63[a]	33.55[ab]	32.36[b]	1.19	0.045
Stearic ($C_{18:0}$)	12.56	13.56	12.40	12.49	0.43	0.222
Myristoleic acid	1.11[a]	0.81[c]	1.20[a]	0.96[b]	0.04	0.001
Palmitoleic ($C_{16:1}$)	1.23[a]	0.87[c]	1.12 [ab]	1.06[b]	0.27	0.004
Oleic ($C_{18:1}$)	21.39[a]	15.91[b]	23.0[a]	21.53[a]	0.81	0.001
Linoleic ($C_{18:2n6}$)	15.46[a]	11.38[b]	16.27[a]	15.38[a]	0.49	0.013
α-lenolinec acid ($C_{18:3n3}$)	0.89[ab]	0.82[b]	0.96[a]	0.84[b]	0.08	0.009
Docosahexaenoic acid ($C_{22:6n3}$)	0.60[a]	0.41[b]	0.58[a]	0.53[a]	0.03	0.001
Eicosapentaenoic acid ($C_{20:5n3}$)	0.70[a]	0.50[c]	0.70[a]	0.61[b]	0.02	0.025

a,b,c Values within a row with different superscripts differ significantly.
[a] Thermonuteral group.
[b] Heat-stressed group.
[c] Group supplemented with curcumin.
[d] Group supplemented with acetylsalicylic acid.
[e] Standard error of means.

4. Discussion

Consistent with the literature, the HS group showed depressions in feed intake, final body weight, weight gain and FCR. Moreover, supplemental curcumin significantly increased the ADFI, average daily gain and final body weight in the heat-stressed broilers. This may be attributed to the ability of dietary curcumin to decrease the lipid peroxidation and improve the intestinal barrier and mitochondrial functions (Ruan et al., 2019). Consistent with our findings, Rajput et al. (2013) suggested that the supplementation of curcumin to broiler diet at 200 mg kg^{-1} enhanced the overall growth performance, which may be attributed to the increased villus height in all segments of the small intestine. Similarly, several studies have been reported that the

Table 5
Effect of dietary supplementation with curcumin and acetylsalicylic acids on the amino acid profile (g/100 g) of breast muscle in heat-stressed broiler chickens.

Item	Experimental groups					
	TN[a]	HS[b]	CR[c]	S[d]	SM[e]	*P*-value
Lysine	7.22[ab]	5.54[c]	7.89[a]	6.52[bc]	0.31	0.003
Leucine	7.67[a]	5.31[c]	7.39[a]	6.47[b]	0.18	0.012
Isoleucine	3.20[a]	2.35[c]	3.20[a]	2.88[b]	0.09	0.001
Valine	3.93[ab]	2.98[c]	4.01[a]	3.55[b]	0.13	0.008
Methionine	1.56[a]	1.12[b]	1.56[a]	1.48[a]	0.05	0.001
Tyrosine	2.31[a]	1.63[b]	2.30[a]	2.10[a]	0.10	0.010
Therionine	3.61[a]	2.59[b]	3.50[a]	3.32[a]	0.12	0.018
Phenylalanine	1.87[a]	1.48[b]	1.98[a]	1.74[a]	0.08	0.007
Histidine	2.73[a]	2.11[b]	2.59[a]	2.53[a]	0.09	0.001
Glycine	5.05[a]	3.55[c]	4.64[ab]	4.35[b]	0.12	0.002
Proline	1.45[a]	1.04[b]	1.49[a]	1.16[b]	0.06	0.026
Arginine	4.88[ab]	3.45[c]	5.12[a]	4.43[b]	0.14	0.001
Serine	2.63[a]	1.98[b]	2.66[a]	2.55[a]	0.09	0.003
Aspartic acid	8.50[a]	6.16[c]	8.47[a]	7.06[b]	0.21	0.009
Glutamic acid	11.58[a]	8.33[b]	11.32[a]	10.46[a]	0.48	0.005
Alanine	5.38[a]	3.65[c]	5.20[ab]	4.68[b]	0.18	0.034

a,b,c Values within a row with different superscripts differ significantly.
[a] Thermonuteral group.
[b] Heat-stressed group.
[c] Group suppemented with curcumin.
[d] Group suppemented with acetylsalicylic acid.
[e] Standard error of means.

inclusion of curcuma at levels of 0.5–1% in the broiler diets improved the body weight gain, feed intake and feed efficiency (Gowda et al., 2009; Al-Kassie et al., 2011). Yarru et al. (2009) also observed that body weight gain in aflatoxin-exposed chicks was improved when chicks were fed a diet supplemented with 0.5% turmeric. Durrani et al. (2006) found that broilers fed a 0.5% turmeric supplemented-diet exhibited significantly improved body weight gain, while feed intake decreased significantly in this group compared to control. In a more recent study, Ruan et al. (2019) suggested that the addition of curcumin to the diets significantly improved the final body weight, feed intake and average daily gain of growing ochratoxin-exposed ducklings. On the contrary, other researchers did not report any beneficial effects of adding turmeric to broiler diets (El-Hakim et al., 2009). In this context, Rajput et al. (2013) stated that curcumin supplement did not affect feed intake of Arbor acre broiler chickens.

Blood biochemicals can indicate the metabolic, nutritional and health condition of broiler chickens (Zhu et al., 2014), and can be used to elucidate the physiological responses to different dietary supplements (Toghyani et al., 2010). Indeed, curcumin or ASA supplements decreased the serum ALT and AST concentrations in heat-stressed broilers, which indicate the absence of hepatic damages in these groups (Polat et al., 2011). Similarly, Zhang et al. (2018) reported that both serum AST and ALT activities were significantly decreased in the heat-stressed broilers fed a curcumin-supplemented diet. On the other hand, a significant increase in serum total proteins and albumin were observed in the curcumin-supplemented group. In accordance with these findings, Zhu et al. (2014) suggested that curcumin has properties that can improve protein metabolism, as well as a protective effect on cells via enzymatic and non-enzymatic mechanisms. In the present study, serum concentrations of TAC, an indicator of capability for scavenging superoxide radicals, restored when curcumin or ASA were added to diets of heat-stressed broilers. These data are in agreement with previous studies done with various antioxidant supplements in the diet (Sahin et al., 2010, 2012). Several studies have shown that curcumin supplements have a strong ability for inhibiting lipid peroxidation (Sankar et al., 2012; Cai et al., 2012). Similar to our results, Kalpana and Menon (2004) suggested that curcumin exerts its protective effect by modulating the biochemical marker enzymes and augmenting antioxidant defense system. Additionally, Sankar et al. (2012) reported that the dietary curcumin significantly increased all antioxidant biomarkers in the serum of cypermethrin-exposed Wistar rats. Acar et al. (2012) also reported that the total antioxidant status was significantly improved in the curcumin-supplemented diabetic group compared to the untreated diabetic group. It has been reported that different thermal stress conditions have an obvious influence on blood electrolyte parameters in various broiler strains (Huang et al., 2018). In this context, the current study showed that both dietary supplements have the ability to restore the serum Na and K concentrations as compared to the HS group. Similarly, Amrutkar et al. (2016) indicated that Na and K excretion levels increased in urine and feces of heat-stressed broilers, and consequently leads to body fluid acidification (Sayed and Scott, 2007).

Lipid peroxidation is an undesirable factor for food, since it can cause a rancid flavor, and consequently, it reduces muscle sensorial and nutritional quality (Olmedo et al., 2014). The enrichment of diets with antioxidant compounds such as dietary vitamin C and vitamin E supplements is crucial to improve the oxidative stability, and hence, to improve the quality of the product when birds are kept under high ambient temperature (Sahin and Kucuk, 2003). In this sense, the addition of curcumin or ASA in the diet of broiler chickens reduced the levels of MDA in the breast muscles, which is one of the main reasons for food deterioration (Galli et al., 2018). This result indicates that curcumin and/or its metabolites may minimize lipid peroxidation in breast muscles. Consistent with these findings, Pita et al. (2004) suggested that curcumin possesses several antioxidant properties, neutralizes the deleterious effects of free radicals, and consequently, improves the food preservation methods. Although curcumin was not deposited in the muscles, it is believed that a direct or indirect transfer of antioxidant compounds to the tissues may have occurred, since increased levels of antioxidant biomarkers (SOD and CAT) in the heart muscles were detected. Probably these antioxidants are involved in the reduction of MDA levels in the muscles (Botsoglou et al., 2005). One possible mode of action could be associated with the presence of phenolic compounds that avoid or minimize the formation of hydrogen peroxide, an important inducer of tissue and cell damage (Farag et al., 1989). In accordance with the improved antioxidant indices (CAT and SOD) in the heart tissues of heat-stressed birds fed a curcumin-supplemented diets, Zhang et al. (2015) suggested that dietary treatment with curcumin significantly attenuated heat stress-induced reductions of CAT and SOD activities in broiler breast muscles; notably the marked effects were found at 100 mg kg^{-1}.

In the current study, the CR and SA groups showed significantly lower SFA contents in the breast muscles, as well as a remarkable increase in the muscular Oleic and Linoleic FA contents of heat-stressed broilers. Consistent with these findings, Daneshyar et al. (2011) determined that supplementation with 0.75% curcuma powder caused a significant decrease in the total SFA of thigh muscles. However, others reported no significant changes in the SFA contents of breast and thigh muscles when Korat chickens were fed curcuminoids-supplemented diets (Hang et al., 2017). Curcumin also was shown to inhibit the microsomal Δ5 and Δ6 desaturases of liver tissues (Shimizu et al., 1992). Other researchers also suggested that antioxidant-rich diets usually inhibit saturated fatty acid levels by modulating the activity of 9-desaturase enzyme complex, which converts SFA into unsaturated FA (Gnoni et al., 2009). Therefore, curcumin is likely to be involved in the regulation of the biosynthesis of PUFA in chickens. In this context, the current study reported a remarkable ability of curcumin supplement to restore the polyunsaturated FA (PUFA) contents in the breast muscles of heat-stressed broilers. Similar findings were reported by Hang et al. (2017), who stated that supplementation of curcumin (20 mg curcuminoids kg^{-1}) to broiler diets significantly increased the linoleic acid and total n-6 PUFA contents in the breast muscles. They also reported that supplementation of curcumin (40 and 60 mg curcuminoids kg^{-1}) to broiler diets led to the proportions of linoleic acid and Docosahexaenoic acid in the breast meat similar to those of the thermoneutral

group. As far as we know, no previous reports have discussed the effect of curcumin supplements on the AA profile of broiler meat. The current study also suggested that both dietary supplements exhibited a marked ability to restore the muscular essential AA contents in heat-stressed broilers, such as leucine, valine, methionine, therionine and phenylalanine. The overall improvement of essential AA contents in the breast muscles of broilers fed a curcumin-supplemented diet suggests the potential benefits of dietary curcumin supplements under thermal stress conditions. These results may be attributed to the presence of bioactive phenolic compounds, as well as the presence of sulfur and non-sulfur compounds in most herb-derived extracts (Amagase et al., 2001). Consistent with these findings, Daneshyar et al. (2011) suggested that supplementation with 0.75% curcuma powder improved the protein content of thigh muscles as compared to control birds.

5. Conclusion

Based on the data mentioned above, it could be concluded that supplemental dietary curcumin and ASA enhanced the growth performance, blood biochemical indices and antioxidant biomarkers of heat-stressed broiler chickens. Moreover, cucumin might be an effective dietary supplement to alleviate the adverse effect of chronic thermal stress on carcass yield and the concentrations of PUFA and essential amino acids in broiler muscles. Further studies with higher amounts of curcumin may be helpful to adjust the optimum supplementation level in broiler diets.

Conflicts of interest

None of the authors have any conflict of interest to declare.

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