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Research article

Effects of shallot (*Allium ascalonicum*) powder supplementation on carcass quality and lipid peroxidation in broiler chickens under heat stress conditions

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Abstract

This study investigated the effects of shallot powder (SP) supplementation on oxidative stress and carcass characteristics in broiler chickens under both normal and heat stress (HS) conditions. A complete randomized design was used to allocate 120 one-day-old Arbor Acre chicks into six groups (4 replicates of 5 broiler chickens), over a duration of 42 days: T1 (control, basal diet), T2 (basal diet + HS), T3 (2 g/kg SP), T4 (4 g/kg SP), T5 (2 g/kg SP + HS), and T6 (4 g/kg SP + HS). Malondialdehyde (MDA) concentrations were assessed on days 21, 28, 35, and 42. On day 42, the carcass weight, component weight, and abdominal fat content were assessed. During the trial, SP administration markedly decreased MDA levels, with T4 exhibiting the lowest values. Compared with T2, T6 resulted in significantly lower MDA levels (P = 0.000), indicating an antioxidant effect under heat stress. SP enhanced carcass attributes. Compared with T2, T4 and T6 presented markedly elevated hot carcass weights (2,072.5±19.6 g and 2,033.8±20.9 g, respectively) (P = 0.000, P = 0.000). The SP-supplemented groups presented increased weights of the breast, drumstick, thigh, and wing cuts, particularly at T4 and T6. Furthermore, SP reduced abdominal fat, with the lowest levels observed at T4 (3.12±0.32%) and T6 (3.53±0.41%). In conclusion, 4 g/kg shallot powder diminishes oxidative stress and enhances carcass quality, particularly at elevated temperatures. The potential of this natural antioxidant feed additive to increase the performance of heat-stressed broilers is emphasized.

Keywords: Broiler chickens, Carcass quality, Heat stress, Oxidative stress, Shallot

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INTRODUCTION

Poultry production contributes to global food security by providing affordable, high-quality protein to millions of people, especially in low- and middle-income countries. However, heat stress (HS) poses substantial challenges for poultry productivity. HS occurs when birds are subjected to temperatures that exceed their thermoneutral zone, generally above 30°C–32°C, particularly in conjunction with elevated humidity (Nawaz et al., 2021). The issue is particularly acute in tropical and subtropical areas where elevated temperatures and humidity levels exacerbate physiological stress experienced by birds, thereby negatively affecting their performance and product quality (Oluwagbenga and Fraley, 2023). In tropical environments, where daytime temperatures often exceed 32°C, these physiological disruptions markedly diminish their production efficiency. HS suppresses growth and induces oxidative stress through the increased production of reactive oxygen species. This decreases the levels of essential antioxidant enzymes, including superoxide dismutase and glutathione peroxidase. Furthermore, malondialdehyde (MDA), an indicator of lipid peroxidation, is frequently increased under these conditions, indicating the presence of cellular damage and diminished immune function (Omar et al., 2020).

HS also negatively impacts carcass quality, as it is linked to decreased breast muscle yield, increased abdominal fat, and adverse alterations in the meat composition, such as reduced protein content and elevated drip loss (Lu et al., 2007; Zaboli et al., 2019). Moreover, prolonged HS during rearing, which is common in tropical production systems, results in diminished meat quality and decreased market value.

Therefore, mitigating HS is crucial for ensuring the sustainability of poultry production and the preservation of meat quality in tropical areas. Recently, herbal supplementation has garnered increasing attention as a viable HS mitigation strategy (Bhawa et al., 2023) because of its natural antioxidant, anti-inflammatory, and immunomodulatory properties. Various plant-derived additives, such as garlic, ginger, turmeric, and onion, have demonstrated potential for enhancing the performance and oxidative stress biomarkers in poultry. However, it is unclear how the addition of shallots (*Allium ascalonicum*) isolated from other herbs or onion varieties affects broiler chickens experiencing HS, particularly in Southeast Asian countries such as Thailand. In addition, there is a lack of studies on the direct measurement of oxidative stress markers, including MDA, in HS-exposed broiler chicks. To address these gaps, this study investigated the effects of shallot supplementation on the MDA levels in broiler chickens subjected to HS and assessed its effect on carcass quality.

MATERIALS AND METHODS

Ethical approval

Khon Kaen University in Thailand's Institutional Animal Care and Use Committee granted approval for the use of animals in this study (license record number. IACUC-KKU-1/65).

Study period, area, and population

Between June 2023 and July 2023, 120 one-day-old mixed-sex Arbor Acres broiler chickens were randomly assigned to different experimental groups. All research activities were conducted within the Division of Animal Science, Faculty of Agriculture and Agricultural Industry, Surindra Rajabhat University, Surin, Thailand.

Shallot powder preparation

Local red onions (shallots) were obtained from Sisaket Province, Thailand, were obtained. The outer layer was removed and the samples were washed twice with tap water. Next, the samples were air-dried until slightly damp, thinly sliced, and steam-baked at 60°C for 24 h. The samples were then ground through a 0.5-mm sieve to produce shallot powder (SP). The ethanolic shallot extract (ESE) was obtained following the methodology described by Surasorn et al. (2024). Bioactive compounds in the ESE, such as phenolics and flavonoids, were quantified. The Folin- Ciocalteu assay was performed to determine the phenolic content as previously described by Singleton et al. (1999). The results were expressed as mg of gallic acid equivalent per 100 mL extract (mg GE/100 mL E). The UV-VIS spectrophotometry approach previously employed by Kurniawan et al. (2025) was utilized to ascertain the flavonoid concentration. The results were expressed as mg of quercetin equivalent per 100 mL extract (mg QE/100 mL E). For the proximate analysis, a portion of the SP was analyzed according to the methods of the Association of Official Analytical Chemists (Latimer and George, 2023). The remaining portion was vacuum-packed at -4°C until it was used for chicken feed.

Diets and experimental animals

In a completely randomized design, 120 one-day-old mixed-sex Arbor Acres broiler chicks were randomly assigned to one of six experimental (treatment; T) groups. Each group was replicated four times, with five chickens per replicate. As recommended by the National Research Council (NRC, 1994), a basal diet with a standard nutrient composition was provided to each group (Table 1), and each had ad libitum access to water. The experimental group had the following feed characteristics:

- T1 received a basal diet (B) under normal conditions (controls).
- T2 received B under HS conditions.
- T3 received B + SP (2 g/kg feed)
- T4 received B + SP (4 g/kg feed)
- T5 received B + SP (2 g/kg feed) + HS.
- T6 received B + SP (4 g/kg feed) + HS

All experimental groups of chickens were vaccinated at 1, 7, and 14 days of age in accordance with the established vaccination protocol for broiler chickens. The chicks were housed at an appropriate temperature using a 25–40 W light bulb, which was adjusted based on the ambient conditions. The chicks were fed twice daily, in the morning at 07:00 AM and in the evening at 4:30 PM, and were subjected to a lighting schedule that reflected the natural light cycle. Broiler chickens in groups T2, T5, and T6 were subjected to chronic HS conditions, as indicated by modifications detailed by Istateh et al. (2025), which involving exposure to 33°C ± 2°C for 8 h daily during the final two weeks of the trial. Furthermore, in the Thai rainy season, the relative humidity typically exceeds 70%.

Table 1 Ingredients and nutrient composition of the basal diets

Item Ingredient (kg)	Starter	Grower
	1 to 21 d	22 to 42 d
Corn	47.80	60.25
Soybean meal (44% crude protein)	28.55	18.00
Full fat soybean	17.05	15.00
Rice bran oil	2.00	2.10
Choline chloride	0.10	0.10
Dicalcium phosphate (21% phosphorus)	1.80	1.80
Limestone	1.60	1.60
DL-Methionine	0.30	0.30
L-lysine	0.15	0.15
Vitamin-mineral premix[1]	0.25	0.30
NaCl	0.40	0.40
Total	100.00	100.00
Nutrient composition Calculated[2]		
Metabolizable energy (kcal/kg)	3001.00	3100.00
Crude protein (%)	22.51	18.01
Calcium (%)	1.24	1.20
Available phosphorus (%)	0.74	0.70

[1]Supplied per kg of diet: vitamin A, 1,500 IU; cholecalciferol, 200 IU; vitamin E, 10 IU; riboflavin, 3.5 mg; pantothenic acid, 10 mg; niacin, 30 mg; cobalamin, 10 μg; biotin, 0.15 mg; folic acid, 0.5 mg; thiamine 1.5 mg; pyridoxine 3.0 mg; iron, 80 mg; zinc, 40 mg; manganese, 60 mg; iodine, 0.18 mg; copper, 8 mg; selenium, 0.15 mg.
[2]Based on NRC (1994) recommendation.

Blood sampling and serum lipid peroxidation test

On days 21, 28, 35, and 42, 3 mL blood samples were collected from the wing veins of eight birds in each treatment group (two birds per replicate). The collected samples were transferred to collection tubes without anticoagulants and left at room temperature (28°C–30°C) for approximately 2 h to allow for clotting. Following clotting, the blood samples were centrifuged at 1000 ×g at room temperature for 10 min to separate the serum. After the serum was separated, the samples were stored at -20°C until they could be tested via the thiobarbituric acid reactive substances (TBARS) assay (Palupi et al., 2023). The produced serum (0.25 mL) was placed in a tube containing 0.50 mL of 10% trichloroacetic acid (TCA) solution. A blank solution was prepared by mixing 0.50 mL of 10% TCA solution with 0.25 mL of distilled water. After mixing, the solutions were then centrifuged for 1 min at ≈2682 ×g. The supernatants were then transferred to fresh tubes, and a 0.67% TBA solution was added to reach a total volume of 0.75 mL. Thereafter, 4 mL of *n*-butanol was added after cooling, and the centrifuged tube was placed in a boiling bath for 10 min. The absorbance of each tube, sample, and blank was measured at a wavelength of 532 nm and reported as nmol MDA/mL.

Carcass quality test

On day 42, eight chicks (two per replicate) were randomly selected from each treatment group and fasted for 10 h before they were weighed and humanely sacrificed via cervical dislocation to evaluate the carcass quality. The birds were then scalded, defeathered, eviscerated, and weighed again to determine the post-slaughter hot carcass weight, excluding the giblets. The giblets included the liver, heart, gizzard, and abdominal fat pads. The carcass cuts, including the abdominal fat, breast, drumstick, thigh, and wing, were weighed on a digital scale (±0.01 g). Furthermore, we also determined the relative weights of the carcass cut sections using the fraction of the carcass cut weights associated with the hot carcass weight.

Statistical analysis

A completely randomized design was used to analyze the variance of all observed data. Subsequently, Tukey's test was employed to analyze the mean differences across the experimental groups. Statistical analyses were performed using SPSS for Windows (version 27; SPSS Inc., Chicago, IL, USA), and $P < 0.05$ was considered statistically significant.

RESULTS

The chemical composition and bioactive compounds of the shallot were analyzed. The chemical composition per 100 g of shallots and the bioactive compounds per 100 mL of ESE are presented in Table 2.

Table 2 Proximate composition of shallot bulbs and the bioactive compounds of ethanol shallot extract.

Composition	Detected quantity
Chemical composition	
Protein (g/100 g)	7.84
Fat (g/100 g)	10.50
Ash (g/100 g)	6.77
Moisture (g/100 g)	87.66
Carbohydrate (g/100 g)	250.15 (Kcal/100 g)
Calcium (mg/100g)	(160.00 mg/100g)
Potassium (mg/100g)	(746.10mg/100g)
Bioactive compounds	
Phenolic content	19.66 mg GE/100 mL E[1]
Flavonoid content	24.07 mg QE/100 mL E[2]

[1]mg GE/100 mL E; milligram of gallic acid equivalent per 100 milliliter extract
[2]mg QE/100 mL; milligram of quercetin equivalent per 100 milliliter extract

Oxidative stress

The MDA levels were measured using the TBARS assay as an oxidative stress marker of lipid peroxidation and are shown in Table 3 and Figure 1. T2 and T5 had the highest MDA levels on days 21, 28, 35, and 45, ranging from 7.55 to 7.86 nmol/mL, thus indicating increased lipid peroxidation and oxidative damage. The SP supplementation groups (T3 and T4) presented with significantly lower MDA levels from days 21 to 45 under normal conditions compared to those of the other groups. Supplementation of broilers with SP at 4 g/kg feed under non-heat-stress conditions resulted in the lowest MDA level on day 21, which was 5.92 nmol/mL. However, under HS conditions, T6 exhibited significantly lower MDA levels than those of T2 and T5. Compared with the control (T1), the MDA levels were significantly lower in T6 on day 21.

Table 3 Effect of shallot powder supplementation on malondialdehyde (MDA) in broiler chickens at 21, 28, 35, and 42 days' old

Treatment	MDA (nmol/mL)			
	Day 21	Day 28	Day 35	Day 42
T1	7.25±0.21^{a}	7.21±0.28^{bc}	7.20±0.16^{b}	7.39±0.24^{b}
T2	7.55±0.24^{a}	7.63±0.22^{a}	7.74±0.29^{a}	7.86±0.19^{a}
T3	6.08±0.16^{c}	6.23±0.14^{d}	6.31±0.20^{c}	6.42±0.19^{c}
T4	5.92±0.19^{c}	6.21±0.14^{d}	6.18±0.21^{c}	6.30±0.19^{c}
T5	7.46±0.27^{a}	7.51±0.41^{ab}	7.74±0.38^{a}	7.75±0.18^{a}
T6	6.69±0.19^{b}	6.92±0.15^{c}	6.95±0.19^{b}	7.17±0.24^{b}
P-value	<0.001	<0.001	<0.001	<0.001

^{a,b,c} Treatment means with different superscripts within the same column are significantly different at $P < 0.05$

[1] Values = means±standard deviation (n =8, each replicate consisted of two birds)

Treatments: T1= basal diet (B) (control), T2= B + heat stress (HS) condition, T3 = B + 2 g of shallot powder (SP) /kg of feed, T4 = B + 4 g of SP/kg of feed, T5 = B + 2 g of SP/kg of feed + HS, and T6 = B + 4 g of SP/kg of feed + HS

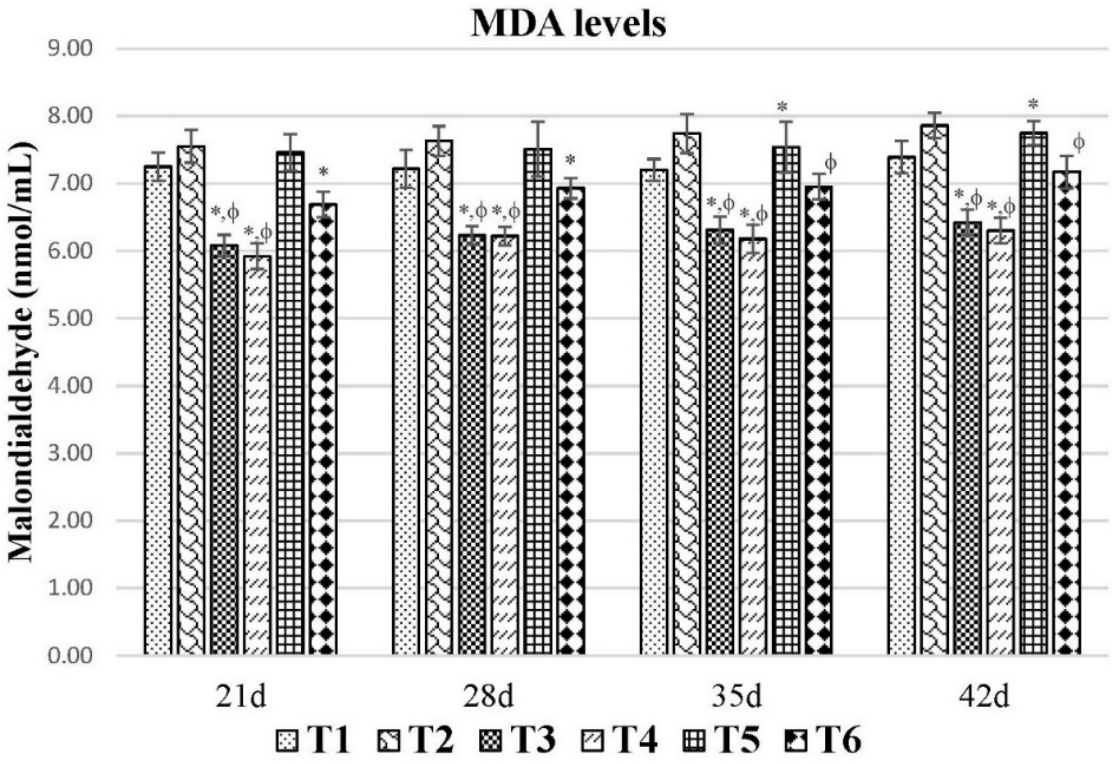

Figure 1 Effect of SP on MDA levels

Values are expressed as mean±SD (n=8); Keys of significance: ∗-when compare with control, ϕ-when compare with HS (Values are significantly different when $P < 0.05$); HS-heat stress, T1= basal diet (B) (control), T2= B + HS condition, T3 = B + 2 g of shallot powder (SP) /kg of feed, T4 = B + 4 g of SP/kg of feed, T5 = B + 2 g of SP/kg of feed + HS, and T6 = B + 4 g of SP/kg of feed + HS

Carcass quality

The hot carcass and cut carcass weights are presented in Table 4. Compared with the other groups, supplementation with 4 g/kg SP, regardless of the presence of HS, led to an increased hot carcass weight. The hot carcass and cut carcass weights in SP supplemented groups were significantly greater than T2 and T1. The shallot-supplemented groups (T4 and T6) exhibited a reduction in abdominal fat, whereas the HS group (T2) showed the greatest fat accumulation.

The weight of breast meat in T4 and T6 were significantly greater than those in T1 and T2. The drumstick weights in T4 and T6 were significantly higher than those in T2 and T1, and the thigh weights in T3 and T4 were significantly higher than those in T2. In addition, wing weights in T4 and T6 exceeded those of the other groups.

Table 5 and Figure 2 present the relative weights of the cut carcass parts expressed as percentages of the hot carcass weights. The abdominal fat contents in T3–T6, which received SP supplementation, were significantly lower. T4 had the lowest fat content (3.12%) among the treatment groups. No significant differences were observed in the breast, drumstick, thigh, or wing percentages across treatments ($P > 0.05$). T2 had the highest abdominal fat percentage and the lowest thigh percentage among the treatment groups.

Table 4 Hot carcass and carcass cutting weights in 42 days' old broiler chickens supplemented with shallots under normal or heat stress condition

Treatment	Hot carcass (g)	Carcass cutting (g)				
		Abdominal fat	Breast	Drumstick	Thigh	Wing
T1	1,766.20	81.75	572.50	278.75	316.87	213.25
	±27.25^{b}	±10.673^{ab}	±43.405^{b}	±15.754^{b}	±14.416^{b}	±14.762^{c}
T2	1,718.80	85.87	554.25	263.88	301.15	193.75
	±20.127^{b}	±8.983^{a}	±38.111^{b}	± 10.881^{b}	±12.574^{b}	±2.052^{d}
T3	2,040.00	73.75	662.88	325.00	369.87	247.38
	±19.179^{a}	±8.031^{bc}	±33.896^{a}	±14.142^{a}	± 11.179^{a}	±7.836^{a}
T4	2,072.50	64.62	677.25	335.00	377.00	257.12
	±19.616^{a}	±5.950^{c}	±24.311^{a}	±15.118^{a}	±20.403^{a}	±8.043^{a}
T5	1,991.20	73.75	644.12	315.62	359.50	225.38
	±24.159^{a}	±8.031^{bc}	±32.991^{a}	±14.985^{a}	±20.535^{a}	±19.063^{bc}
T6	2,033.80	71.75	658.75	326.88	368.75	239.00
	±20.953^{a}	±7.667^{c}	±27.233^{a}	±13.249^{a}	±24.760^{a}	±16.970^{ab}

^{a,b}Treatment means with different superscripts within the same column are significantly different at $P < 0.05$

[1]Values = means±standard deviation (n =8, each replicate consisted of two birds)

Treatments: T1= basal diet (B) (control), T2= B + heat stress (HS) condition, T3 = B + 2 g of shallot powder (SP) /kg of feed, T4 = B + 4 g of SP/kg of feed, T5 = B + 2 g of SP/kg of feed + HS, and T6 = B + 4 g of SP/kg of feed + HS

Table 5 Percentage of carcass cutting related to the hot carcass in 42 days' old broiler chickens supplemented with shallot powder and under heat stress condition

Treatment	Carcass cutting (%)				
	Abdominal fat	Breast	Drumstick	Thigh	Wing
T1	4.64± 0.722^{a}	32.41±2.095	15.78± 0.537	17.94±0.401	12.08±0.844
T2	5.00±0.549^{a}	32.24±1.851	15.36±0.666	17.53±0.913	11.28±0.337
T3	3.61±0.397^{b}	32.51±1.747	15.94± 0.926	18.14±0.795	12.13±0.432
T4	3.12±0.319^{b}	32.69±1.151	16.18± 0.988	18.18±0.555	12.41±0.448
T5	3.70±0.415^{b}	32.35±1.414	15.880± 1.088	18.05±0.685	11.34±1.159
T6	3.53±0.412^{b}	32.39±1.160	16.081± 0.732	18.14±1.387	11.76±1.033
P-value	<0.000	0.99	0.47	0.65	0.06

^{a,b}Treatment means with different superscripts within the same column are significantly different at $P < 0.05$

[1]Values = means±standard deviation (n =8, each replicate consisted of two birds)

Treatments: T1= basal diet (B) (control), T2= B + heat stress (HS) condition, T3 = B + 2 g of shallot powder (SP) /kg of feed, T4 = B + 4 g of SP/kg of feed, T5 = B + 2 g of SP/kg of feed + HS, and T6 = B + 4 g of SP/kg of feed + HS

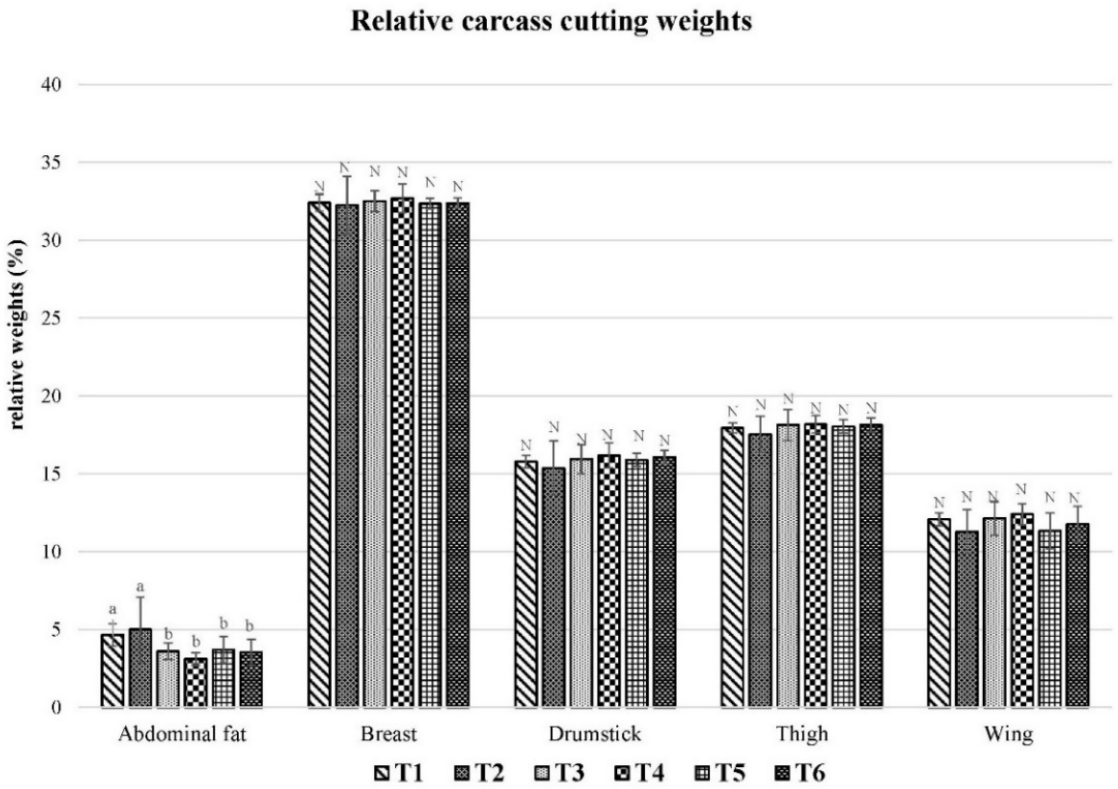

Figure 2 Effect of SP on relative carcass cutting weights. a and b = mean±SD (n=8). Means with different letters in the same cluster are significantly different ($P < 0.05$). N = Nonsignificant. HS-heat stress, T1= basal diet (B) (control), T2= B + HS condition, T3 = B + 2 g of shallot powder (SP) /kg of feed, T4 = B + 4 g of SP/kg of feed, T5 = B + 2 g of SP/kg of feed + HS, and T6 = B + 4 g of SP/kg of feed + HS

DISCUSSION

This study revealed that broilers that experienced HS but did not receive SP supplementation (T2) exhibited the highest MDA levels, thus highlighting the oxidative impact of HS. This finding is consistent with those of Abass et al. (2022), who reported elevated levels of oxidative stress markers, such as MDA, in poultry subjected to HS. On day 21, T5 revealed elevated MDA levels in the broilers, although these levels were marginally lower than those observed in T2, and remained slightly higher than those in T1 (control). This study revealed that supplementation with a low dose (2 mg/kg) of SP in chick feed reduces the MDA levels under normal conditions; however, this effect was not detected during HS conditions in chicks on days 35 and 42 (P = 1.000, P = 0.910, respectively). Furthermore, increasing the SP inclusion level to 4 mg/kg in chick feed reduced the MDA levels under normal conditions in chicks on days 21, 28, 35, and 42, as depicted in Figure 1. These results align with the findings of Sobanke et al. (2025), who demonstrated a reduction in the effects of HS in a rat model by supplementation with red onions. Thus, research has revealed a partial decrease in oxidative stress in HS-exposed animals receiving red onion feed supplementation. T3 and T4 exhibited significantly lower MDA values compared with those of T1, thereby confirming the shallot's antioxidant properties. Moreover, T6 revealed reduced MDA levels in normal and HS chickens on day 21 compared with those of T2; however, the MDA levels were significantly lower (P = 0.000) when 4 mg/kg SP was supplemented in HS chickens on days 28, 35, and 42, indicating a partial alleviation of oxidative stress. T4 resulted in the lowest MDA concentration,

thus indicating a dose-dependent antioxidant effect. Furthermore, our study demonstrated a consistent antioxidant effect of onion powder, which corroborates the findings from Bedrníček et al. (2020), who noted the antioxidant activity and prolonged shelf life of fish sausage when onion powder was added, and of Shah et al. (2023), who reported a reduced MDA levels in HS broiler chickens when ginger was combined with onion powder in their feed. This study revealed that SP supplementation can reduce the levels of the MDA as a marker of oxidative stress. The incorporation of SP into chicken feed demonstrated optimal efficacy in reducing oxidative stress at day 21; however, the effectiveness of this supplementation decreased with age, which is consistent with the findings of Punyatong et al. (2026) on glutamine supplementation in the diets of indigenous chicken. This study by Punyatong et al. (2026) revealed that including SP in broiler chicken feed lowered the MDA levels in 4-week-old chicks compared with supplementing glutamine in the native chicken diet (9.31% vs. 22.30%). These results may have been influenced by differences in the chicken breeds used in the experiment. This study investigated the efficacy of the SP supplementation in broiler diets for chickens under normal and HS conditions. The results revealed comparable levels of MDA reduction at 4 weeks of age (13.87% vs. 9.31%), thus emphasizing the significant safety of including SP in chicken feed and rearing procedures.

This study demonstrated that higher SP inclusion levels in broiler chicken feed under normal temperature conditions led to a significant increase in hot carcass weight and a reduction in abdominal fat compared with those of the control group (T1). This is in contrast with the findings of Aditya et al. (2017), who reported that the inclusion of onion (*Allium cepa* L.) at the 5%–10% level did not affect the hot carcass or abdominal fat weights. It is also in contrast with the findings of Malematja et al. (2023), who reported that incorporating onion (*A. cepa*) extract into chicken feed at concentrations of 5%–25% under normal conditions did not influence the hot carcass weight or other carcass components. These discrepancies may arise from the higher concentrations of phenolic compounds and flavonoids in shallots (*A. ascalonicum*) compared with those of onions (Adeyemo et al., 2022; Moldovan et al., 2022). These higher concentrations increase the antioxidant activity, thereby promoting the growth of broiler chickens, as reported in our previous study (Surasorn et al., 2024). Furthermore, our findings support those of Al-Ramamneh (2018), who reported that the inclusion of onion (*A. cepa*) extract in the drinking water and feed of stressed broiler chickens at a 2.5% concentration increased their hot carcasses and cutting weights.

There were no significant differences in the relative weights of the breasts, drumsticks, thighs, or wings across the various treatments ($P > 0.05$; Table 5). In contrast, supplementation with 4 mg/kg SP resulted in the lowest abdominal fat accumulation, whereas the broilers under HS without SP supplementation presented the highest fat accumulation. These findings demonstrate the dose-dependent lipolytic effects of shallots and their ability to mitigate stress-induced carcass changes, as shown in Figure 2. In this study, reducing the accumulation of abdominal fat increases the weight of other carcass sections, possibly because of the shallots' antioxidant and prebiotic properties, which facilitated fat synthesis and deposition by the intestinal microbiota. However, this mechanism is not fully elucidated (Ding et al., 2022). We used the G*Power tool to estimate the sample size before the experiment, but the limited number of chicks in each experimental group may reduce statistical robustness of this study. The chicken samples used in this investigation to measure the MDA levels were collected weekly for four consecutive weeks. This increased the number of blood samples, which may have resulted in a more exact statistical analysis. In future studies, different indicators of oxidative stress, including stress gene activity, cortisol levels, and pro-/anti-inflammatory cytokine levels, should be investigated to verify these supplements reduce stress in broiler chickens.

CONCLUSIONS

SP supplementation at the 4 mg/kg inclusion level significantly reduced oxidative stress and enhanced the carcass characteristics of broiler chickens, especially under HS conditions. Compared with the HS groups, T4 and T6 exhibited lower serum MDA levels and had significantly higher hot carcass and cut weights. Furthermore, SP supplementation decreased abdominal fat accumulation, thus improved lipid metabolism. Overall, these findings support the use of SP feed supplementation as a natural antioxidant to improve broiler performance under HS conditions.

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AUTHOR CONTRIBUTIONS

Pairat Sornplang: conceptualization and design (lead); formal analysis (lead); writing–original draft *(*lead*)*; writing–review and editing (lead). Benyapha Surasorn: conceptualization (supporting); collection of samples (lead); writing–review and editing (supporting).

CONFLICT OF INTEREST

The authors declare that there are no competing interests.

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