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Effects of Bamboo Leaf Flavonoids on Growth Performance, Slaughter Performance, Serum Biochemical Parameters, Serum Antioxidant Status, and Intestinal Function in Broilers under Chronic Heat Stress

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Abstract

This study was conducted to investigate the effects of dietary bamboo leaf flavonoids (BLF) on growth performance, slaughter performance, serum biochemical parameters, serum antioxidant status, and intestinal function in broilers subjected to chronic heat stress (CHS). A total of 200 Arbor Acres broilers at 28 days of age were randomly allocated to five experimental groups with equal replicates. The thermoneutral control group (TN) was maintained at 24 ± 1°C and fed a basal diet, whereas the other four groups were exposed to CHS at 33 ± 1°C and fed the basal diet supplemented with 0, 400, 800, or 1600 mg/kg BLF, respectively. Compared with the TN group, the CHS group showed significantly decreased serum glucose, Ca, and Pi concentrations, as well as reduced T-AOC, GSH-PX, and T-SOD levels, but significantly increased serum TC, TG, LDL-C, creatinine, and UA concentrations ($P < 0.05$). Dietary supplementation with 400, 800, and 1600 mg/kg BLF significantly increased average daily gain (ADG) and average daily feed intake (ADFI) in CHS broilers, and 400 and 800 mg/kg BLF further reduced the feed conversion ratio (F:G) during 28–42 d compared with the CHS group ($P < 0.05$). BLF supplementation also improved slaughter traits, with 800 and 1600 mg/kg increasing semi-eviscerated yield at 35 d, and 400, 800, and 1600 mg/kg increasing carcass yield at 42 d; moreover, 1600 mg/kg increased semi-eviscerated yield, eviscerated yield, and abdominal fat percentage ($P < 0.05$). In serum, 800 and 1600 mg/kg BLF reduced TC, LDL-C, and creatinine at 35 d, whereas all three BLF doses reduced TG at 42 d; additionally, 1600 mg/kg increased HDL-C and glucose, 400 mg/kg increased Ca, and 800 or 1600 mg/kg increased Mg and reduced UA in specific periods ($P < 0.05$). For antioxidant status, BLF at 400, 800, and 1600 mg/kg increased T-AOC, while 1600 mg/kg enhanced CAT at 35 d and 800 mg/kg enhanced T-SOD at 42 d; 400 mg/kg also reduced MDA at 35 d ($P < 0.05$). In the small intestine, the CHS group exhibited marked reductions in maltase, sucrase, amylase, lipase, and trypsin activities, whereas BLF at 400, 800, and 1600 mg/kg generally increased maltase and sucrase activities, with improvements in lipase, amylase, and trypsin depending on intestinal segment, age, and dose. In conclusion, BLF supplementation alleviated the adverse effects of chronic heat stress on broilers by improving growth performance and slaughter traits, maintaining serum biochemical homeostasis, enhancing serum antioxidant status, and improving intestinal function. Among the tested doses, 1600 mg/kg BLF showed the most consistent beneficial effects overall.

Introduction

With the intensification of global warming, the impact of temperature on modern animal husbandry has become increasingly significant (Oluwagbenga et al. 2023). Heat stress (HS) occurs when the dynamic balance between the heat production process of an animal's body and its ability to dissipate heat to the environment is disrupted, specifically when the rate of heat production exceeds the efficiency of heat dissipation through the body surface (Mangan et al. 2024). HS not only leads to a decrease in ADG and ADFI, but also causes an increase in free radicals, resulting in oxidative stress (Jimoh et al. 2022). In addition, HS can hinder intestinal development, disrupt the activity of intestinal digestive enzymes, reduce the activities of amylase, lipase, maltase, damage intestinal epithelial cells, and affect the body's fat metabolism (He et al. 2018). It can also increase the levels of glucose and HDL-C in broiler serum,

leading to metabolic disorders (He et al. 2020). Meanwhile, it reduces the activities of CAT, T-SOD and GSH-PX in the liver, disrupting the body's redox balance (Akinyemi et al. 2022). Therefore, exploring effective regulatory measures that can alleviate the oxidative damage of HS to poultry bodies, improve intestinal function and metabolic disorders has become one of the key research directions for the current livestock industry to deal with HS.

Bamboo leaf flavonoids (BLF) are major bioactive compounds derived from bamboo leaves and are rich in flavonoids, polyphenols, and other functional constituents. Previous studies have shown that BLF or bamboo-leaf-derived extracts can improve growth performance, meat quality, antioxidant capacity, and lipid metabolism in poultry (North et al. 2019; Ouyang et al. 2016). BLF supplementation has been reported to increase feed intake and average daily gain, reduce feed conversion ratio, and improve redox status in broilers (Zhang et al. 2017; Cao et al. 2023). In addition, some studies have demonstrated that bamboo leaf extracts or related flavonoid preparations can regulate serum lipid indices and enhance antioxidant enzyme activities under heat stress conditions (Dai et al. 2021). However, these studies have mainly focused on growth, serum oxidative status, or isolated metabolic indicators, whereas the integrated relationship among intestinal digestive function, serum biochemical homeostasis, carcass traits, and production performance under chronic heat stress remains insufficiently clarified. Moreover, differences in bird genotype, heat stress model, feeding period, and flavonoid source may lead to inconsistent findings across studies. Therefore, it remains necessary to evaluate BLF from a more systematic perspective and to determine whether its protective effects under CHS are mediated through improvements in intestinal function and metabolic stability.

Although the beneficial effects of flavonoids on antioxidant status and growth performance have been reported in broilers exposed to acute or continuously high ambient temperatures, most previous studies have focused on single-dose supplementation or non-cyclic heat stress models. Evidence regarding the dose-dependent effects of bamboo leaf flavonoids on intestinal digestive function, serum biochemical homeostasis, and antioxidant defense in broilers under cyclic chronic heat stress remains limited. Therefore, the present study was designed to evaluate whether dietary BLF supplementation could alleviate CHS-induced impairment in growth performance, slaughter performance, serum biochemical parameters, serum antioxidant status, and intestinal function in broilers, and to identify a potentially effective supplementation level.

Materials and methods

Experimental animal, design, and diet

A total of 200 one-day-old Arbor Acres (AA) broiler chicks, with an average initial body weight of 45 g and a balanced 1:1 male-to-female ratio, were obtained from a commercial poultry farm. All chicks were raised under standard commercial husbandry procedures from day 1 to day 27 to ensure homogeneous growth performance before the initiation of the formal trial. On day 28, the broilers were randomly assigned to 5 experimental groups, each comprising 4 replicates with 10 birds per replicate. Each

replicate was housed in an individual cage sized at 100 cm × 80 cm × 60 cm (length × width × height), and the experimental phase lasted 14 consecutive days.

Specifically, the thermoneutral control group (TN) reared at a constant ambient temperature of 24 ± 1 ℃ and fed a standard basal diet without any additives. The other four groups were subjected to chronic heat stress (CHS) treatment, with the ambient temperature increased to 33 ± 1 ℃ for 8 h daily (09:30–17:30) and restored to 24 ± 2 ℃ for the rest of the time. These four CHS groups received the basal diet supplemented with BLF at graded dosages of 0, 400, 800, and 1600 mg/kg, respectively. The detailed composition and nutrient levels of the basal diet are listed in Table 1. Heat supply for the CHS groups was implemented using industrial heaters (Model IFH04-30A, JiYi Co., Ltd.). The relative humidity of the whole rearing environment was stably maintained at (60 ± 5)% throughout the experiment. The BLF utilized in this study was purchased from Shaanxi Baichuan Biotechnology Co., Ltd., containing no less than 90% total flavonoids; its remaining components were mainly polyphenols and amino acids.

Table 1
Composition and nutrient levels of basal diets (%)

Ingredients	growth phase	
	1–21 d	22–42 d
Corn	60.9	62.9
Beanpulp	28.1	26.8
Soybeanoil	3.5	3.5
Fishpowder	3.5	3.5
$CaHPO_4$	1.5	1.5
NaCl	0.5	0.5
Premix[1]	2	2
Total	100	100
Nutrientlevels[2]		
ME/(MJ/kg)	12.96	13.03
Crudeprotein(%)	22.5	22.02
Crudefat	5.88	5.96
Crudefiber	2.49	2.44
Crudeash	3.65	3.6
Lys(%)	1.05	1.02
Ca(%)	1.2	1.2
P(%)	0.71	0.67

[1] The premix supplied per kilogram of the diet included the following components: manganese (as $MnSO_4$) 66 mg; zinc (as ZnO) 44 mg; copper (as $CuSO_4$) 9 mg; iron (as $FeSO_4$) 50 mg; iodine (as KI) 0.4 mg; vitamin A 7,000 International Units (IU); vitamin D_3 875 IU; vitamin E 20 IU; vitamin K_3 1 mg; vitamin B_2 4.5 mg; vitamin B_6 2.5 mg; vitamin B_{12} 0.6 mg; niacin 50 mg; D-pantothenic acid 12 mg.

[2] Metabolizable energy (ME) was a calculated value.

Determination of growth performance

Daily feed consumption per replicate was recorded at 08:00 throughout the experimental period. Additionally, Broilers were individually weighed at 08:00 on days 28, 35, and 42 of the trial after an

overnight feed withdrawal of approximately 12 h (water available ad libitum) to minimize variation caused by gut fill. Growth performance parameters including ADFI, ADG, and F:G were calculated and statistically analyzed for two phases: 28–35 d and 35–42 d of age.

Determination of slaughter performance

Carcasses were processed through a sequential procedure of scalding, defeathering, rinsing, and air-drying. Carcass traits, including hot dressed weight, semi-eviscerated weight, fully eviscerated weight, pectoral muscle weight, leg muscle weight, and abdominal fat weight, were subsequently measured, and the corresponding ratios (dressing percentage, semi-evisceration rate, eviscerated carcass yield) were calculated thereafter. In this study, hot dressed weight referred to the carcass after bleeding and defeathering with the head, feet, and most viscera removed; semi-eviscerated weight referred to the carcass with the heart, liver, gizzard, and kidneys retained but with the digestive tract and reproductive organs removed; and fully eviscerated weight referred to the carcass after complete removal of internal organs and abdominal fat. All sampling and measurement protocols were strictly executed in compliance with the Chinese Agricultural Industry Standard Performance Terminology and Measurement Methods for Poultry (NY/T 823–2020).

Serum biochemical parameters

On days 7 and 14 post the initiation of CHS, broilers with medium body weights were randomly selected from each replicate, with 8 birds per experimental group, totaling 40 sampled individuals. The selected broilers were fasted overnight for 12 h with ad libitum access to drinking water, prior to individual BW measurement. Wing vein blood sampling was then conducted on each bird. Ten-milliliter aliquots of the collected blood were transferred into sterile centrifuge tubes. The blood samples were allowed to clot at room temperature and then centrifuged at 3000 × g for 20 min at 4 ℃. The resulting serum supernatant was collected and stored at -20 ℃ for subsequent serum biochemical index analysis. Serum concentrations of TG, TC, HDL-C, LDL-C, glucose, creatinine, urea, UA, Ca, Mg, and Pi were determined using an automated biochemical analyzer (Model BS-200, Shenzhen Mindray Biomedical Electronics Co., Ltd.).

Antioxidant parameters

The enzymatic activities of T-SOD, GSH-PX, and CAT, as well as the levels of T-AOC and MDA in broiler serum, were determined strictly following the manufacturer’s protocols from Nanjing Jiancheng Bioengineering Institute.

Determination of intestinal development indices and digestive enzyme activities

Slaughter sampling was performed on broilers at 35 and 42 days of age, respectively, to collect intestinal tissues for subsequent analysis. During sampling, duodenal, jejunal, and ileal segments were carefully dissected, with their lengths documented right away. Intestinal digesta was fully evacuated; the segments were rinsed with sterile normal saline, blotted dry with filter paper, and weighed promptly. Relative weight and relative length were then computed for each intestinal segment. A 3-cm middle portion of each intestinal segment was excised, placed into a sterile centrifuge tube, and snap-frozen at -70 ℃ for subsequent digestive enzyme activity assays. For laboratory analysis, approximately 0.5 g of the cleaned intestinal tissue (with digesta, fascia, and adipose tissue completely removed) was weighed and homogenized following the instructions provided with the corresponding assay kits. The resulting supernatant was aliquoted and stored at -20 ℃ until analysis. The activities of maltase (Cat. No. A082-3-1), sucrase (Cat. No. A082-2-1), amylase (Cat. No. C016-1-2), lipase (Cat. No. A054-2-1), and trypsin (Cat. No. A080-2-2) were measured using commercial diagnostic kits.

Statistical analysis

All experimental data were collated and statistically analyzed using the SPSS 27.0 software package (SPSS Inc., Chicago, IL, USA). One-way analysis of variance (ANOVA) coupled with Duncan's multiple comparison test was adopted to evaluate the impacts of graded dietary BLF supplementation on the performance and physiological parameters of CHS-exposed broilers. All data are expressed as mean ± standard error (SE), with statistical significance set at $P < 0.05$.

Results

Effect of BLF on improving growth performance of CHS broilers

Broiler growth performance parameters are summarized in Table 2. During the overall experimental period (28–42 d of age), the CHS group exhibited significantly lower ADFI and ADG compared with the TN group ($P < 0.05$). Dietary supplementation with BLF at 400, 800, and 1600 mg/kg effectively elevated ADFI and ADG in heat-stressed broilers ($P < 0.05$). During 28–42 d of age, dietary BLF supplementation at 400 and 800 mg/kg significantly reduced the F:G ratio in CHS broilers compared with the CHS group ($P < 0.05$).

Notably, compared with the CHS group, the F:G ratio was significantly reduced in the 800 mg/kg BLF-supplemented group during the 28–35 d phase, and in the 400 mg/kg BLF-supplemented group during the 35–42 d phase ($P < 0.05$).

Table 2
Effect of BLF on growth performance of CHS broilers

Items	Groups					
	TN	CHS	400mg/kg BLF + CHS	800mg/kg BLF + CHS	1600mg/kg BLF + CHS	*P* value
Day 28–42						
ADG(g)	78.15 ± 1.58^{a}	54.35 ± 2.06^{b}	81.00 ± 2.56^{a}	74.36 ± 2.45^{a}	76.39 ± 0.77^{a}	< 0.001
ADFI(g)	175.71 ± 0.94^{ab}	131.48 ± 5.34^{c}	165.48 ± 4.17^{ab}	158.57 ± 7.97^{b}	180.77 ± 7.79^{a}	< 0.001
F:G	2.25 ± 0.05^{b}	2.43 ± 0.17^{b}	2.04 ± 0.03^{a}	2.14 ± 0.18^{a}	2.37 ± 0.10^{b}	0.014

Note: Within each row of the tables, data without superscript letters or with identical lowercase letter superscripts indicate no statistically significant difference ($P > 0.05$), while those with distinct lowercase letter superscripts signify a significant difference ($P < 0.05$). This labeling standard applies to all subsequent tables.

Effect of BLF on slaughter performance of CHS broilers

The impacts of dietary BLF supplementation on the slaughter traits of CHS-challenged broilers are summarized in Table 3. At 35 days of age, broilers supplemented with 800 and 1600 mg/kg of BLF exhibited a marked elevation in semi-eviscerated yield relative to the CHS group ($P < 0.05$). At 42 days of age, the CHS group presented significantly lower carcass yield and semi-eviscerated yield in comparison with the TN control group ($P < 0.05$). Notably, relative to the CHS group, BLF inclusion notably improved slaughter performance parameters: carcass yield was enhanced in the 400, 800, and 1600 mg/kg BLF groups, whereas semi-eviscerated yield, eviscerated carcass yield, and abdominal fat percentage were significantly elevated specifically in the 1600 mg/kg BLF supplementation group ($P < 0.05$).

Table 3
Effect of BLF on slaughter performance of CHS broilers (%)

Items	Groups					
	TN	CHS	400mg/kg BLF + CHS	800mg/kg BLF + CHS	1600mg/kg BLF + CHS	*P* value
Day 35						
Carcass yield	91.54 ± 1.18	92.26 ± 0.64	91.60 ± 1.42	92.10 ± 1.17	92.08 ± 1.45	0.920
Semi-eviscerated carcass yield	85.27 ± 1.28^{b}	85.41 ± 1.07^{b}	86.19 ± 1.59^{ab}	86.92 ± 0.62^{a}	86.66 ± 0.77^{a}	0.023
Eviscerated carcass yield	73.14 ± 2.96	73.85 ± 2.53	73.34 ± 1.98	74.03 ± 1.15	72.91 ± 2.82	0.971
Breast muscle ratio	31.24 ± 3.33	30.02 ± 0.77	31.48 ± 2.38	32.54 ± 3.02	31.03 ± 2.65	0.827
Leg muscle ratio	20.46 ± 0.34	19.80 ± 1.16	19.63 ± 0.98	20.53 ± 0.48	19.88 ± 0.37	0.494
Abdominal fat percentage	1.40 ± 0.32	1.41 ± 0.36	1.22 ± 0.35	1.10 ± 0.51	1.31 ± 0.51	0.875
Day 42						
Carcass yield	92.30 ± 1.07^{a}	90.31 ± 1.55^{b}	92.33 ± 1.58^{a}	91.59 ± 0.92^{a}	92.38 ± 0.74^{a}	0.018
Semi-eviscerated carcass yield	87.34 ± 0.75^{a}	85.61 ± 1.81^{b}	87.12 ± 1.91^{ab}	86.58 ± 1.33^{ab}	88.03 ± 1.65^{a}	0.031
Eviscerated carcass yield	73.52 ± 1.13^{ab}	71.95 ± 2.73^{b}	74.12 ± 6.05^{ab}	73.42 ± 1.30^{ab}	75.12 ± 0.77^{a}	0.026
Breast muscle ratio	33.91 ± 1.80	32.03 ± 3.12	31.48 ± 4.31	31.73 ± 2.52	31.46 ± 1.40	0.804
Leg muscle ratio	21.92 ± 1.45	20.10 ± 1.97	21.38 ± 0.53	19.54 ± 0.94	20.81 ± 1.61	0.300
Abdominal fat percentage	1.08 ± 0.28^{b}	1.19 ± 0.24^{b}	1.27 ± 0.22^{ab}	1.16 ± 0.09^{b}	1.58 ± 0.15^{a}	0.009

Effect of BLF on serum lipid-metabolism level of CHS broilers

Data presented in Table 7 revealed that at 35 d of age, relative to the TN control group, broilers in the CHS group exhibited significantly elevated serum concentrations of TC and LDL-C ($P < 0.05$),

accompanied by a marked reduction in glucose levels ($P < 0.05$). In contrast, dietary BLF supplementation exerted a hypolipidemic effect in CHS-challenged broilers ($P < 0.05$). Specifically, serum TC and LDL-C levels were notably lowered in the 800 and 1600 mg/kg BLF treatment groups.

At 42 d of age, the CHS group displayed a significant elevation in serum TG levels along with a concurrent decline in glucose levels in comparison with the TN group ($P < 0.05$). Notably, BLF inclusion at doses of 400, 800, and 1600 mg/kg effectively reduced serum TG levels in CHS broilers ($P < 0.05$). Furthermore, supplementation with 1600 mg/kg BLF significantly elevated serum HDL-C and glucose concentrations relative to the CHS group ($P < 0.05$).

Table 7
Effect of BLF on serum glucose and lipid levels in CHS broilers

Items	**Groups**					
	TN	CHS	400mg/kg BLF + CHS	800mg/kg BLF + CHS	1600mg/kg BLF + CHS	*P* value
Day 35						
TG(mmol/L)	0.46 ± 0.03	0.42 ± 0.14	0.50 ± 0.10	0.47 ± 0.08	0.46 ± 0.07	0.879
TC(mmol/L)	2.84 ± 0.14^{d}	3.74 ± 0.23^{a}	3.72 ± 0.10^{ab}	3.13 ± 0.10^{cd}	3.41 ± 0.33^{bc}	< 0.001
LDL-C(mmol/L)	0.67 ± 0.06^{b}	0.87 ± 0.12^{a}	0.98 ± 0.09^{a}	0.69 ± 0.06^{b}	0.73 ± 0.10^{b}	0.002
HDL-C(mmol/L)	2.30 ± 0.21	2.30 ± 0.37	2.51 ± 0.18	2.61 ± 0.31	2.60 ± 0.30	0.493
GLU(mmol/L)	7.37 ± 1.09^{ab}	6.14 ± 0.97^{c}	6.80 ± 1.00^{bc}	8.21 ± 0.46^{a}	7.38 ± 0.59^{ab}	0.006
Day 42						
TG(mmol/L)	0.28 ± 0.05^{bc}	0.40 ± 0.05^{a}	0.26 ± 0.01^{cd}	0.19 ± 0.05^{d}	0.33 ± 0.06^{b}	0.003
TC(mmol/L)	2.88 ± 0.19	3.27 ± 0.20	3.19 ± 0.43	3.01 ± 0.21	3.18 ± 0.31	0.478
LDL-C(mmol/L)	0.69 ± 0.16	0.61 ± 0.29	0.67 ± 0.19	0.53 ± 0.24	0.64 ± 0.22	0.915
HDL-C(mmol/L)	2.39 ± 0.31^{ab}	2.12 ± 0.14^{bc}	2.34 ± 0.28^{ab}	2.02 ± 0.23^{c}	2.58 ± 0.27^{a}	0.009
GLU(mmol/L)	7.48 ± 0.88^{a}	5.44 ± 1.18^{c}	6.10 ± 0.60^{c}	6.29 ± 1.09^{bc}	7.43 ± 0.96^{ab}	0.010

Effect of BLF on serum renal-function and electrolyte-balance-related indices in CHS broilers

Data summarized in Table 8 indicated that at 35 d of age, relative to the TN control group, broilers in the CHS group presented markedly elevated serum creatinine and UA concentrations ($P < 0.05$), whereas serum Ca and Pi concentrations were significantly diminished ($P < 0.05$).

In contrast, dietary BLF supplementation exerted a regulatory effect on these serum indices in CHS-challenged broilers ($P < 0.05$). Specifically, serum creatinine levels were reduced in the 800 and 1600 mg/kg BLF treatment groups, UA levels were lowered in the 1600 mg/kg BLF group, Ca concentrations were elevated across all three BLF-supplemented groups (400, 800, 1600 mg/kg), and Pi concentrations were increased in the 800 and 1600 mg/kg BLF groups.

At 42 d of age, the CHS group still exhibited significantly higher serum creatinine and UA levels in comparison with the TN group ($P < 0.05$). Notably, BLF inclusion at 800 mg/kg significantly reduced serum UA levels in CHS broilers ($P < 0.05$). Additionally, serum Ca concentrations were elevated in the 400 mg/kg BLF group, while Mg concentrations were significantly increased in the 800 and 1600 mg/kg BLF groups relative to the CHS group ($P < 0.05$).

Table 8
Effect of BLF on serum renal function and electrolyte balance related indices in CHS Boilers

Items	**Groups**					
	TN	CHS	400mg/kg BLF + CHS	800mg/kg BLF + CHS	1600mg/kg BLF + CHS	*P* value
Day 35						
CREA(μmol/L)	1.37 ± 0.14^{b}	1.62 ± 0.19^{a}	1.38 ± 0.22^{ab}	1.15 ± 0.21^{b}	1.28 ± 0.21^{b}	0.015
UREA(mmol/L)	0.30 ± 0.09^{a}	0.30 ± 0.08^{a}	0.26 ± 0.09^{a}	0.23 ± 0.09^{a}	0.11 ± 0.07^{a}	0.032
UA(μmol/L)	0.28 ± 0.08^{b}	0.37 ± 0.05^{a}	0.32 ± 0.03^{ab}	0.34 ± 0.05^{ab}	0.29 ± 0.06^{b}	0.013
Ca(mmol/L)	1.96 ± 0.12^{ab}	1.54 ± 0.23^{c}	2.06 ± 0.15^{a}	1.82 ± 0.16^{b}	1.82 ± 0.13^{b}	0.007
Mg(mmol/L)	1.19 ± 0.17	1.15 ± 0.14	1.33 ± 0.17	1.21 ± 0.17	1.28 ± 0.11	0.632
P(mmol/L)	3.50 ± 0.50^{a}	2.56 ± 0.34^{b}	3.52 ± 0.69^{a}	2.92 ± 0.96^{ab}	3.45 ± 0.50^{a}	0.018
Day 42						
CREA(μmol/L)	0.86 ± 0.24^{b}	1.24 ± 0.15^{a}	1.22 ± 0.23^{a}	1.28 ± 0.19^{a}	1.18 ± 0.25^{a}	0.020
UREA(mmol/L)	0.24 ± 0.07	0.26 ± 0.05	0.29 ± 0.09	0.24 ± 0.09	0.27 ± 0.08	0.920
UA(μmol/L)	0.23 ± 0.07^{c}	0.38 ± 0.04^{a}	0.20 ± 0.08^{abc}	0.25 ± 0.08^{bc}	0.32 ± 0.05^{ab}	0.002
Ca(mmol/L)	1.92 ± 0.15^{b}	1.90 ± 0.07^{b}	2.14 ± 0.19^{a}	2.00 ± 0.11^{ab}	2.04 ± 0.07^{ab}	0.012
Mg(mmol/L)	1.25 ± 0.13^{b}	1.23 ± 0.16^{b}	1.25 ± 0.19^{b}	1.43 ± 0.11^{a}	1.45 ± 0.08^{a}	<0.001
P(mmol/L)	2.86 ± 0.52	2.89 ± 0.29	3.00 ± 0.34	2.91 ± 0.41	3.29 ± 0.25	0.633

Effect of BLF on serum antioxidant function of CHS broilers

The modulatory impacts of dietary BLF supplementation on serum antioxidant capacity in CHS-challenged broilers are illustrated in Fig. 1. At 35 d of age, relative to the TN control group, broilers in the CHS group exhibited a marked reduction in serum T-AOC capacity ($P < 0.05$). Dietary BLF inclusion exerted a pronounced antioxidant-promoting effect in CHS broilers ($P < 0.05$). Specifically, serum T-AOC capacity was significantly elevated in all three BLF-supplemented groups (400, 800, 1600 mg/kg), CAT activity was significantly enhanced in the 1600 mg/kg BLF treatment group, and MDA concentration was notably reduced in the 400 mg/kg BLF group. At 42 d of age, CHS exposure induced a significant decline in multiple serum antioxidant indices relative to the TN group, including T-AOC capacity, as well as GSH-PX and T-SOD activities ($P < 0.05$). Notably, BLF supplementation effectively ameliorated the antioxidant impairment caused by CHS ($P < 0.05$). T-AOC capacity was improved across all BLF dosage groups, CAT activity was significantly upregulated in the 400 mg/kg BLF group, and T-SOD activity was enhanced in the 800 mg/kg BLF group relative to the CHS group.

Effect of BLF on relative mass and length of small intestine of CHS broilers

Effects of dietary BLF supplementation on relative weight and length of the small intestine in CHS-challenged broilers are shown in Table 4. At 35 d of age, compared with the TN group, the CHS group showed markedly decreased relative weight and length of the duodenum, as well as significantly reduced relative weight of the jejunum ($P < 0.05$). Dietary BLF exerted significant ameliorative effects: specifically, 400 mg/kg BLF increased duodenal relative weight, while BLF at 400, 800, and 1600 mg/kg significantly elevated duodenal and jejunal relative length in CHS broilers ($P < 0.05$). At 42 d of age, the CHS group exhibited significantly lower relative weights of jejunum and ileum relative to the TN group ($P < 0.05$). Moreover, supplementation with 1600 mg/kg BLF markedly increased relative weights of jejunum and ileum in CHS-exposed broilers ($P < 0.05$).

Table 4
Effect of BLF on relative mass and relative length of small intestine in CHS broilers

Items	Groups					
	TN	CHS	400mg/kg BLF + CHS	800mg/kg BLF + CHS	1600mg/kg BLF + CHS	*P* value
Day 35						
Relative mass of duodenum	6.30 ± 0.65^{a}	5.33 ± 0.97^{b}	6.16 ± 0.89^{a}	5.83 ± 0.81^{ab}	5.52 ± 0.62^{ab}	0.024
Relative length of duodenum	12.00 ± 0.65^{a}	11.38 ± 0.61^{b}	12.10 ± 0.50^{a}	12.49 ± 0.73^{a}	11.98 ± 0.34^{a}	0.017
Relative mass of jejunum	11.55 ± 1.70^{a}	9.99 ± 1.84^{b}	9.54 ± 1.20^{b}	9.49 ± 1.08^{b}	9.02 ± 0.92^{b}	0.006
Relative length of jejunum	28.63 ± 0.64^{bc}	27.67 ± 0.84^{c}	29.08 ± 1.15^{ab}	29.50 ± 1.01^{ab}	29.66 ± 1.06^{a}	0.004
Relative mass of ileum	6.79 ± 1.29	5.99 ± 0.82	5.80 ± 0.94	6.33 ± 2.30	6.56 ± 1.50	0.919
Relative length of ileum	27.88 ± 2.05	28.40 ± 3.93	27.10 ± 4.32	27.31 ± 5.74	29.06 ± 3.95	0.975
Day 42						
Relative mass of duodenum	4.58 ± 0.75	4.79 ± 0.61	4.74 ± 0.52	4.59 ± 0.64	4.36 ± 0.42	0.911
Relative length of duodenum	10.27 ± 1.31	10.87 ± 1.66	9.64 ± 1.22	10.23 ± 1.11	9.66 ± 1.17	0.770
Relative mass of jejunum	9.68 ± 1.04^{a}	8.37 ± 0.80^{c}	8.68 ± 0.40^{bc}	9.05 ± 0.84^{abc}	9.32 ± 0.56^{ab}	0.008
Relative length of jejunum	24.92 ± 3.52	25.38 ± 3.35	24.17 ± 2.18	25.45 ± 2.47	24.32 ± 2.50	0.966
Relative mass of ileum	7.23 ± 1.10^{a}	6.08 ± 0.97^{b}	6.49 ± 0.76^{ab}	6.17 ± 0.83^{b}	7.35 ± 1.16^{a}	0.012
Relative length of ileum	26.29 ± 4.09	24.71 ± 3.84	25.24 ± 1.95	26.83 ± 2.31	24.47 ± 2.25	0.849

Effect of BLF on small intestine digestive enzyme activities of CHS broilers

Effects of dietary BLF supplementation on digestive enzyme activities in the small intestine of CHS-challenged broilers are presented in Table 5. At 35 d of age, duodenal maltase, sucrase, and amylase

activities in the CHS group were markedly lower than those in the TN group ($P < 0.05$). Dietary BLF significantly elevated duodenal enzyme activities ($P < 0.05$). Maltase and sucrase activities were increased in broilers fed 400, 800, and 1600 mg/kg BLF, while amylase activity was improved only in the 1600 mg/kg BLF group. In the jejunum, CHS exposure significantly reduced maltase, sucrase, and lipase activities compared with the TN group ($P < 0.05$). Notably, BLF supplementation at 400, 800, and 1600 mg/kg effectively restored jejunal maltase activity in CHS broilers ($P < 0.05$). In the ileum, maltase and trypsin activities were also significantly decreased in the CHS group relative to the TN group ($P < 0.05$). Dietary BLF exerted a dose-dependent regulatory effect on ileal enzymes ($P < 0.05$). Maltase activity was enhanced in all BLF-supplemented groups (400, 800, 1600 mg/kg), while trypsin activity was increased in the 400 and 1600 mg/kg BLF groups.

Table 5
Effect of BLF on digestive enzyme activity in cyclic heat-stressed broilers at 35 days of age (U/mg prot)

Items	**Groups**					
	TN	CHS	400mg/kg BLF + CHS	800mg/kg BLF + CHS	1600mg/kg BLF + CHS	*P* value
duodenum						
maltase	188.81 ± 6.11^{ab}	155.15 ± 9.68^{c}	190.84 ± 9.11^{a}	180.71 ± 8.96^{b}	178.25 ± 10.42^{b}	< 0.001
sucrase	9.17 ± 0.66^{a}	5.73 ± 0.93^{c}	8.48 ± 0.91^{a}	8.81 ± 0.80^{a}	7.22 ± 0.43^{b}	< 0.001
amylase	0.20 ± 0.03^{a}	0.16 ± 0.03^{b}	0.18 ± 0.03^{ab}	0.16 ± 0.02^{b}	0.20 ± 0.03^{a}	< 0.001
lipase	6.47 ± 0.95	6.29 ± 0.77	6.56 ± 0.89	6.37 ± 0.41	6.10 ± 0.92	0.964
trypsin	1073.37 ± 33.56^{a}	955.62 ± 66.49^{b}	922.87 ± 75.83^{b}	928.52 ± 58.28^{b}	903.19 ± 86.01^{b}	< 0.001
jejunum						
maltase	185.86 ± 6.64^{b}	175.55 ± 9.58^{c}	197.47 ± 6.25^{a}	187.03 ± 4.83^{b}	195.78 ± 6.23^{a}	0.015
sucrase	9.83 ± 0.50^{a}	9.11 ± 0.70^{b}	9.55 ± 0.35^{ab}	9.59 ± 0.70^{ab}	9.12 ± 0.47^{b}	0.028
amylase	4.64 ± 0.57^{a}	3.71 ± 0.47^{b}	3.67 ± 0.50^{b}	3.63 ± 0.29^{b}	4.42 ± 0.75^{ab}	0.042
lipase	6.47 ± 0.95	6.29 ± 0.77	6.56 ± 0.89	6.37 ± 0.41	6.10 ± 0.92	0.964
trypsin	824.87 ± 84.49	829.99 ± 76.82	851.40 ± 62.21	831.65 ± 86.80	832.95 ± 38.92	0.994
ileum						
maltase	313.72 ± 11.70^{a}	277.97 ± 11.81^{b}	301.99 ± 11.92^{a}	315.78 ± 13.35^{a}	301.72 ± 10.13^{a}	0.016
sucrase	10.13 ± 1.05	9.94 ± 0.92	9.43 ± 0.74	9.73 ± 0.82	9.43 ± 0.96	0.841
amylase	0.17 ± 0.03^{a}	0.14 ± 0.03^{b}	0.17 ± 0.03^{a}	0.16 ± 0.03^{ab}	0.14 ± 0.01^{b}	0.006

Items	Groups					
lipase	4.98 ± 0.56	4.46 ± 0.42	4.79 ± 0.46	4.79 ± 0.46	4.41 ± 0.59	0.620
trypsin	1010.28 ± 67.42^{a}	898.72 ± 88.48^{b}	1032.13 ± 64.35^{a}	1009.53 ± 72.50^{ab}	1045.76 ± 42.88^{a}	< 0.001

Effect of BLF on small intestine digestive enzyme activities in CHS broilers

The regulatory effects of dietary BLF supplementation on small intestinal digestive enzyme activities in CHS-challenged broilers are presented in Table 6. At 42 d of age, relative to the TN control group, the CHS group exhibited a marked reduction in duodenal maltase, sucrase, lipase, and trypsin activities ($P < 0.05$). Dietary BLF inclusion exerted a notable elevation effect on these duodenal enzymes ($P < 0.05$). Maltase and sucrase activities were enhanced in all BLF-supplemented groups (400, 800, 1600 mg/kg), lipase activity was increased in the 800 and 1600 mg/kg BLF groups, and trypsin activity was specifically improved in the 800 mg/kg BLF group. In the jejunum, sucrase, lipase, and trypsin activities were significantly diminished in the CHS group in comparison with the TN group ($P < 0.05$). BLF supplementation significantly upregulated jejunal digestive enzyme activities ($P < 0.05$). Sucrase activity was elevated in the 400 mg/kg BLF group, lipase activity was enhanced across all three BLF dosage groups, and trypsin activity was increased in the 800 and 1600 mg/kg BLF groups. Within the ileum, CHS exposure induced a significant decline in maltase, sucrase, amylase, and lipase activities relative to the TN group ($P < 0.05$). Moreover, BLF addition effectively improved ileal enzyme activities ($P < 0.05$). Maltase, sucrase, and lipase activities were increased in all BLF-supplemented groups, while amylase activity was upregulated specifically in the 400 and 1600 mg/kg BLF groups.

Table 6
Effect of BLF on digestive enzyme activity in cyclic heat-stressed broilers at 42 days of age (U/mg prot)

Items	**Groups**					
	TN	CHS	400mg/kg BLF + CHS	800mg/kg BLF + CHS	1600mg/kg BLF + CHS	*P* value
duodenum						
maltase	221.99 ± 8.79^{a}	182.81 ± 7.28^{c}	201.68 ± 11.16^{b}	203.89 ± 12.46^{b}	207.31 ± 5.65^{b}	0.006
sucrase	8.45 ± 0.81^{b}	6.25 ± 0.81^{c}	9.70 ± 0.62^{a}	8.10 ± 0.81^{b}	9.62 ± 0.53^{a}	< 0.001
amylase	0.17 ± 0.01	0.18 ± 0.03	0.19 ± 0.02	0.18 ± 0.03	0.16 ± 0.02	0.607
lipase	6.66 ± 0.34^{a}	5.28 ± 0.59^{b}	5.78 ± 0.58^{ab}	6.43 ± 0.73^{a}	6.67 ± 0.56^{a}	< 0.001
trypsin	940.53 ± 78.79^{ab}	800.36 ± 73.18^{c}	902.54 ± 70.37^{abc}	979.24 ± 67.45^{a}	845.70 ± 95.46^{bc}	< 0.001
jejunum						
maltase	186.88 ± 7.22	188.00 ± 6.76	181.97 ± 10.56	189.06 ± 10.65	180.75 ± 5.21	0.670
sucrase	12.43 ± 0.83^{a}	9.87 ± 0.65^{b}	12.67 ± 0.98^{a}	10.39 ± 0.82^{b}	10.72 ± 0.91^{b}	0.006
amylase	0.14 ± 0.01	0.14 ± 0.03	0.14 ± 0.02	0.14 ± 0.02	0.15 ± 0.02	0.967
lipase	5.96 ± 0.60^{a}	4.69 ± 0.56^{b}	6.42 ± 0.55^{a}	6.53 ± 0.81^{a}	6.37 ± 0.70^{a}	0.034
trypsin	881.28 ± 39.96^{a}	713.24 ± 37.67^{c}	752.93 ± 44.72^{bc}	815.17 ± 59.17^{ab}	879.84 ± 61.03^{a}	0.005
ileum						
maltase	311.33 ± 9.87^{a}	278.65 ± 4.21^{b}	308.35 ± 8.07^{a}	310.22 ± 10.32^{a}	309.21 ± 10.99^{a}	0.004
sucrase	11.45 ± 0.59^{ab}	8.92 ± 0.74^{d}	11.56 ± 0.73^{a}	10.29 ± 0.52^{c}	10.65 ± 1.03^{bc}	0.008
amylase	0.18 ± 0.02^{a}	0.13 ± 0.03^{b}	0.16 ± 0.02^{a}	0.13 ± 0.01^{b}	0.16 ± 0.03^{a}	0.021

Items	Groups					
lipase	6.57 ± 0.41[a]	4.23 ± 0.51[b]	5.98 ± 0.45[a]	6.20 ± 0.53[a]	6.41 ± 0.31[a]	<0.001
trypsin	1005.48 ± 53.91[b]	930.33 ± 43.5[b]	997.87 ± 47.85[b]	1116.83 ± 46.01[a]	976.80 ± 41.11[b]	0.007

Discussion

Growth performance is the final phenotypic manifestation of feed intake, digestive efficiency, metabolic balance, and stress adaptation. In this study, CHS significantly reduced ADFI and ADG, which is consistent with the well-established suppressive effect of heat exposure on appetite, energy utilization, and endocrine regulation in broilers (Ding et al. 2026). However, F:G showed no significant change, which differed from previous studies, this may be because the reduction in ADFI and ADG was relatively synchronous, resulting in no significant change in the feed-to-gain ratio possibly due to different feeds. BLF contains polyphenols, flavonoids and other bioactive substances and dietary BLF improved ADG and ADFI while reducing feed conversion ratio in broilers (Cao et al. 2022). In the present trial, BLF significantly increased ADG and ADFI and reduced F:G. Based on these results, BLF is suggested to exert a favorable promoting effect on growth performance.

In the present study, CHS significantly decreased carcass yield and semi-eviscerated yield in AA broilers at 42 d, but had no significant effects on abdominal fat, leg muscle, or breast muscle percentages. This suggests that cyclic CHS mainly impaired the overall efficiency of nutrient deposition into carcass tissues rather than markedly altering the relative proportions of individual tissue components. Mechanistically, the reduction in carcass traits under CHS was likely related to the oxidative stress and intestinal dysfunction observed in the present study. Oxidative imbalance can impair intestinal development and digestive enzyme activities, thereby reducing nutrient digestion and absorption, while the associated disturbances in serum biochemical homeostasis further limit effective tissue deposition. Dietary supplementation with 1600 mg/kg BLF significantly increased carcass yield, semi-eviscerated yield, eviscerated yield, and abdominal fat percentage. These improvements suggest that BLF alleviated the adverse effects of CHS on carcass performance, at least in part, by improving antioxidant status, maintaining intestinal digestive function, and promoting metabolic stability.

Serum biochemical parameters are pivotal mirrors reflecting systemic homeostasis and nutritional-physiological status in poultry, with lipid profiles (TC, TG) and lipoproteins (LDL-C, HDL-C) serving as core indicators for evaluating metabolic health (He et al. 2017; Wang et al. 2021). Consistent with prior reports that HS disrupts metabolic equilibrium and induces lipometabolic disorders (Hu et al. 2016; Ma et al. 2025), CHS in the present study elevated serum TC and TG levels, reflecting impaired lipid catabolism and enhanced de novo lipogenesis under thermal pressure. Mechanistically, this perturbation is tightly linked to HS-triggered oxidative stress, which impairs hepatic mitochondrial function and upregulates lipogenic genes, thereby disrupting cholesterol and triglyceride homeostasis (Lan et al.

2023; Gao et al. 2025). Notably, unlike studies showing consistent increases in both LDL-C and HDL-C under continuous HS, CHS failed to alter HDL-C in the trial. This discrepancy likely stems from our 8-h daily cyclic HS model, which allows broilers to restore metabolic balance during non-stress intervals (Teyssier et al. 2022), whereas continuous HS impairs lipoprotein transport and adaptive regulation. Collectively, these lipidomic changes not only reflect systemic stress but also mediate the cascade: HS-induced oxidative stress impairs intestinal absorption and barrier function, disrupts serum biochemistry, alters carcass lipid distribution and meat quality, and ultimately compromises growth performance in broilers.

As the main functional active component in bamboo leaves, BLF has antioxidant, anti-stress, antimicrobial and lipid-lowering activities. Studies showed that bamboo leaf extract improves antioxidant status and cholesterol metabolism and reduces serum TG and LDL-C in broilers (Shen et al. 2019). In the present experiment, BLF significantly decreased TC and LDL-C and increased HDL-C and glucose, consistent with the above findings. However, at 35 d, TG levels were increased to varying degrees in BLF-supplemented groups compared with the CHS group. This may be attributed to HS-induced elevation of serum corticosterone. BLF may affect hormone balance in early HS, further alter the secretion of stress hormones such as corticosterone, and promote fat decomposition into fatty acids. Fatty acids that cannot be oxidized timely for energy are re-synthesized into TG and stored, leading to increased TG levels (Honda et al. 2022).

Creatinine is a key indicator of glomerular filtration function, with elevated serum levels typically reflecting renal dysfunction (Wang et al. 2024). Urea, reflective of renal excretory function, and UA, a hallmark of purine metabolism, serve as sensitive markers for renal injury under stress (Li et al. 2023; Marín-García et al. 2022). Consistent with these definitions, CHS significantly increased serum urea, UA, and creatinine levels in the present study, indicating impaired renal clearance under thermal pressure. Mechanistically, this reflects a systemic cascade: HS-induced oxidative stress compromises intestinal barrier integrity, leading to malabsorption and increased catabolism of muscle and purine nucleotides. Regarding mineral homeostasis, Ca is critical for skeletal development, while Mg and P are indispensable for energy metabolism and bone health (Estevez et al. 2019; Wei et al. 2022). Studies have shown that HS induces transient hypocalcemia, which is negatively correlated with intestinal mucosal damage (Han et al. 2022), and the overall pattern of mineral perturbation in this study aligns with this trend. Multiple studies have confirmed that HS reduces the retention of Pi, Na, K, and Mg in broilers (Farag et al. 2018). The consistency between our results and these reports further indicates that HS-induced oxidative stress disrupts mineral transport systems and exacerbates metabolic imbalance. Changes in renal function and mineral parameters are not isolated events, but downstream consequences of HS-triggered intestinal dysfunction, which disrupt serum biochemical homeostasis, alter carcass quality, and ultimately reduce broiler growth performance.

Previous studies showed that BLF significantly reduces serum urea and UA levels in laying hens, and low-dose BLF also decreases serum creatinine, Ca and Mg contents (Zhang et al. 2023). In the present study, BLF similarly decreased serum creatinine, urea and UA levels, but unlike Zhang et al. BLF

significantly increased Ca, Mg and Pi contents. This discrepancy may be attributed to different research subjects: laying hens are mainly for egg production, with Ca and Mg mainly used for eggshell formation, whereas broilers are mainly for meat production, with Ca and Mg mainly used for skeletal development and other physiological processes (Sinclair-Black et al. 2023; David et al. 2023). Nevertheless, BLF may alleviate HS-induced damage, restore normal function of enzymes and transporters related to Ca and Mg metabolism, promote intestinal absorption of Ca and Mg, and increase their serum contents. Based on the above studies and the present results, BLF improves CHS-induced abnormal renal function and electrolyte imbalance in broilers.

Chen et al. found that HS significantly reduces T-AOC and the activities of GSH-PX, T-SOD and CAT, and increases MDA content in broilers (Chen et al. 2024). The present study similarly showed that CHS significantly decreased T-AOC and the activities of GSH-PX, T-SOD and CAT, indicating that chronic heat exposure disrupted the antioxidant defense system and redox homeostasis. This oxidative imbalance may further impair intestinal development and digestive function, reduce nutrient digestion and absorption, and thereby contribute to the changes in serum biochemical indices, carcass traits and growth performance observed in the present study. However, unlike the common response reported under HS, serum MDA content in the CHS group at 42 d was significantly decreased compared with the TN group. This may be related to physiological adaptation under the cyclic CHS model during prolonged heat exposure. Broilers may gradually adjust metabolic and physiological processes to maintain internal stability, which could partly influence MDA accumulation (Xie et al. 2015). Nevertheless, considering the overall decline in antioxidant capacity under CHS, the present findings still support an important role of oxidative stress in mediating CHS-induced intestinal dysfunction, metabolic disturbance and production decline.

Studies found that adding bamboo leaf extract to drinking water significantly reduces blood MDA and increases T-SOD activity in broilers (Williams et al. 2024). Wu et al. found that BLF increases serum immunoglobulin contents, reduces inflammatory factors and enhances T-AOC, CAT and GSH-PX activities in broilers (Wu et al. 2024). In the present trial, BLF increased T-AOC and the activities of CAT, T-SOD and GSH-PX to varying degrees, and significantly decreased MDA levels. These results indicate that BLF alleviated CHS-induced oxidative damage by improving antioxidant defense capacity, and that this antioxidant effect may be an important basis for its beneficial effects on intestinal function, serum biochemical homeostasis, carcass traits and growth performance in broilers.

Digestive enzymes are central to the gastrointestinal system, driving the breakdown of fats, proteins and carbohydrates and thus determining nutrient absorption efficiency (Ianiro et al. 2016). The present study showed that at 35 d, CHS significantly reduced the relative weight and length of the duodenum and jejunal relative weight, consistent with prior evidence that HS impairs intestinal development by disrupting metabolic homeostasis and inducing oxidative stress (Quinteiro-Filho et al. 2010). In contrast, at 42 d, the relative length and weight of the duodenum and jejunum increased, a change likely attributed to adaptive regulation under prolonged HS and advancing age (Schmidt et al. 2025). Mechanistically, HS-induced oxidative stress exacerbates intestinal barrier dysfunction, which directly impairs mucosal

integrity and nutrient transport. This process is further amplified by reduced activities of maltase, sucrase, lipase, amylase and trypsin, as observed here and in other studies showing that HS diminishes digestive enzyme secretion and disrupts gut microbiota (Miao et al. 2025; Giannenas et al. 2022). Collectively, these findings highlight a causal cascade. HS triggers oxidative stress, leading to intestinal morphological damage, reduced digestive enzyme activity, and impaired nutrient absorption, which in turn disrupt serum biochemistry, alter carcass and meat quality traits, and ultimately compromise growth performance.

Digestive enzyme activity is an important indicator reflecting digestive capacity (Shu et al. 2020). The present study showed that dietary BLF increased the relative length and weight of the duodenum, jejunum and ileum in CHS broilers to varying degrees. These results suggest that BLF may alleviate CHS-induced intestinal underdevelopment. In addition, studies reported that dietary flavonoids enhance jejunal lipase and trypsin activities, indicating beneficial effects on digestion in HS broilers (Song et al. 2018). The present study showed that BLF significantly increased duodenal maltase, sucrase, amylase and lipase activities. Similarly, consistent results were observed in the jejunum and ileum, indicating that BLF significantly improved small intestinal digestive enzyme activities in CHS broilers. Notably, duodenal trypsin activity was decreased to varying degrees at 35 d, inconsistent with other enzymes. Previous studies showed that high temperature significantly reduces gastrointestinal trypsin activity in broilers (Kikusato et al. 2023). Although BLF has antioxidant effects, it may not function fully in the short term, and HS remains the dominant factor leading to reduced trypsin activity. At 42 d, duodenal trypsin activity was significantly increased in BLF-supplemented broilers. These results indicate that BLF may alleviate the negative impacts of high temperature on intestinal nutrient digestion and absorption in CHS broilers by enhancing digestive enzyme activities, thus promoting growth.

Conclusion

Chronic heat stress impaired growth performance and slaughter performance in broilers, disrupted serum biochemical homeostasis, and weakened serum antioxidant capacity. As shown in Fig. 2. Dietary supplementation with BLF, particularly at 1600 mg/kg, effectively improved ADG, ADFI, and carcass traits, regulated serum lipid metabolism, renal function, and electrolyte balance, and enhanced serum antioxidant status in broilers exposed to CHS. In addition, BLF improved intestinal function by promoting the development of some small intestinal segments and enhancing digestive enzyme activities. Overall, BLF can alleviate multiple adverse effects induced by CHS in broilers and may serve as a useful nutritional strategy for broiler production under heat stress.

Declarations

Ethical approval

The ethical approval was obtained from the Institutional Animal Care and Use Committee of Anhui Science and Technology University, China (Approval No. AHSTU2024001).

Competing interest

The authors declare no competing interests.

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Data availability

The data for this study are available from the corresponding author upon reasonable request.

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Figures

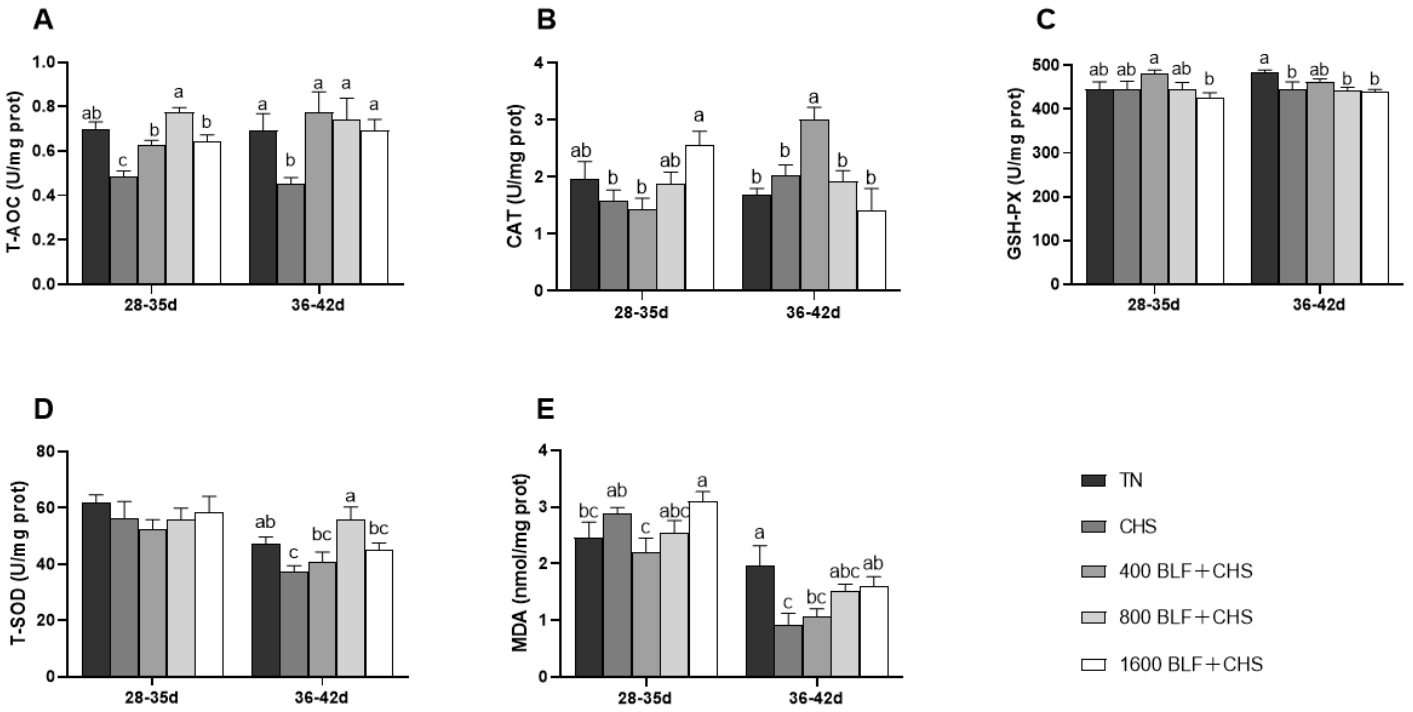


Figure 1

Effects of dietary BLF supplementation on serum antioxidant status in CHS-challenged broilers. (A) T-AOC capacity; (B) CAT activity; (C) GSH-PX activity; (D) T-SOD activity; (E) MDA concentration. Data are expressed as means ± SD. Bars with different lowercase letters (a, b, c) at the same sampling time point indicate significant differences ($P < 0.05$).

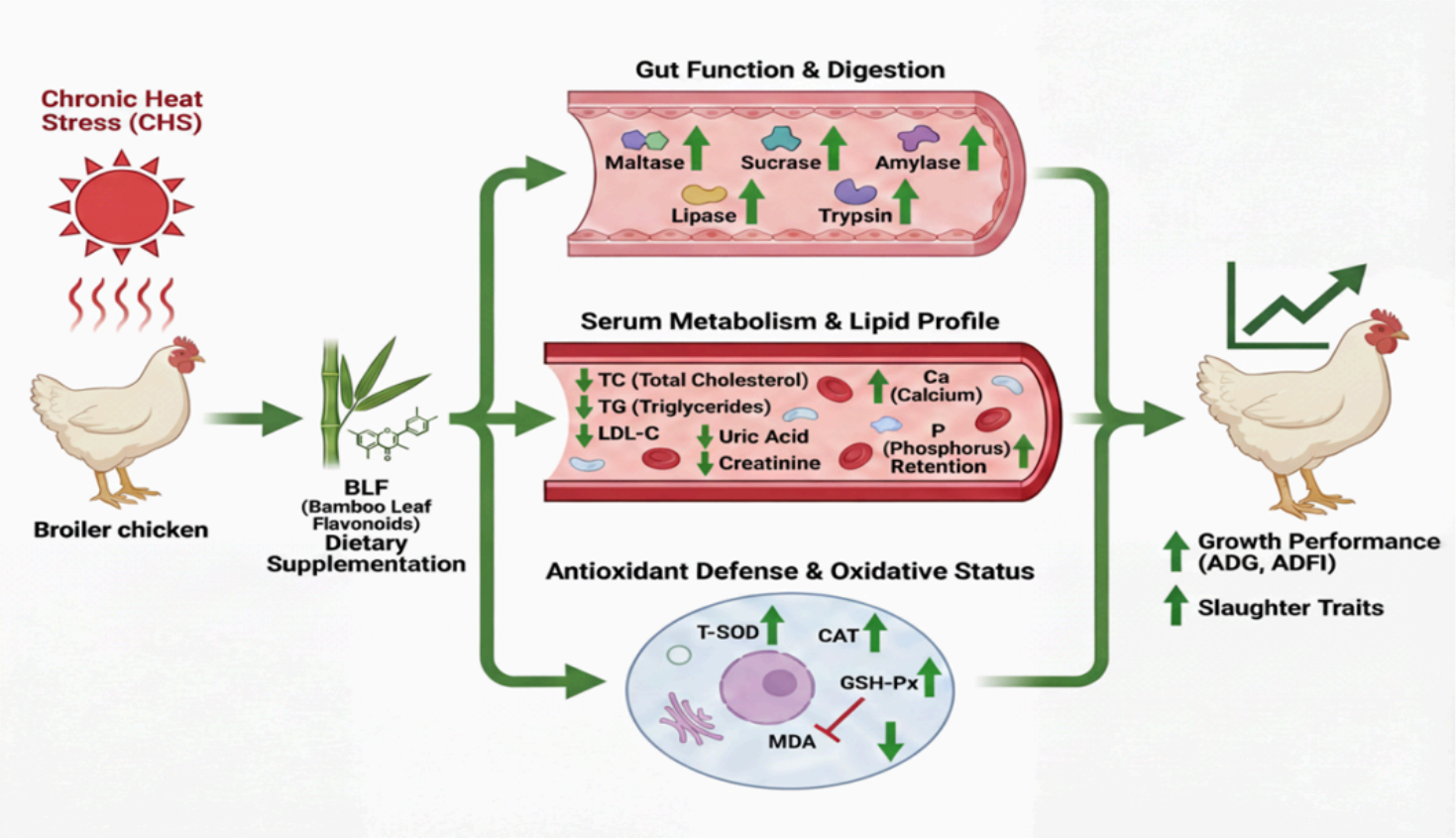


Figure 2

This schematic illustrates the mechanism by which BLF alleviates the decline in growth performance of broilers induced by CHS. LDL-C = Low-Density Lipoprotein Cholesterol; T-SOD = Total Superoxide Dismutase; CAT = Catalase; GSH-PX = Glutathione Peroxidase; MDA = Malondialdehyde; ADG = Average Daily Gain; ADFI = Average Daily Feed Intake